Physics News In 2000

A Supplement to APS News

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INTRODUCTION

Physics News in 2000 is the most recent in a series of annual surveys of important physics stories prepared by AIP. All of the entries in this compendium appeared first in the weekly online newsletter *Physics News Update*. Many of them appeared also on the "Physics Update" page in *Physics Today* magazine, having been edited further by Stephen Benka. One should keep in mind, however, the important difference between *Physics Today*, which is aimed chiefly at physicists, and *Physics News Update*, which is aimed primarily (although not exclusively) at science journalists. For this reason, and because of the relatively small sample of news items presented here, some fields of physics might be under-represented in this compilation. Readers can get a much wider view of the year's highlights in physics, and search a 10-year archive of physics news items, by going to the *Physics News Update* website: http://www.aip.org/physnews/update.

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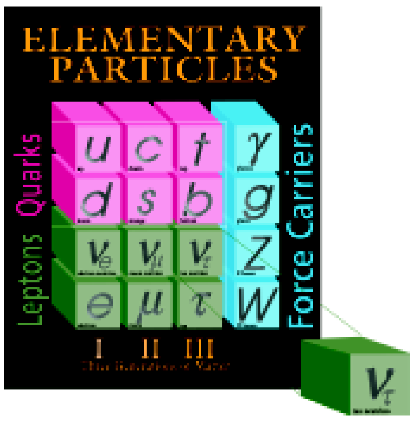
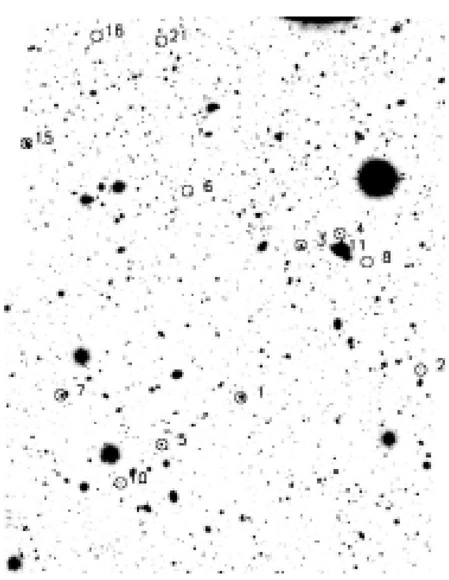


Above: Detected conclusively for the first time in 2000, the tau neutrino is the third and last kind of light neutrino in the Standard Model. (Courtesy Fermilab)

ASTROPHYSICS

THE X-RAY BACKGROUND, the glow of x rays seen in all directions in space, has now largely been resolved into emissions from discrete sources by the Chandra X-Ray Telescope, ending the notion that the x rays come from distant hot gas. Previously only about 20-30% of the x-ray background had been ascribed to point sources (by such telescopes as ASCA). Chandra was launched in July 1999 and put in an elliptical orbit. With its high angular resolution and acute sensitivity it could tell apart x-ray objects (many of them thought to be accretion disks around black holes) that before had been blurred into a continuous x-ray curtain. (Of course, now that the background has been resolved into points it ceases to be a background.) Richard Mushotzky of Goddard Space Flight Center reported these Chandra results at the January 2000 meeting in Atlanta of the American Astronomical Society (AAS). Resolving the x-ray background was not all. Mushotzky added that the Chandra survey had revealed the existence of two categories of energetic galaxies that had been imaged only poorly or not at all by optical telescopes. He referred to one category as "veiled galactic nuclei," objects (with a redshift of about 1) bright in x rays but obscured by dust at optical wavelengths. The other category was "ultra-faint galaxies.." One interpretation of these galaxies is that optical emission is suppressed owing to absorption over what could be a very long pathway to Earth. Mushotzky speculated that such high redshift (z greater than 5) galaxies could be the most distant, and hence earliest, objects ever identified. The XMM x-ray telescope, just launched, should provide complementary information in the form of high-precision spectra (from which redshifts are derived) of the distant objects.

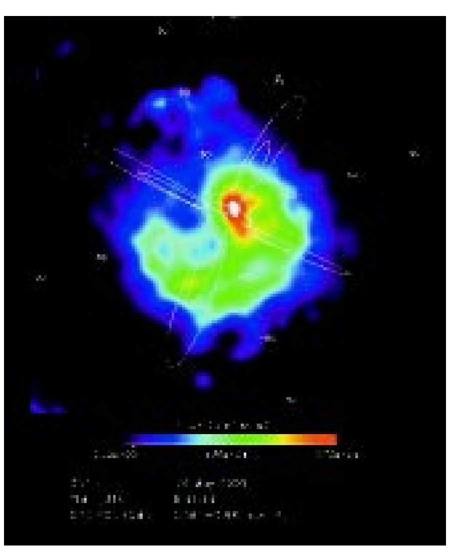


Optical image of the Chandra x-ray field. The circles indicate regions when Chandra has detected an X-ray source. Note that many circles (6,8,16,21) do not show an optical source at their center. (Credit: NASA/GSFC/ R.Mushotzky et al.)

THE RAREST NATURALLY OCCURRING ISOTOPE, tantalum-180, is less of a mystery now. The isotope is scarce because its nucleosynthesis is mainly bypassed in the two processes that produced most of the heavy elements we find here on Earth: the s-process (slow neutron capture within stars) and the r-process (rapid neutron capture during supernova explosions). The ^{180}Ta nucleus, with a halflife of more than 10^{15} years, is also the only naturally occurring nuclear isomer; it is essentially in a perpetually excited state. Now, a group of physicists in Germany has found that some ^{180}Ta can arise in the s-process. At the Dynamitron accelerator in Stuttgart, they exposed this isotope to an intense beam of gamma rays, simulating the thermal-photon conditions inside a star, and found that the long-lived isomer can be jarred through an intermediate state into its short-lived ground state (with an effective halflife of only a month, 10^{17} times less than that of the isomer!). Moreover, the temperature of the radiation field corresponded to that of the brief "helium flash" phase in a star's evolution; rapid convection of the stellar material would quickly remove the ^{180}Ta to cooler regions, where it could then survive in its stable isomeric form. (D. Belic et al., *Phys. Rev. Lett*. **83**, 5242, 1999.)

THE FAR SIDE OF THE SUN can be monitored for activity, in principle, with two new techniques. Both methods use instruments aboard the SOHO satellite, a joint mission of the European Space Agency and NASA. One method, dubbed helioseismic holography, uses the distortion introduced into sound waves forever rumbling through the body of the Sun when they reflect from magnetically active regions around sunspots. The wave fields are observed by SOHO on the near side of the Sun, but some of the distortions can be traced back to sources on the far side. The other method makes use of hydrogen's Lyman-alpha emission, which is stronger from active regions than from elsewhere on the Sun. SOHO routinely makes all-sky Ly-alpha maps of interplanetary hydrogen. With careful processing, those maps can show where an active region's beacon Ly-alpha excites more than the usual amount of complementary emission from interplanetary space, and researchers can watch as the beacon moves across the sky with the Sun's rotation. Both groups of researchers are part of a large effort to predict "space weather"; they see their efforts as leading to an extra week or two of advance warning, for astronauts and satellite operators, of large Earth-bound disturbances coming from the Sun. (C. Lindsey, D.C. Braun, *Science* **287**, 1799, 2000. J.-L. Bertaux *et al, Geophys. Res. Lett*. **27**, 1331, 2000.)

FIRST IMAGES ARRIVE FROM THE IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite. Launched in March 2000, IMAGE will study the global properties of Earth's magnetosphere, that tenuous plasma reaching from the top of the atmosphere out into space, controlled jointly by Earth's magnetic field and the solar wind. To do so, the satellite has an array of neutral atom, ultraviolet, and radio plasma imagers. The ability to view Earth and its environs through what might be considered plasma-colored glasses is important for understanding and monitoring space weather, the general name for disturbances in our planet's vicinity caused by fields and particles streaming from the Sun. The two images seen here were among the first data, released at the Spring 2000 meeting of the American Geophysical Union in Washington DC, by James Burch (Southwest Research Institute) and his colleagues. Above is the first global view of Earth's plasmasphere, looking away from the Sun at extreme UV light scattered from ionized helium. The helium plasma clearly extends to about three times the size of our planet, and the irregularity in the upper left indicates magnetic storm activity. The other image shows Earth's aurora, in far UV wavelengths. The aurora is caused by electrons and ions smashing into the neutral atmosphere, traveling along magnetic field lines toward the Earth's poles. The green shows the electron aurora, red is where the proton aurora dominates, and both are comparable in the yellow regions.



Energetic Neutral Atom image of a storm cloud of energetic particles from the High Energy Neutral Atom Imager instrument. Red colors indicate the highest intensity of incoming particles, blue represents the lowest. The view is from the Sun looking towards the Earth. (Courtesy NASA)

BEST MAP YET OF THE COSMIC MICROWAVE BACKGROUND (CMB). The CMB is a redshifted picture of the universe at the moment photons and newly formed hydrogen atoms parted company roughly 300,000 years after the big bang. First detected in the 1960s, the CMB appeared to be utterly uniform until, eight years ago, the COBE satellite provided the first hint of slight temperature variations, on a coarse scale, with an angular resolution of about 7 degrees. Since then several detectors have obtained resolutions of better than 1 degree. Actually, the contribution to small-scale fluctuations in the CMB is customarily rendered in terms of multipoles (a sort of coefficient), denoted by the letter l. The contribution to the temperature fluctuations in the CMB for a multipole value of l comes from patches on the sky with an angular size of π/l. COBE's CMB measurements extended to a multipole of only about 20, but a major new map, made using a detector mounted on a balloon blown all the way around the Antarctic continent, covers the multipole range from 50 to 600, thus probing CMB fluctuations with much finer angular detail, over about 3% of the sky. The 36-member, international "Boomerang" (Balloon Observations of Millimetric Extragalactic Radiation and Geomagnetics) collaboration, led by Andrew Lange of Caltech and Paolo de Bernardis of the University of Rome, confirms that a plot of CMB strength peaks at a multipole value of about 197 (corresponding to CMB patches about one degree in angular spread), very close to what theorists had predicted for a cosmology in which the universe's overall curvature is zero and the existence of cold dark matter is invoked. The absence of any noticeable subsidiary peaks (higher harmonics) in the data, however, was not in accord with theory. The shape of the observed pattern of temperature variations suggests that a disturbance very like a sound wave moving through air passed through the high-density primordial fluid and that the CMB map can be can be thought of as a sort of sonogram of the infant universe. (de Bernardis et al., *Nature*, 27 April 2000.)

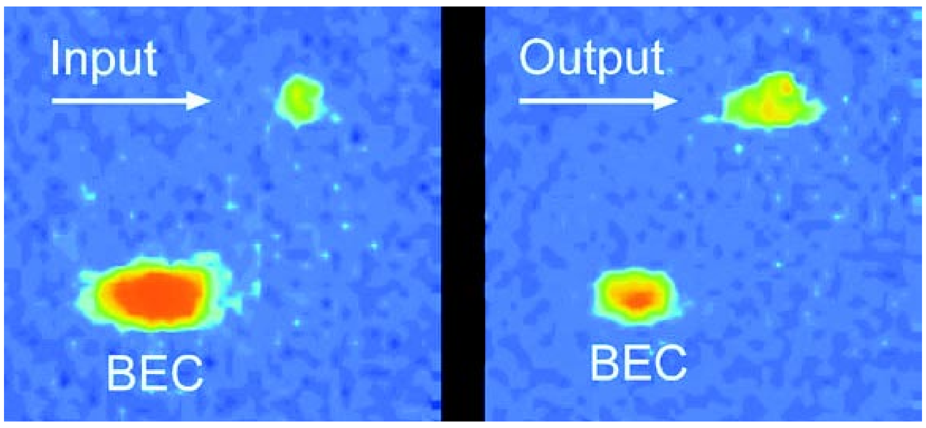
BEST MEASUREMENT OF THE GRAVITATIONAL CONSTANT. At the 2000 Spring meeting of the American Physical Society Meeting in Long Beach, Jens H. Gundlach of the University of Washington reported a long-awaited higher precision measurement of the gravitational constant, usually denoted by the letter G. Although G has been of fundamental importance to physics and astronomy ever since it was introduced by Isaac Newton in the seventeenth century (the gravitational force between two objects equals G times the masses of the two objects and divided by their distance apart squared), it has been relatively hard to measure, owing to the weakness of gravity. Now a group at the University of Washington has reduced the uncertainty in the value of G by almost a factor of ten. Their preliminary value is G=6.67390 x 10^{-11} $m^3/kg/s^2$ with an uncertainty of 0.0014%. Combining this new value of G with measurements made with the Lageos satellite (which uses laser ranging to keep track of its orbital position to within a millimeter) permits the calculation of a brand new, highest precision mass for the earth: 5.97223 (+/- .00008) x 10^{24} kg. Similarly the new mass of the sun becomes 1.98843 (+/- .00003) x 10^{30} kg. The setup is not unlike Cavendish's venerable torsion balance of two hundred years ago: a hanging pendulum is obliged to twist under the influence of some nearby test weights. But in the Washington experiment measurement uncertainties are greatly reduced by using a feedback mechanism to move the test weights, keeping pendulum twisting to a minimum.

ATOMIC, MOLECULAR AND OPTICAL PHYSICS

A WAVE-PARTICLE CORRELATOR for photons has been demonstrated. In most experiments, researchers focus either on light's particle aspects (by counting photons, for example) or on its wave aspects (perhaps by measuring an interference between electromagnetic fields). Now, physicists from SUNY-Stony Brook and the University of Oregon have demonstrated an experimental setup—using rubidium atoms in a strongly coupled cavity QED system—that let them determine the relationships between both aspects of light. In their setup, a laser beam entered the cavity through one of its mirrors. The cavity acted as a sort of "artificial molecule," absorbing and re-emitting the light many times. Occasionally, a photon escaped through an output mirror and was detected as a particle by a photodiode. That event triggered a measurement of wavelike properties of the cavity field through a comparison with the original laser beam. For some of the triggering photon detections, a second photon was emitted as the cavity relaxed to a stable state. That emission caused a fluctuation in the cavity's field that was directly tied to the exit of the first photon; the researchers caught those fluctuations in the act. After averaging over many such "conditional" particle and wave measurements, the physicists concluded not only that the field fluctuations significantly exceeded the classically allowed limits, but that the fluctuations were also surprisingly out of phase with the average field. (G. T. Foster e*t al*, *Phys. Rev. Lett.* **85**, 3149, 2000.)

ULTRASENSITIVE ATOM TRAP TRACE ANALYSIS (ATTA) has been demonstrated. Some well-developed trace analysis techniques, such as accelerator mass spectrometry or low-level counting, lose their effectiveness when the sample being examined is highly contaminated with other isotopes and elements. Now, a group of physicists at Argonne National Laboratory has trapped, detected, and counted single atoms of krypton-85 (with a relative natural abundance of only 10^{-11}) and krypton-81 (abundance of 10^{-13}) in a magneto-optical trap, starting with naturally occurring krypton gas. The ^{85}Kr isotope (halflife 10.8 years) is useful for studies of oceanic, atmospheric, and groundwater transport, while ^{81}Kr is good for dating million-year-old samples of ice and groundwater. ATTA is also sensitive to other useful isotopes, including cesium-135 and cesium-137 for monitoring long-lived nuclear waste, lead-205 for measuring solar neutrinos, and argon-39 for tracing deep ocean currents. (C.Y. Chen *et al*., *Science* **286**, 1139, 1999.)

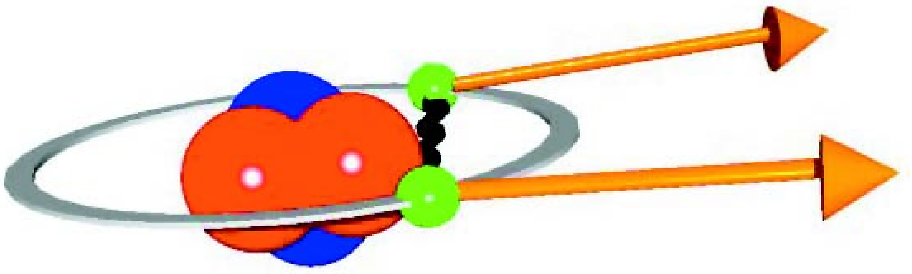
PHASE-COHERENT AMPLIFICATION of matter waves has been demonstrated by two independent research groups. Unlike photons in an optical laser, the number of atoms is conserved in an atom laser, so researchers must rely on a reservoir of atoms to amplify the initial atomic beam. Both groups used similar techniques, starting with a Bose-Einstein condensate (of sodium atoms at MIT, and of rubidium atoms at the University of Tokyo). First, lasers were used to isolate a small fraction of atoms from the BEC to act as a "seed." Then, another laser was used to set up the so-called superradiant Rayleigh scattering condition, under which the seed population grew in a demonstrably phase-coherent way. These atom-wave amplifiers are the first truly active elements for atom-optics research; earlier elements such as mirrors, polarizers, and beam splitters have all been passive. Active amplification could offer improvements in, for example, atom-wave gyroscopes and lithography. (S. Inouye *et al.*, *Nature* **402**, 641, 1999; M. Kozuma *et al.*, *Science* **286**, 2309, 1999.)



The two pictures compare results without (left) and with (right) atom amplification. The spot marked BEC is the shadow of the Bose-Einstein condensate which acted as the amplifier. The spot labeled "input" shows the input atoms which are amplified to a larger and darker spot marked as "output" (Courtesy MIT)

HIGH PROTON POLARIZATION has been achieved at 77 K and with modest 0.3-tesla magnetic fields. Researchers at Kyoto University in Japan used naphthalene doped with pentacene (an aromatic organic molecule chain), knowing that pentacene is diamagnetic in its ground state and paramagnetic in its optically excited triplet state. First, the physicists used a laser beam to optically polarize the electrons in the pentacene. Next, they used carefully tuned microwaves to transfer the polarization to protons in both the pentacene and the naphthalene. The technique, called microwave-induced optical nuclear polarization (MIONP), gave them 32% polarization, and they are working to extend it to room temperature. For comparison, proton targets for particle physics experiments can reach polarizations of up to about 70%, but both higher fields (2 or 5 T) and lower liquid-helium temperatures (0.3 K) are needed. And magnetic resonance imaging involves proton polarization levels of only 0.0003% (still good enough for spotting tumors) at room temperature in a typical magnetic field of 1 T. The Kyoto researchers suspect that their approach will be useful in both of those arenas, as well as in quantum computing and neutron scattering. The polarized protons would be portable, having a relaxation time of more than 3 hours at almost zero magnetic field. (M. Iinuma *et al*., *Phys. Rev. Lett*. **84**, 171, 2000.)

MULTIPLE-IONIZATION MECHANISMS in an intense laser beam have been investigated in two multi-institutional experiments in Germany. At the focus of a strong laser field, an electron in an atom is subjected to an electric field almost as strong as that from the nucleus. Under such conditions, a surprisingly large number of atoms become multiply ionized—losing two (or more) electrons at the same time. It is generally accepted



Schematic drawing of correlated electron emission in a helium atom. Electrons act cooperatively when a laser light pulse ejects two of them from an atom. (Courtesy Harald Giessen, University of Marburg and colleagues.)

that the two electrons are not ejected independently, but rather are correlated. There has been debate, however, over the applicability of three possible mechanisms: shake-off, in which the second electron is removed by the altered potential field after the first electron is emitted; collective multi-electron tunneling; and rescattering, in which an electron is freed by the strong field and then, about half of an optical cycle later, accelerated back toward the parent ion, knocking out the second electron. The new experiments used cold target recoil-ion momentum spectroscopy (COLTRIMS) on helium and neon atoms to determine the three-dimensional momentum distributions of the resulting ions. Both groups found a two-peak distribution along the direction of the laser polarization, interpreted by the neon experimenters as clear evidence for the rescattering model. Before ruling a mechanism in or out, the helium collaboration performed subsequent electron-electron correlation measurements on ionized lithium atoms; they too found the re-scattering model to be a plausible mechanism for their observations. (Th. Weber *et al.*, *Phys. Rev. Lett.* **84**, 443, 2000; *Nature*, **405**, 658, 2000; R. Moshammer *et al.*, *Phys. Rev. Lett.* **84**, 447, 2000.)

CHEMISTRY IN A BOSE EINSTEIN CONDENSATE (BEC). Physicists at the University of Texas at Austin, led by Daniel Heinzen, created diatomic molecules (dimers) using stimulated free-bound transitions in a BEC of individual rubidium-87 atoms. They illuminated the BEC with two laser fields that had frequencies a mere 636 MHz apart, a difference equal to the dimer's binding energy. In this situation, a pair of nearby ^{87}Rb atoms simultaneously absorb a photon from one laser field, then emit a photon into the other field, binding to each other in the process. Unlike molecular recombination in three-body collisions, the ^{87}Rb dimer was formed essentially at rest. The lack of kinetic energy made high-precision spectroscopy possible, and a line width of a scant 1.5 kHz, 10,000 times narrower than for previous experiments in laser-cooled gases, was measured. Such high resolution, in turn, allowed the group to measure molecule condensate interactions for the first time. (R. Wynar *et al*., *Science* **287**, 1016, 2000.)

NEUTRAL ATOMS ON A CURVY TRACK. Physicists at the University of Colorado at Boulder and the nearby National Institute of Standards and Technology facility sent laser-cooled atoms into a 10 cm long, 100 fm-wide channel between two current-carrying wires attached to a glass substrate. The rubidium atoms were attracted to the low magnetic field along the channel's center. The "atom waveguide" followed a path similar to that of a pedestrian avoiding a lamppost, curving out, around, and back to the original trajectory. All three curves had a 15 cm radius of curvature, and as many as two million atoms per second were sent through the course. Part of a growing toolbox of atom optics components, the new waveguide may find use in atom interferometers and in other forms of high-precision metrology. (D. Mueller *et al*., *Phys. Rev. Lett*. **83**, 5194, 1999.)

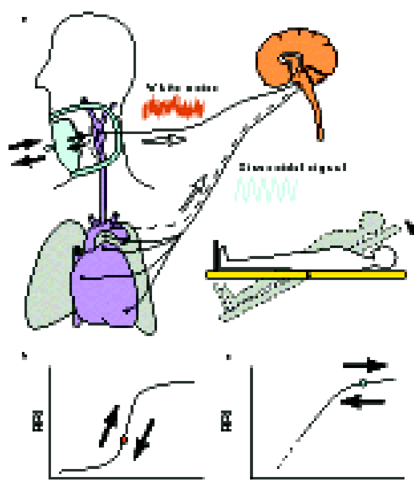
ENTANGLEMENT OF FOUR PARTICLES has been experimentally achieved by researchers at the National Institute of Standards and Technology in Boulder. Entanglement refers to a special linking that persists between the wavefunctions of particles (such as photons or ions) even when the particles are physically separated or otherwise isolated from one another. The NIST group used beryllium ions and, following a proposal put forth last year by Klaus Molmer and Anders Sorensen (University of Aarhus, Denmark), first prepared the ions in their spin-down state and nearly in the ground state of their collective motion. Then, with a single, carefully tuned and timed laser pulse, the four ions were driven through their coupled motion into an entangled superposition of being all spin-down and all spin-up. In principle, according to NIST's Chris Monroe, the technique can be used to entangle many more than four particles, with evident usefulness for quantum information technologies. (C.A. Sackett *et al.*, *Nature* **404**, 256, 2000.)

HARD X RAYS STORED in a crystal resonator. Cavities for optical wavelengths of light are commonplace, but not so for x rays, particularly the high-energy (hard) ones. Now, however, physicists have built and demonstrated such a cavity at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. The "mirrors" were a pair of vertical thin slabs, each 70% reflective, cut from a single crystal of silicon (ensuring the perfect alignment of rows of atoms in both walls) and placed 150 mm apart. The researchers, led by ESRF's Klaus-Dieter Liss, sent 10^{-10}–second pulses of 15.8 keV x rays into the resonator, and saw as many as 14 back-and-forth reflections between the crystals due to multiple Bragg scattering. The new resonator can serve as a narrow-band filter, because the x rays that leak through the crystals on each pass have an ever-narrowing range of energies. Other x-ray optics applications are expected. (K.-D. Liss *et al.*, *Nature* **404**, 371, 2000.)

LASER COOLING BY COHERENT SCATTERING in an optical cavity has been proposed. By making use of atomic scattering, rather than absorption, Stanford's Vladan Vuleti and Steven Chu say their new method can cool atoms, ions, or molecules because it is largely independent of a particle's internal energy level structure. In a cavity, some light modes can propagate but not others. The Stanford physicists' analysis showed that if they detune the incident laser light based on what the cavity will accept, rather than on what an atom can absorb, they will encourage scattering events in which the particles lose energy, and light subsequently leaks out of the cavity. They believe the technique will be demonstrated within the next year, and could be useful for cooling molecules, dense samples of interacting atoms, or collections of mixed isotopes. (V. Vuleti and S. Chu, *Phys. Rev. Lett*. **84**, 3787, 2000.)

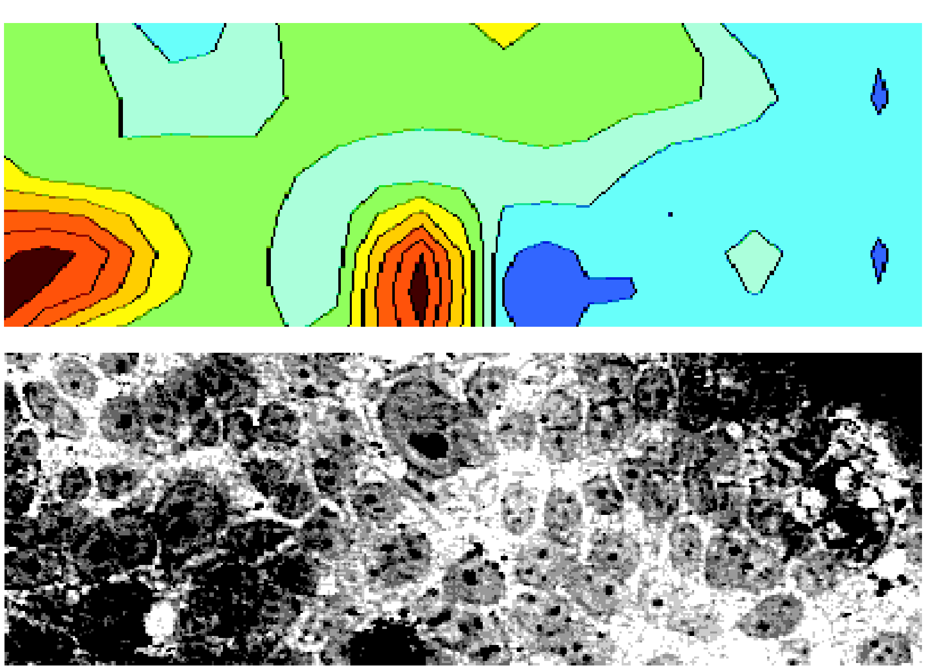
BIOLOGICAL, MEDICAL PHYSICS

NEURAL NOISE can help regulate human blood pressure. In common with other living organisms, the human body operates with unavoidable electrical noise, analogous to radio static, in its nervous system. A new experiment, performed by researchers in Japan, provides evidence that the body can exploit this noise to aid the transmission of weak signals in the nervous system. Such signal enhancement using noise is called stochastic resonance. Working with eight healthy human subjects, the researchers studied the human "baroreflex" system, in which an increase (or decrease) in blood pressure triggers a decrease (or increase) in heart rate. By tilting a subject back and forth on a horizontal table, the researchers moved blood to and from the lower part of the body. Blood draining from the chest area stimulated a weak repeating signal in the body, which the brain interpreted as a drop in venous blood pressure. To create neural noise, the researchers randomly added and removed mechanical pressure from the neck, telling the body that the arterial blood pressure was increasing and decreasing randomly. Measurements indicated that the noise from the arterial receptors in the neck enhanced the signal from the cardiopulmonary receptors near the heart. (I. Hidaka *et al.*, *Phys. Rev. Lett.* **85**, 3740, 2000. For an introduction to stochastic resonance, see Physics Today, March 1996, page 39.)



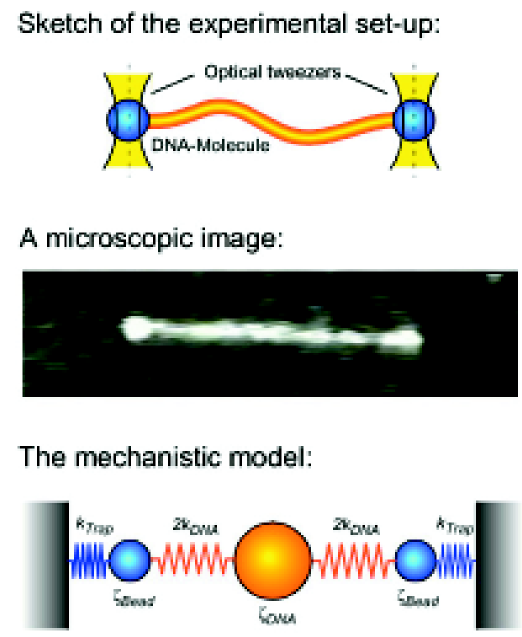
(a) Setup for experiment investigating how random electrical ("neural") noise can enhance the function of the human "baroreflex" system, and response of (b) arterial and (c) cardiopulmonary nerve receptors to changes in blood pressure. (Courtesy University of Tokyo)

EARLY CANCER DETECTION, using backscattered light and an optical fiber probe, has been developed. An MIT group developed a method for detecting precancerous (dysplastic) tissue in the epithelium, the layer of tissue lining the inner surfaces of the body, where more than 85% of all cancers originate. Dysplasia involves characteristic changes in the cell nuclei—they become enlarged, crowded, and more varied in size and shape, and they contain more chromatin (genetic material). Described by the researchers at the APS March Meeting held in Minneapolis, the MIT researchers use a narrow fiber-optic probe both to shine white light onto epithelial tissue, and to collect the light that is backscattered by the cell nuclei—in other words, light scattering spectroscopy applied to small spheres. The spectral and polarization properties of the returned light then provide information on the nuclei's size distribution, location, and (through the index of refraction) chromatin content. The researchers have successfully identified precancerous colon and esophageal tissue in clinical tests, and believe that their technique will reach the commercial market in the next few years.



Top: Obtained from light-scattered spectroscopy, the top image is a map of a 300-micron-wide sample of epithelial tissue from the colon; the lower photograph is a microscopy image of the tissue sample (Courtesy MIT)

FEMTONEWTON FORCE SPECTROSCOPY has been used on DNA molecules. Caltech physicists Jens-Christian Meiners and Stephen Quake attached a bead to each end of a DNA molecule, then held the beads in separate optical tweezers focused laser beams that trap the beads with radiation pressure. By analyzing the cross-correlations of the beads' jiggling motions, they were able to extract force information about the molecule that connected them, with 6 fN resolution and on millisecond time scales. Further, they did it in a wet, warm environment typical of biology, not in a chilled vacuum. One of their findings, contrary to expectation, was that the molecule's relaxation time actually decreased as its extension increased. (J.-C. Meiners, S.R. Quake, *Phys. Rev. Lett*. **84**, 5014, 2000.)



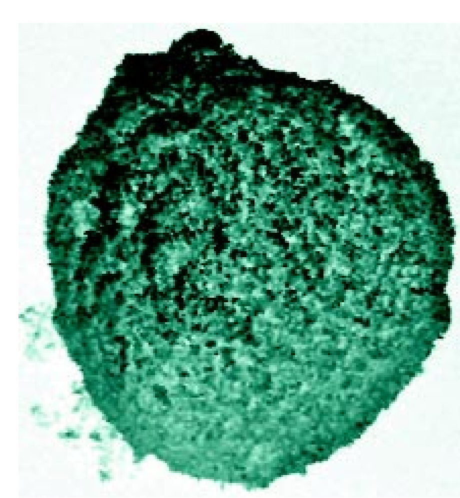
with beads attached at both ends, in the laser beams of an "optical tweezer." MIDDLE: a microscopic picture of the DNA molecule. Bottom: a mechanical model depicting the interactions of molecule, beads, and laser beams in terms of springs; k is a spring constant and zeta is a coefficient of friction. (Courtesy Caltech.)

THE COMPLETE ATOMIC STRUCTURE of a bacterial ribosome's major subunit has been determined. Some of the food we eat gets broken down into amino acids, which are then reassembled into useful proteins in a workshop called the ribosome. Yale crystallographers, led by Thomas Steitz and Peter Moore, presented their 2.4-resolution map at the July meeting of the American Crystallographic Association. Their work presents the largest (by a factor of four) asymmetric molecular structure that has thus far been mapped at the atomic scale. Key to their success was a procedure by which they could reproducibly grow crystals untwinned and much thicker than was previously possible. The crystals could diffract x rays to at least 2.2-angstrom resolution in the synchrotron light sources at Brookhaven and Argonne. The researchers found that the ribosome contains RNA (gray, in this image) at its very core, with surrounding proteins (gold) stabilizing the structure, and they identified an adenosine base in RNA as the site (green) that catalyzes the formation of the peptide bonds that string together amino acids to form proteins. (N. Ban *et al.*, *Science* **289**, 905, 2000; P. Nissen *et al.*, *Science* **289**, 920, 2000.)

MICROFLUIDIC FLOWS driven by thermal gradients. Microfluidics is to the mixing of fluids what integrated circuits are to the processing of electrical signals: Transactions occur quickly, controllably, and in a very small region of space. A common technique involves excavating nano-sized channels in a substrate and then propelling tiny fluid volumes around the system of aqueducts with electric fields. Such systems allow for turbulence-free mixing and analysis of small samples of, for example, blood or DNA. At the November 1999 meeting of the American Physical Society's division of fluid dynamics, Princeton University professor Sandra Troian reported moving tiny parallel rivulets along the surface of a silicon wafer using mild temperature gradients rather than electric fields. In such a system, the liquid experiences a variable liquid surface tension, which causes it to seek out a relatively colder region. The pathways were drawn by chemical lithography or UV ablation of a monolayer. With thermocapillary microfluidics, high electric fields and the precision carving of channels are not necessary, and everything happens on an open planar surface, which could simplify the fabrication of labs-on-a-chip. (D.E. Kataoka, S.M. Troian, *Nature* **402**, 794, 1999.)

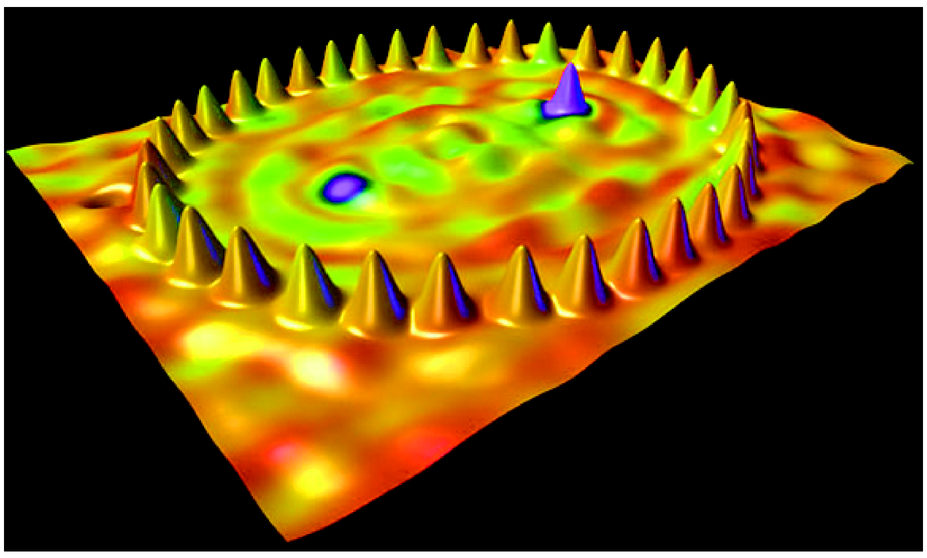
CONDENSED MATTER, MATERIAL PHYSICS

SUPERCONDUCTING BALLS have been observed. Physicists at Southern Illinois University created a "mud" of micrometer-sized high-T$_c$ particles suspended in liquid nitrogen, placed it between two electrodes in a nitrogen bath, and switched on a DC electric field. Normally, particles in this situation would either bounce between the two electrodes or tend to line up in chains; after all, a uniform electric field defines a preferred direction in space. However, the superconducting particles ignored this hint and, to the researchers' great surprise, formed themselves into a ball instead, which then bounced rapidly between the electrodes, frantically acquiring and releasing charge. Such balls formed in milliseconds and were very sturdy, surviving many high-impact collisions with the electrodes. One ball, about 0.25 mm across and containing over a million particles of $Bi_2Sr_2CaCu_2O_{8+x}$, is shown here. Using a bath of liquid argon, the researchers showed that the ball dissolved at temperatures above T$_c$. Apparently, the balls form through a new surface tension phenomenon that arises from a competition between coherence and screening effects. According to Rongjia Tao, the new discovery might provide an important clue for distinguishing high- from low-T$_c$ superconductivity, and could have applications in the area of superconducting thin films and unusual forms of wetting. (R. Tao *et al.*, *Phys. Rev. Lett*. **83**, 5575, 1999.)



Scanning electron micrograph of a 0.25-mm-diameter ball consisting of Bi-Sr-Ca-Cu-O particles packed closely together (Courtesy Southern Illinois University).

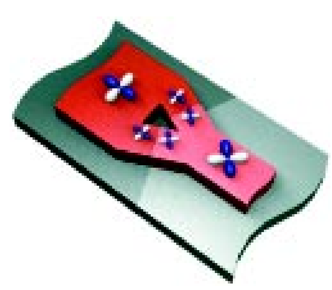
MAGNETIC MIRAGE IN A QUANTUM CORRAL. The scanning tunneling microscope enables researchers to push individual atoms around on a surface and to image them. Shown here is an elliptical quantum corral made of 36 cobalt atoms carefully positioned on a copper surface. An extra magnetic cobalt atom is at one of the two foci of the ellipse, where its magnetic moment interacts with the confined surface electron waves, and is seen as the Kondo effect (the purple peak). Remarkably, the same Kondo effect is seen at the other focus, where no magnetic impurity exists. Nonmagnetic atoms, or atoms placed off of a focus, produced no such phantoms. The researchers, three IBM Almaden physicists, speculate that it may be possible to perform remote spectroscopy on such a mirage rather than on a real atom or molecule (thus completely avoiding atomic perturbations). (H. C. Manoharan, C. P. Lutz, D. M. Eigler, *Nature* **403**, 512, 2000.)



In an elliptical structure of 36 cobalt atoms, electron waves moving in the copper surface interact both with a magnetic cobalt atom carefully positioned at one of the foci of the ellipse and apparently with a "mirage" of another cobalt atom (that isn't really there) at the other focus. (Courtesy IBM.)

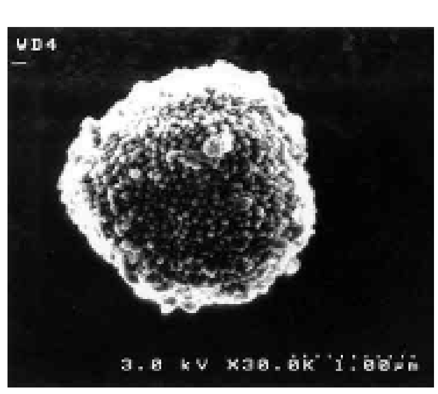
A D-WAVE SQUID (superconducting quantum interference device) has been built by a group led by Jochen Mannhart at Augsburg University in Germany, together with Chang Tsuei of IBM Yorktown Heights. The working fluid of superconductors consists of Cooper pairs of electrons or holes that form a macroscopic quantum state with specific symmetry properties. For example, most low-temperature superconductors have a spherical, or s-wave, symmetry if you imagine one electron at the origin of some coordinate system, the likelihood of finding the paired electron is pretty much the same in all directions. In high-temperature superconductors, the symmetry is thought to resemble a four-leaf clover, and is referred to as d-wave. A fundamental consequence of d-wave symmetry is a phase-change of pi between neighboring lobes of the clover in the quantum wavefunction describing the Cooper pair. The new device, dubbed the pi-SQUID, uses one standard Josephson junction and one so-called pi-junction, and it might prove useful for novel superconducting electronics or even superconducting qubits in a future quantum computer. (R. R. Schulz *et al.*, *Appl. Phys. Lett*. **76**, 912, 2000.)

A MILLION-VOLT FIELD EMISSION TRANSMISSION ELECTRON MICROSCOPE (FE-TEM) has been built by a team led by Akira Tonomura at Hitachi's Advanced Research Laboratory in collaboration with the Japan Science and Technology Corp. In an FE-TEM, electrons are drawn out of a cathode and accelerated by a high voltage. The one million volts produced a beam of electrons that was four times brighter than the best previous FE-TEM (300 kV) and 1000 times brighter than conventional thermionic-emission TEMs. The device is a marvel of engineering. The 1 MV must be stable to within half a volt, and the electron source must be held steady to within 0.5 nm. As shown here, the new device can image rows of atoms only half an angstrom apart (thus rivaling scanning tunneling microscopes) and can even take pictures fast enough, 60 per second, to make movies of fine gold particles changing their shapes. In addition, due to their higher energies, the electrons can penetrate deeper into a sample than was previously possible, and thus provide three-dimensional information. Hitachi's Takeshi Kawasaki says that the microscope will be useful for observing certain dynamic properties of condensed matter systems for example, the movement of vortices in high-temperature superconductors. (T. Kawasaki *et al.*, *Appl. Phys. Lett*. **76**, 1342, 2000.)



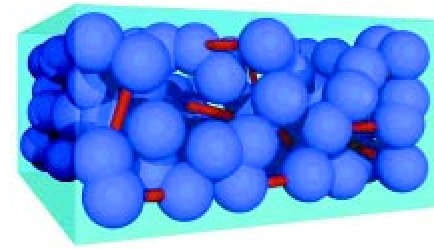
The dumbbell-shaped blobs represent the quantum wavefunctions of Cooper pairs of electrons at they move through a crystal of superconductor and approach a thin insulating layer which they must tunnel through to enter yet another crystal. (Courtesy Augsberg University.)

MICROLASERS IN A SEMICONDUCTOR POWDER. Most current microlasers, including vertical-cavity surface-emitting, microdisk, and photonic bandgap defect-mode lasers, are fabricated in expensive, state-of-the-art facilities. But now, Hui Cao and her colleagues at Northwestern University have created microlasers in a glass beaker, using zinc oxide powder, a simple disordered medium. About 20000 of the 50 nm ZnO crystallites were induced to coalesce into a 1-micron sized cluster. Light fed into the cluster was strongly scattered, and some of it became trapped in highly localized spots (via interference effects) and enhanced, as shown by the bright areas (at 380 nm) in the accompanying image. The light amplification occurred through an active, coherent feedback of the interference effects. (H. Cao *et al.*, *Appl. Phys. Lett*. **76**, 2997, 2000; *Phys. Rev. Lett*. **84**, 5584, 2000.)



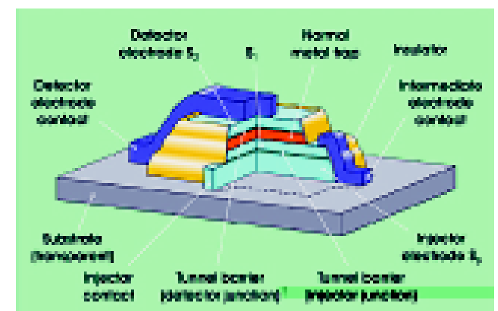
Scanning electron microscope photo of a micron-sized ZnSe particle used in a powder laser. (Courtesy Northwestern.)

LIQUID MOLECULAR DEUTERIUM has been transformed into a metallic fluid. Physicists at Lawrence Livermore National Laboratory used the powerful Nova laser to push a plunger that, in turn, sent a shock wave through a sample of cryogenic liquid D_2, an insulator. Using another beam from a separate probe laser, the researchers simultaneously monitored the velocity of the shock (as a diagnostic of the pressure) and the sample's reflectivity (as a diagnostic of metallic behavior). They found that the reflectivity began to increase at around 20 GPa, at which pressure the D_2 begins to dissociate into single deuterium atoms. Above 50 GPa, the reflectivity was saturated, and the change from an insulating to a conducting state was complete. The change was continuous rather than abrupt, indicating that the metallization was not a first-order phase transition. At 50 GPa, the temperature of the metallic deuterium was about 8000 K, near the conditions expected in Jupiter's interior. (P.M. Celliers *et al.*, *Phys. Rev. Lett*. **84**, 5564, 2000.)



Deuterium molecules, under high pressure generated by Livermore's Nova laser, break into atoms and are converted into a conducting state. (Courtesy Livermore.)

A SUPERCONDUCTING TRANSISTOR-LIKE DEVICE has been fabricated and tested. A group led by Norman Booth (University of Oxford) and Antonio Barone (University of Naples) stacked together two tunnel junctions to build a device having three metallic layers separated by two insulating barriers. A signal current or voltage applied to the superconducting injector junction breaks some of the bound Cooper pairs of electrons. One of the resulting two electronic excitations (called quasiparticles) tunnels into the middle layer, actually a bilayer composed of superconducting niobium followed by normal aluminum. There, it gives up its energy to many of the free electrons in the normal metal; these electrons can then tunnel through the second junction. The highly directional current gain can be as high as a factor of 70. The device operates at 4.2 K, a temperature at which conventional transistors perform poorly, on a power of about 1 microwatt and voltages of millivolts. By reversing the bias polarities, this quasiparticle trapping transistor, which the researchers call a "quatratran," becomes the superconducting analog of both the pnp and npn transistors. Furthermore, by reversing only one polarity, a new device results that has negative current gain. (G. P. Pepe *et al.*, *Appl. Phys. Lett*. **77**, 447, 2000.)



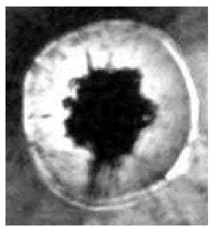
Schematic diagram showing the various parts of a superconductor transistor device. (Courtesy Norman Booth, Oxford, et al.)

QUANTUM SUPERPOSITION OF DISTINCT MACROSCOPIC STATES has been demonstrated. In general, a large, complex system can show quantum effects only if it is completely decoupled from the environment. Hence, experimental realizations of quantum superposition have involved a very few individual particles, whether electrons, ions, or photons. Now, however, physicists at SUNY Stony Brook, led by James Lukens and Jonathan Friedman, have broken the macroscopic barrier using a carefully isolated superconducting quantum interference device (SQUID) operating at 40 mK. The SQUID could accommodate either zero or one magnetic flux quantum, corresponding to a few microamps of current flowing either clockwise or counterclockwise around the device. The experimenters used microwaves to induce coherent tunneling between the two flux states, thereby putting the states into a quantum superposition. The magnetic moments of the two states differ by about 10^{10} Bohr megnetrons, which is truly macroscopic. Such a large coherent quantum state might find a use in quantum computing. (J. R. Friedman *et al.*, *Nature* **406**, 43, 2000.)

NONMOLECULAR NITROGEN has been observed by scientists at the Carnegie Institution of Washington. Because of its triple bond, diatomic nitrogen is one of the most strongly bound simple molecules in nature. Atomic nitrogen has not been seen under ambient conditions, but was thought to exist at very high pressure, such as in Jupiter's core. The physicists squeezed (and monitored) N_2 in a diamond anvil cell. At pressures above 150 GPa, the sample became optically opaque, and rotational and vibrational features disappeared from the Raman and infrared spectra. The researchers interpret these results to mean that the N_2 dissociated into a nonmolecular state of nitrogen that appeared to be semiconducting. There is speculation that nitrogen might become metallic at pressures above 275 GPa, a regime the group is currently exploring. (A.F. Goncharov *et al.*, *Phys. Rev. Lett*. **85**, 1262, 2000.)

A HIGH-PERFORMANCE ALL-POLYMER INTEGRATED CIRCUIT has been developed. Scientists at the Philips Research Laboratories in The Netherlands have turned production of polymer transistors on its head. Previously, the group had sandwiched the semiconducting material between the first electrode and the gate, but that arrangement proved to be difficult to fabricate and optimize. Now, Gerwin Gelinck and his colleagues have produced an IC with the gate on the bottom, followed by an insulating layer, then by the source and drain electrode layer. In the figure, the two tiny squares are vertical interconnects (vias), 5 micron on a side, and the structure is poised to receive the top layer of semiconductor. In this geometry, the researchers can streamline the processing, photochemically pattern the vias, and virtually eliminate material compatibility problems. They have built a working IC that combines more than 300 transistors and 200 vias. Although not yet as fast as silicon circuits, polymer components have the virtues of being lightweight, flexible, and potentially easier to fabricate. (G.H. Gelinck, T.C.T. Geuns, D.M. de Leeuw, *Appl. Phys. Lett*. **77**, 1487, 2000.)

SINGLE-MOLECULE CHEMISTRY with a scanning tunneling microscope (STM). Normally, one produces biphenyl ($C_{12}H_{10}$) molecules from iodobenzene (C_6H_5I) molecules with a copper catalyst, using thermal activation at about 200 K. But now, Saw-Wai Hla and his colleagues at the Free University of Berlin used an STM at 20 K to manipulate single molecules through every stage of the complete chemical reaction. They started with several C_6H_5I molecules nestled at a step on a terraced copper substrate. They then dissociated some of the molecules into iodine and phenyl (C_6H_5) by injecting electrons from the STM tip. Next, they used the STM tip to move the iodine atoms away from the step, and then to bring two phenyl molecules next to each other. The phenyls could still be independently manipulated, and thus were not yet chemically bound. In the final step, another splash of electrons from the tip effectively welded the two phenyls together; when one was now pulled with the tip, the other came along for the ride. The researchers believe that more complex chemical reactions can be studied on the atomic scale with these techniques, and that new molecules, never before seen in nature, can be engineered in this way, perhaps for molecular based nanodevices. (S.-W. Hla *et al*., *Phys. Rev. Lett*. **85**, 2777, 2000.)



Microphotograph of an opaque sample of nitrogen at a pressure of 160 GPa. The reflected light indicates the dissociation of molecular nitrogen (N_2) into a nonmolecular phase. (Courtesy Carnegie Institution)

AN ELECTRICALLY POWERED, ORGANIC SEMICONDUCTOR LASER has been built for the first time by Bell Labs researchers, offering the hope of more versatile, easier-to-make lasers. Bell Labs researchers grew high-purity crystals of tetracene, an organic molecule consisting of four linked rings of carbon. They then sandwiched the crystal above and below with field-effect transistors (FETs). Applying a voltage between the two FETs caused one of them to send electrons into the tetracene, while the other provided positively charged holes. When electrons and holes met, they produced yellow-green light that bounced between a pair of mirrors to produce laser action and an output beam. The high purity of the tetracene provided a low-defect environment for the electrons and holes (so they would produce light rather than heat) and the FETs were able to inject electrons and holes at the sufficiently high rate required for laser action. Technological challenges remain before this laser is mass-produced: manufacturers must learn how to make large quantities of the ultrapure tetracene, and they must learn how to place FETs above and below the organic material. (Schoen *et al*, *Science* **289**, 599, 2000.)

THE FIRST TRUE "LEFT HANDED" MATERIAL has been devised by scientists at the University of California at San Diego. In this medium, light waves are expected to exhibit a reverse Doppler effect. That is, the light from a source coming toward you would be reddened and the light from a receding source would be blue shifted. The UCSD composite material, consisting of an assembly of copper rings and wires should eventually have important optics and telecommunications applications. To understand how a reverse Doppler shift and other bizarre optical effects come about, consider that a light wave is a set of mutually reinforcing oscillating electric and magnetic fields. The relationship between the fields and the light motion is described picturesquely by what physicists call the "right hand rule": if the fingers of the right hand represent the waves' electric field, and if the fingers curl around to the base of the hand, representing the magnetic field, then the outstretched thumb indicates the direction of the flow of light energy. Customarily one can depict the light beam moving through a medium as an advancing plane of radiation, and this plane, in turn, is equivalent to the sum of many constituent wavelets, also moving in the same direction as the energy flow. But in the UCSD composite medium this is not the case. The velocity of the wavelets runs opposite to the energy flow (an animated video illustrates this concept nicely, and this makes the UCSD composite a "left handed substance," the first of its kind. Such a material was first envisioned in the 1960's by the Russian physicist Victor Veselago of the Lebedev Physics Institute (Soviet Physics Uspekhi, Jan-Feb 1968), who argued that a material with both a negative electric permittivity and a negative magnetic permeability would, when light passed through it, result in novel optical phenomena, including a reverse Doppler shift, an inverse Snell effect (the optical illusion which makes a pencil dipped into water seem to bend), and reverse Cerenkov radiation. Permittivity (denoted by the Greek letter ε) is a measure of a material's response to an applied electric field, while permeability (denoted by the letter μ) is a measure of the material's response to an applied magnetic field. In Veselago's day no negative-mu materials were known, nor thought likely to exist. More recently, however, John Pendry of Imperial College has shown how negative-ε materials could be built from rows of wires (Pendry et al., *Physical Review Letters*, 17 June, 1996) and negative-μ materials from arrays of tiny resonant rings (Pendry *et al*., *IEEE, Trans. MTT* **47**, 2075, 1999). Then at the American Physical Society meeting in Minneapolis, Sheldon Schultz and David Smith of UCSD reported that they had followed Pendry's prescriptions and succeeded in constructing a material with both a negative μ and a negative ε, at least at microwave frequencies. The raw materials used, copper wires and copper rings, do not have unusual properties of their own and indeed are non-magnetic. But when incoming microwaves fall upon alternating rows of the rings and wires mounted on a playing-card-sized platform and set in a cavity, then a resonant reaction between the light and the whole of the ring-and-wire array sets up tiny induced currents, which contribute fields of their own. The net result is a set of fields moving to the left even as electromagnetic energy is moving to the right. This effective medium is an example of a "meta-material." Another example is a photonic crystal (consisting of stacks of tiny rods or solid material bored out with a honeycomb pattern of voids) which excludes light at certain frequencies. Schultz has said that having demonstrated that their medium possessed a negative μ and ε, they were now proceeding to explore the novel optical effects predicted by Veselago. Furthermore, they hope to adapt their design to accommodate shorter wavelengths. As for applications in microwave communications, a medium which focuses waves when other materials would disperse them (and vice versa) ought to be useful in improving existing delay lines, antennas, and filters (Smith *et al.*, *Physical Review Letters*, 1 May 2000).

ALL-OPTICAL NMR has been achieved by David Awschalom's research group at the University of California, Santa Barbara. Previous versions of nuclear magnetic resonance (NMR) have relied on radio-frequency electromagnetic fields to tip nuclear magnetic moments. This approach (nearing its 50th anniversary with proven success in medical imaging and chemistry), is modified by the UCSB scientists in the following way. They use a laser to excite a bath of electron spins, which then do all the work. As these electron magnetic moments swarm about the nuclei, their number and direction are controlled by the laser in a way that tips nuclear spins. Nuclei are monitored during the process by a second laser beam, making this an entirely optical approach. Demonstrated in the semiconductor GaAs, this fundamentally different alternative to ordinary NMR offers potentially increased resolution because light can be focused more tightly than RF fields. Moreover, because the UCSB strategy exploits electrons as an intermediary, individual electron orbits themselves might be used to obtain atomic-scale focusing. (For background, see Kikkawa and Awschalom, Science, Jan. 21, 2000). One aim of this research is to "imprint" electron spin on the nuclear system within integrated "spintronic" devices, where electron spin supplants charge as a source of information.

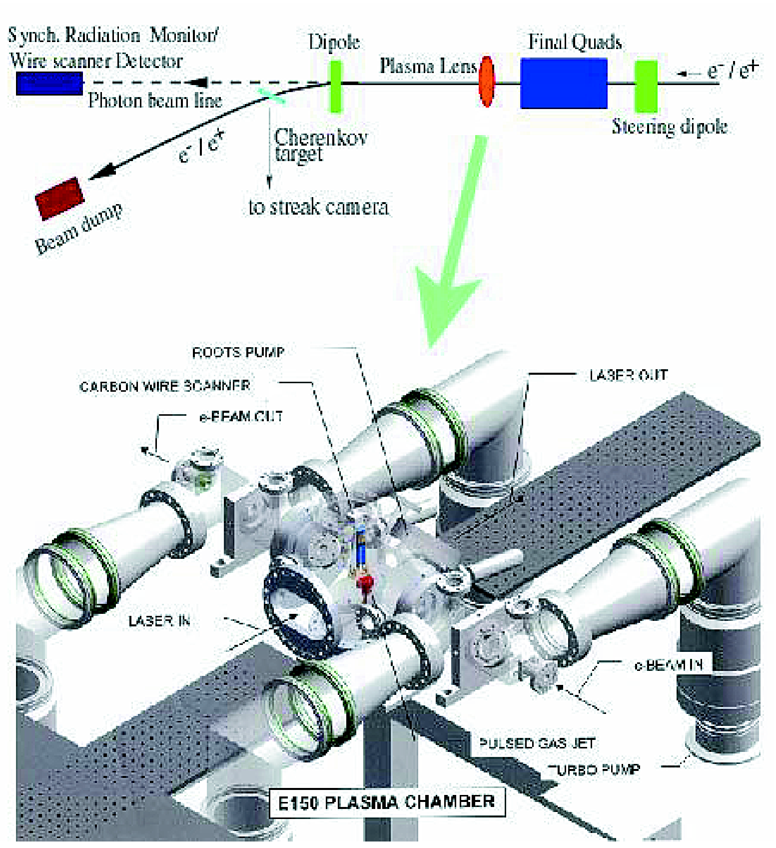
PARTICLE, NUCLEAR AND PLASMA PHYSICS

DIRECT EVIDENCE FOR TAU NEUTRINOS has been reported at Fermilab. While the existence of neutrinos associated with the tau lepton was not in doubt, actually observing the particle interact had not occurred until now. This rounds out the program of experimental sightings of the truly fundamental building blocks prescribed by the standard model of particle physics. This official alphabet consists of six quarks— known as up, down, strange, charm, top, and bottom—and six leptons—electron, electron neutrino, muon, muon neutrino, tau, and tau neutrino. All matter, according to the theory, should be made up from these most basic of constituents. Other particles, such as the anti-matter counterparts of the quarks and leptons, the force-carrying bosons (e.g., photons, gluons, etc.), and the Higgs boson (which confers mass upon some of the other particles) also appear in the theory. (Still other candidates, such as the "supersymmetric" particles, are not part of, but are expected to be compatible with, the standard model.) The evidence for the tau neutrino is slim but impressive: four scattering events exhibited at a July 2000 seminar by Fermilab physicist Byron Lundberg, leader of Experiment 872, the Direct Observation of Nu Tau (or DONUT) collaboration (http://fn872.fnal.gov/). Their experiment proceeds in the following manner. Fermilab's 800-GeV proton beam was steered onto a tungsten target, where some of the prodigious incoming energy is turned into new particles. Some of these quickly decay into taus and tau neutrinos. Next comes an obstacle course of magnets (meant to deflect charged particles away) and shielding material (meant to absorb most of the other particles except for rarely interacting neutrinos). Beyond this lies a sequence of emulsion targets in which the neutrinos can interact, leaving a characteristic signature. Evidence for a tau neutrino in the emulsion is the creation of a tau lepton, which itself quickly decays (after traveling about 1 mm) into other particles. The E872 physicists estimate that about 10^{14} tau neutrinos entered the emulsion, of which perhaps 100 interacted therein. It was a carefully analyzed handful of such events that was presented to the public in evidence. The tau neutrino is the third neutrino type to be detected. The detection of the electron neutrino by Clyde Cowan and Frederick Reines garnered Reines the 1995 Nobel Prize for physics (Cowan had died some years before). For discovering the muon neutrino, Leon Lederman, Melvin Schwartz, and Jack Steinberger won the Nobel Prize in 1988.

A NEW FORM OF NUCLEAR MATTER has been detected at the CERN lab in Geneva. Results from seven different experiments, conducted at CERN over a span of several years, were announced at a series of seminars on February 10, 2000. In the experiments a high energy beam of lead ions (160 GeV/nucleon, times 208 nucleons, for a total energy of about 33 TeV) smashes into fixed targets of lead or gold atoms. The center-of-mass energy of these collisions, the true energy available for producing new matter, is about 3.5 TeV. From the debris that flies out of the smashups, the CERN scientists estimate that the "temperature" of the ensuing nuclear fireball might have been as high as 240 MeV (under these extreme conditions energy units are substituted for degrees kelvin), well above the temperature where new nuclear effects are expected to occur. In the CERN collisions the effective, momentary, nuclear matter density was calculated to be 20 times normal nuclear density. It is not quite certain whether the novel nuclear state is some kind of denser arrangement of known nuclear matter or a manifestation of the much-sought quark-gluon plasma (QGP), in which quarks, and the gluons which normally bind the quarks into clumps of two quarks (mesons) or three quarks (baryons), spill together in a seething soup analogous to the condition of ionized atoms in a plasma. Such a nuclear plasma might have existed in the very early universe only microseconds after the big bang. Evidence for the transition from a hadron phase (baryons and mesons) into a QGP phase is expected to consist of (1) an enhanced production of strange mesons, (2) a decrease in the production of heavy psi mesons (each consisting of a charm and anticharm quarks), and (3) an increase in the creation of energetic photons and lepton-antilepton pairs. Just this sort of (indirect) evidence (at least of types 1 and 2) is hat turned up in the CERN data. (CERN press release, www.cern.ch). To demonstrate the existence of QGP more directly, one would like the plasma state to last longer, and one should observe the sorts of particle jets and gamma rays that come with still higher-energy fireballs. That energy (about 40 TeV, center-of-mass) will be available soon at the Relativistic Heavy Ion Collider undergoing final preparations at Brookhaven.

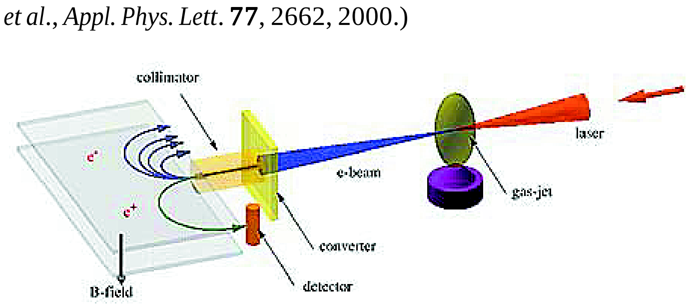
FIRST RESULTS FORM RHIC. Brookhaven's Relativistic Heavy Ion Collider (RHIC) had their first heavy-ion collisions back in June and since then extremely energetic smashups between gold atoms have been lighting up detectors in the four interaction halls, creating fireballs that approximate tiny pieces of the universe as it might been only microseconds after the big bang. One conspicuous goal at RHIC is to rip apart protons and neutrons inside the colliding nuclei in order to create novel new forms of nuclear matter, such as quark gluon plasma. The beam energies have been as high as 130 GeV per nucleon and the beam density is up to about 10% of its design value. In this first published RHIC paper, the PHOBOS collaboration describes the "pseudorapidity" (related to the velocity along the direction of the beams) of the myriad particles emerging from the collisions. The researchers pay special attention to particles emerging at right angles to the incoming beams. These particles emanate from the most violent of collisions, which on average create about 6000-7000 particles per event, more than have ever been seen in accelerator experiments before. The number of particles produced in turn is indicative of the energy density of the fireball produced at the moment of collision; this density, 70% higher than in previous heavy-ion experiments, carries the RHIC researchers into a new portion of the nuclear phase diagram. The data presented here help to constrain models of this high-density nuclear realm. (Back *et al*., *Physical Review Letters*, 9 October 2000.)

A PLASMA LENS for GeV electrons and positrons has been demonstrated. To get a reasonable number of interactions between colliding particles in an accelerator, a particle beam's cross section must be squeezed as tightly as possible. Typically, such focusing is done with large quadrupole magnets. Another possible technique, however, involves plasmas. Charged particles in a beam experience two competing forces: a Coulomb force, which tries to push like charges apart, and magnetic forces that can push them together. If a charged beam traverses a plasma, it will quickly redistribute the plasma's electrons; this can reduce the net Coulomb force while leaving the magnetic force unaffected. The result is a magnetically pinched beam. Within the past year, two experiments at SLAC have demonstrated the effect. In the E-157 experiment, such beam pinching was seen as a by-product of the plasma wakefield acceleration process. By contrast, the E-150 experiment was intended to explicitly examine plasma focusing, independent of the sign of the beam's charge. The E-150 experimenters found that a beam of 30 GeV electrons (or positrons) propagating through just a few millimeters of plasma could have its diameter reduced by two thirds. The E-150 results were presented by Hector Baldis (Lawrence Livermore National Laboratory) at the October 2000 meeting of the American Physical Society's Division of Plasma Physics and the International Congress on Plasma Physics, held in Quebec City. According to Baldis, the focusing region of the next generation of linear colliders could be reduced in length from kilometers to meters by using the plasma-focusing approach.



Schematic of experimental setup for using plasma to focus a beam. (Courtesy E150 Collaboration, Livermore)

TABLETOP POSITRONS. Most laboratory positrons are generated in accelerators. A common method is to accelerate electrons to energies greater than 1.022 MeV and then pass them through a target with heavy nuclei, such as lead. Electron-positron pairs are thereby created, and the two species can be separated with a magnetic field. Now, a similar procedure has been followed using a tabletop femtosecond laser. Physicists led by Klaus Witte at the Max Planck Institute for Quantum Optics in Garching, Germany, focused pulses from their ATLAS laser into a jet of helium gas. The laser both ionized the gas and accelerated the resulting free electrons to multi-MeV energies, directed toward a lead target. ATLAS produced ten laser pulses per second, each of which generated up to 10^6 positrons, with a mean energy of about 2 MeV, in the lead. The experimenters estimate that the maximum intensity of the source is equivalent to 2 x 10^8 Bq. George Tsakiris, a member of the group, says that their experiment could be the forerunner of a tabletop positron source for applications in materials science and fundamental physics. (C. Gahn *et al.*, *Appl. Phys. Lett*. **77**, 2662, 2000.)



An intense femtosecond laser strikes a gas-jet target, creating energetic electrons; these in turn are directed into a secondary target which converts the energy into electron-positron pairs; a magnetic field move the electrons one way, the positrons the other. (Courtesy Max-Planck Institute.)

AN INTRIGUING HINT OF THE HIGGS BOSON in collider data at the LEP accelerator at CERN prompted officials there to extend the running period of the Large Electron Positron (LEP) collider by a month, before turning it off for good to make way for the building of the Large Hadron Collider to be housed in the same deep tunnel as LEP. The extension allowed the high energy electron-positron collisions at LEP to continue temporarily, the better to supplement the meager, but potentially crucial, evidence for the Higgs boson, the particle widely thought to be responsible for endowing other known particles with mass. What happens at LEP, in effect, is that a lot of energy squeezed into a very tiny volume almost instantly rematerializes in the form of new particles. Theorists have said that in some collisions a Higgs boson (h) might be produced back to back with a Z boson, one of the carriers of the weak force and itself the object of a dramatic particle hunt at CERN 20 years ago. In these rare events, both h and Z are expected to decay quickly into two sprays, or jets, of particles. One tactic then is to search 4-jet events for signs that the combined mass of two jets at a special energy seems to stand out above pedestrian "background" events in which no true exotic particle had been produced. What caught LEP physicists' attention is just such an enhancement, at a mass around 114 GeV/c^2. The enhancement is not statistically significant enough for CERN to claim a discovery yet, even when all four detector groups combine their data, but sufficient to cause excitement since the Higgs is perhaps the most sought after particle in all of high energy physics. (Some websites: press.web.cern.ch; opal.web.cern.ch/Opal/; alephwww.cern.ch/WWW/)

EVIDENCE OF A SOFT DIPOLE RESONANCE has been found. In neutron-rich light nuclei, the extra neutrons can constitute a "halo" around the core nucleus. According to predictions dating back to the mid-1980s, if such nuclei are properly excited, the core and halo should oscillate. Yet the very existence of this "soft dipole resonance" has remained controversial, both experimentally and theoretically. Now, a group in Japan led by Shintaro Nakayama (University of Tokushima) may have seen it in helium-6. The physicists bombarded a lithium-6 target with a beam of $7Li^{3+}$ and acquired data on the energy and angular distributions of the ^7Be ejecta. After subtracting the effects of the spin dipole and giant dipole resonances, a feature remained whose properties were consistent with the long-sought soft dipole resonance. (S. Nakayama *et al.*, *Phys. Rev. Lett*. **85**, 262, 2000.)

A NUCLEAR-ATOMIC ENERGY RESONANCE. works in both directions. Normally, thousands or millions of eV separate atomic and nuclear energies. But for heavy atoms, the innermost (K-shell) electrons can have binding energies comparable to some nuclear transition energies, a crucial feature in two recent experiments. A multinational experiment, conducted at the GANIL accelerator in France, took tellurium atoms with 47 or even 48 of their 52 electrons removed and smashed them into a target. In those collisions, the Te nucleus was put into an excited state and subsequently emitted a virtual photon, a gamma ray that was immediately absorbed by a K-shell electron. Rather than kicking the electron out of the atom, however, the gamma-ray energy was just right to promote the electron into a highly excited, bound (Rydberg) state. Such internal conversion, from one atomic bound state to another, had not been seen before. Meanwhile, a group of physicists in Japan observed the inverse process, nuclear excitation by electronic transition (NEET). That group used the Spring-8 synchrotron source to knock K-shell electrons out of gold-197 atoms. Usually an outer electron will fill the K-shell vacancy, giving up energy in the form of x rays and throwing Auger electrons from the atom during the process. The researchers, however, observed that the energy occasionally excited the nucleus instead of creating Auger electrons and x rays. Together, these experiments can help explain anomalous lifetimes of some nuclear species, and have implications reaching from the laboratory to astrophysical plasmas. (T. Carreyre *et al.*, *Phys. Rev. C* **62**, 024311, 2000. S. Kishimoto *et al.*, *Phys. Rev. Lett* **85**, 1831, 2000.)

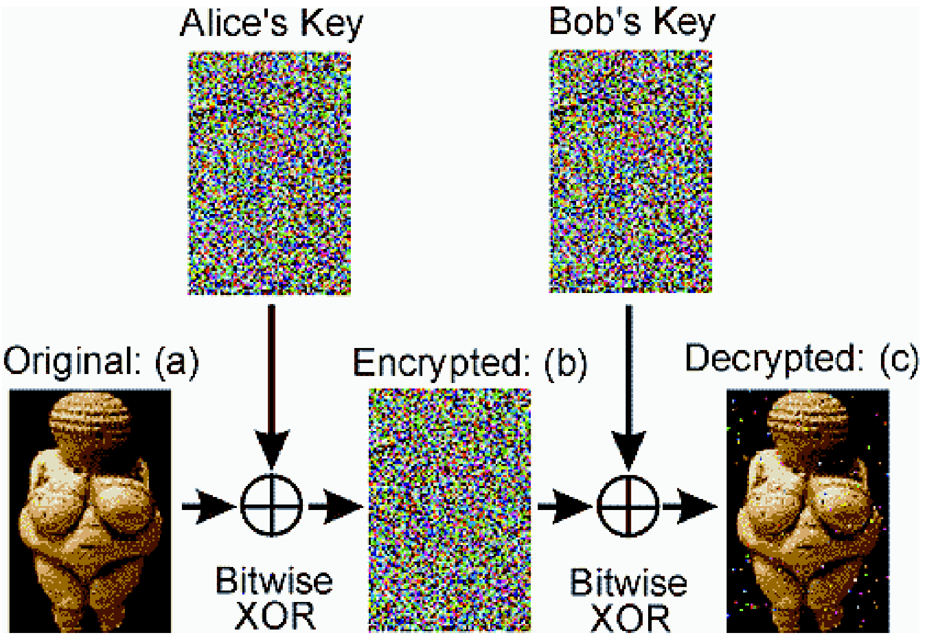
OTHER PHYSICS HIGHLIGHTS

COLLISONALLY IONIZED HYDROGEN, the simplest nontrivial three-body Coulomb scattering problem in quantum mechanics, has now been solved from first principles. When a sufficiently energetic free electron impinges on a neutral hydrogen atom, the bound electron is separated from its proton, and the resulting now-indistinguishable electrons move farther and farther apart from each other (and from the proton) at arbitrary angles and momenta. The wavefunction for that final, asymptotic state is a boundary condition for the problem, and has proven intractable to calculate; thus the dynamical details of the scattering have been impossible to predict. Now, however, a collaboration of California theorists has reformulated the problem. Using massively parallel computational techniques, they first computed the complete wavefunction in a limited region of space, without explicitly referring to an asymptotic state (somewhat analogous to near-field optics), then extracted the dynamical details from the computed solution. By solving the problem for different sized regions, they were able to extrapolate to the asymptotic state. Because the only approximations are numerical rather than physical in nature, the results can be made as accurate as the computational resources allow. Indeed, the researchers are able to fit the best recent experimental cross sections exquisitely well, with no adjustable parameters. (T.N. Rescigno *et al.*, *Science* **286**, 2474, 1999.)

THE LIMITS OF CONTROL have been derived. MIT researchers Seth Lloyd and Hugo Touchette combined statistical mechanics, thermodynamics, and information theory to examine the complementary roles of information and uncertainty in control processes. From the perspective of thermodynamics, controlling a system means reducing its disorder, or entropy; that reduction also removes some of our uncertainty about the system and therefore increases our information about it. The two theorists analyzed an arbitrary system coupled to an uncontrollable environment. Such a system, which can be closed, open, linear, nonlinear, chaotic, quantum, or more complex, is monitored by an appropriate measurement apparatus and acted on by a controlling device. The controller itself can be either open-loop (acting independently of the state of the system) or closed-loop (based on some information gathered about the system). Lloyd and Touchette established a formalism for looking at the general control problem, and showed that the amount of entropy that a controller can remove from a dynamical system has an upper bound. They believe that their statistical approach is particularly suited for controlling chaotic dynamics and quantum systems. (H. Touchette, S. Lloyd, *Phys. Rev. Lett.* **84**, 1156, 2000.)

HIGHLY OPTIMIZED TOLERANCE (HOT), has recently been proposed as a mechanism for generating complexity and power laws. One characteristic of many natural and man-made systems is power-law statistics. That is, the likelihood of an event (such as a forest fire, power outage, or web file transfer) occurring decreases as some power of the event's size. In addition, many systems are complex, made up of a plethora of components whose individual properties are of little use in predicting the behavior of the entire system. Interactions or phenomena at many size scales (from very small to very large) contribute to the overall state of these systems. One theory that tries to explain all this is self-organized criticality (SOC). Now, Jean Carlson of the University of California, Santa Barbara, and John Doyle of Caltech have proposed an alternative that not only generates power laws, but, they believe, provides better insight into systems that are tuned, through either natural selection or engineering design, for robust performance in uncertain environments. They describe their model as "robust, yet fragile," in the sense that perturbations not accounted for in the design (or evolution) may have especially far-reaching consequences. For example, organisms and ecosystems are remarkably robust with regard to large variations in temperature, moisture, nutrients, and predation, but can be catastrophically sensitive to unexpected perturbations, such as a novel virus or a crashing asteroid. Carlson and Doyle say that, unlike SOC, the HOT theory accounts for the profound tradeoffs in robustness and uncertainty that drive complex systems. They believe that fundamental limitations exist that could turn out to be as important as other conservation principles in physics. They have been exploring the application of their theory to a number of biological and engineering problems with the help of experts in those fields. (J.M. Carlson, J. Doyle, *Phys. Rev. Lett*. **84**, 2529, 2000. Also see their full paper in *Phys. Rev. E* **60**, 1412, 1999.)

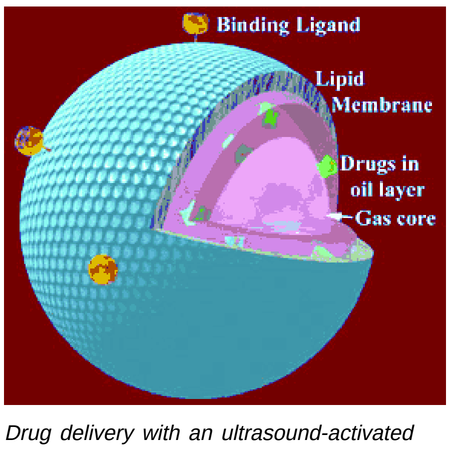
QUANTUM KEY DISTRIBUTION using entangled photons has been demonstrated by three independent research groups. For any coded message to be useful, a key must be available for decoding it. Classically, however, it is always possible for an eavesdropper both to intercept the key and avoid being detected. Using quantum entanglement, though, a completely secure key can be generated and distributed. Any eavesdropper's attempt to intercept the quantum key will alter the contents in a detectable way, enabling the users to discard the compromised parts of the data. To generate the key, a nonlinear crystal splits a single photon into a pair of entangled photons. The sender (Alice) and the receiver (Bob) each get one of the photons. Alice and Bob each have a detector for measuring their photon's properties, such as polarization or time of arrival. With the right combination of detector settings on each end, Alice and Bob will get the exact same value of the property. After receiving a string of entangled photons, Alice and Bob discuss which detector settings they used, rather than the actual readings they obtained, and they discard readings made with incorrect settings. At that point, Alice and Bob have their secure key. The three groups of researchers—based at the University of Vienna, Los Alamos National Laboratory, and the University of Geneva—all succeeded in distributing their keys while avoiding interception. In these experiments, the three groups used relatively slow key generation rates, but improvements are anticipated. (T. Jennewein *et al.*, *Phys. Rev. Lett.* **84**, 4729, 2000. D.S. Naik *et al.*, *Phys. Rev. Lett.* **84**, 4733, 2000. W. Tittel *et al.*, *Phys. Rev. Lett.* **84**, 4737, 2000.)



Use of quantum cryptography to encrypt an image of the Venus von Willendorf, one of the oldest pieces of art at 30,000 years old. (Courtesy University of Vienna)

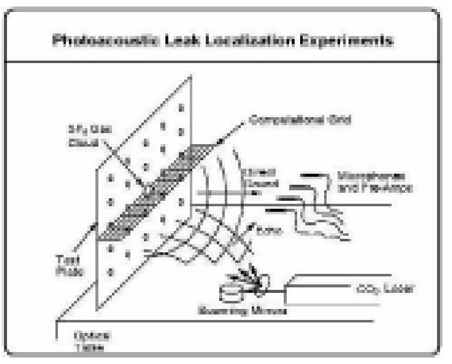
ATMOSPHERIC GAMMA-RAY BURSTS have been observed on the ground. Physicists from the University of Bologna in Italy, operating scintillation detectors atop the Gran Sasso mountains, observed two kinds of gamma-ray events during thunderstorms. One type showed a slow increase of radiation, with photon energies up to 3 MeV, and lasted for an hour or more before slowly decreasing again. The researchers attribute those photons to radioactive aerosol particles descending in rainfall. Superimposed on these gradual data were impulsive bursts of higher-energy photons (up to 10 MeV) that lasted mere minutes, a phenomenon previously observed at energies up to only a few hundred keV. These more powerful gamma rays are most likely bremsstrahlung radiation emitted by high-energy electrons colliding with atoms in the atmosphere. The scientists postulate that the acceleration mechanism is the so-called runaway electron effect, in which strong electric fields during the storms impart tremendous energies to electrons that initially exceed a certain energy threshold. A similar acceleration process could operate during other upper atmospheric and cosmic phenomena, including solar flares. (M. Brunetti *et al*, *Geophys. Res. Lett*. **27**, 1599, 2000.)

ULTRASOUND-ACTIVATED BUBBLES can break up clots and deliver drugs and genes. Because they reflect sound very well, so-called "contrast agents," specially designed micron-sized bubbles which are encapsulated by polymer, lipid, or other kinds of fluid shells, have traditionally been used to enhance ultrasound images of the heart, for example. At the spring 2000 meeting in Atlanta of the Acoustical Society of America, Evan Unger (University of Arizona and ImaRx Therapeutics, both in Tucson) presented several possible medical uses for such contrast agents, injected into the bloodstream. In one application, Unger reported that he and his coworkers used ultrasound to burst microbubbles near a blood clot in a rabbit's artery, thereby sweeping away the clot in small pieces. Unger and his colleagues have also attached various ligands, drugs, and genes to the microbubbles in several ways, for several uses. For example, bubbles coated with a specific antibody can attach to a tumor or other targeted tissue. Once attached, the bubbles can be made to pop, perhaps gently to release an encapsulated drug, or perhaps violently to deliver a lethal dose of energy to the tissue. The researchers have also introduced gene-containing microbubbles into an animal, and have seen the gene expressed. Such a procedure could be safer than traditional gene therapy, in which the gene is delivered via a modified virus, with potentially serious allergic reactions. In addition, genes exposed to ultrasound seem to express themselves with an enhanced rate, but the mechanism for the enhancement is unknown. Although promising, these applications require further testing and development.



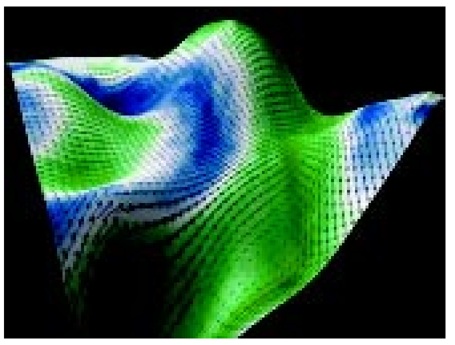
Drug delivery with an ultrasound-activated microbubble (Courtesy ImaRx)

TINY LEAKS CAUGHT WITH SOUND. A new "photoacoustic" technique, described at the Spring 2000 meeting of the Acoustical Society of America in Atlanta, can remotely detect pinprick leaks (as small as 10^{-6} cm^3/s) in sealed containers, and pinpoint them to within a millimeter, in mere seconds. Serdar Yonak and David Dowling of the University of Michigan, Ann Arbor, use sulfur hexafluoride, an inert, nontoxic tracer gas, to fill the part being tested. A carbon dioxide laser then scans the part up to 7500 times per second. When the laser beam passes through a cloud of leaking gas, the rapidly heated gas expands and generates a sound pulse. To find the exact location of the leak, the researchers use a sonar signal processing technique called matched field processing. An array of sensitive microphones 0.4 m away records the sound, and computer processing essentially reconstructs the trajectory of the sound waves backward in time until they reconverge at the location of the leak.



Schematic of technique for detecting small leaks with sound. (Courtesy of the University of Michigan)

TWO-DIMENSIONAL TURBULENT FLOWS leak significant energy to their surroundings, new experiments have confirmed. All 2D laboratory fluids are immersed in their 3D environments and thus can dissipate their turbulent energy through either the fluid's internal viscosity or its friction with its surroundings. The same holds true for atmospheric flows, which are often modeled as 2D even though they couple to Earth's surface. For such flows, modelers have used the 2D Navier-Stokes equation with a linear drag term, but the validity of this approach had not been quantitatively tested—until now. In a new experiment, Michael Rivera and Xiao-Lun Wu (University of Pittsburgh) created turbulence in a salt-based soap film by sending electric and magnetic fields through it. They then monitored the turbulence for 30 minutes (and measured 1000 vector fields) by tracking lycopodium particles (mushroom spores) in the film. They found that the familiar, simple model applied but that energy transfer to the surrounding air molecules was often greater than the energy dissipated to internal viscosity. That result demonstrates that an interaction with the surroundings is essential for maintaining a steady state in such a 2D system, and implies that ideal 2D fluids are unlikely to be found in our observable world. (M. Rivera, X. L. Wu, *Phys. Rev. Lett.* **85**, 976, 2000.)



In this still image of a soap film, the height indicates high- and low-pressure regions, the colors represent vorticity (green is positive and blue is negative), while finally the vectors are the flow field of the fluid at that instant (Courtesy University of Pittsburgh).

FISSIONING ELECTRONS? Thousands upon thousands of physics experiments have never suggested that the electron is anything but an indivisible particle. But now, physicist Humphrey Maris (Brown University and Ecole Normale Supérieure, Paris) has asked, What happens if a single particle's wavefunction becomes confined in two separated regions of space? Maris analyzed a particular experimental situation, known for more than 30 years: An electron injected into liquid helium quickly comes to a halt and, in its ground state (1s), excludes helium atoms from a small region around it, forming an "electron bubble." If one then optically excites the electron into the 1p state, the extra energy will cause the bubble to oscillate. Furthermore, says Maris, because the electron's wavefunction now has a node at the center, the oscillating bubble can fission onto two smaller bubbles, each in its own ground state with half of the original electron's wavefunction. In such a scenario, one would detect fragments of the original electron. He calls these partial electron bubbles "electrinos," and says that this hypothesis can account for several unexplained observations made over the past few decades, including anomalous conductivities and exotic ions seen in liquid helium with electron bubbles. Other physicists contend that there are other equally plausible explanations for the anomalous experimental results, ranging from the presence of impurities to the occurrence of entanglement. Maris suggests that his ideas on electrino bubbles can be tested using optical techniques. (H.J. Maris, *J. Low Temp. Phys.* **120**, 173, 2000. For more on bubbles in helium, see "Negative Pressures and Cavitation in Liquid Helium," by Maris and Sebastien Balibar, *Physics Today*, February 2000, page 29.)

ULTRASOUND IMAGING WITHOUT PHYSICAL CONTACT between device and patient has been achieved, providing a potential solution to a pressing medical need—determining the depth and severity of burns in a convenient, accurate, and pain-free fashion. Currently, physicians usually diagnose burns by visual inspection, but that cannot provide direct information on whether there is damage to underlying blood vessels, a condition that requires surgery. Technologies such as magnetic resonance imaging or conventional ultrasound (US) are too slow, too cumbersome, or too painful if they require direct contact with the burn area. In particular, conventional US requires direct contact because of the great impedance mismatch between air and the transducer; without contact, most of the sound would bounce right back into the device without having penetrated any tissue. At the November 1999 meeting of the Acoustical Society of America, Joie Jones (University of California, Irvine) reported passing the US through a multilayered material, with each succeeding layer having an impedance value closer to that of air; the technique is similar to using antireflective coatings on optical systems. He and his colleagues were then able to image burns by holding their device about 5 cm away from the skin for about a minute or so. Having tested this device on over 100 patients, the researchers plan to begin larger clinical studies and develop a device that can take images in real time.

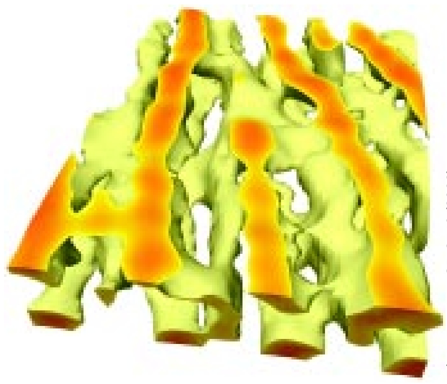
Physical Review Focus

Physical Review Focus presents explanations of selected papers from *Physical Review* and *Physical Review Letters* at a level accessible to undergraduate physics majors. The stories are posted once or twice per week at http://focus.aps.org as a free service of the American Physical Society. Below are some samples from the year 2000. Go to the web site to sign up for weekly *Focus* e-mail summaries.

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

Scanning Probe Gets Beneath the Surface

For almost two decades, scanning probe microscopy (SPM) has revealed surface features of solid samples in stunning, atomic-scale detail. Although this technique has been a boon to condensed matter and materials science research, it has been limited to surface studies, shedding little light on a solid material's inner structure. That limitation has now been overcome. In the 25 September *Physical Review Letters*, a German physicist demonstrates an extension of SPM to volume imaging—an advance that may have broad applications in both the electronics and materials industries.



Phys. Rev. Lett. **85**, 2749 (2000)

New view of rubber. *"Nanotomography" uses a scanning probe microscope—which is normally a surface imaging device—to create 3D images of solid materials at the nanometer scale.*

Robert Magerle, of the University of Bayreuth in Germany, says the basic idea for his "nanotomography" is to scan the surface of an object in serial fashion, stripping away the sample, layer by layer, and scanning the remaining material at each stage. He compares the approach to "excavation on a nanometer scale." A computer adds up the two-dimensional images from individual scans to create a composite three-dimensional picture of the object. "No other volume imaging technique available today can achieve nanometer-scale resolution in such a simple and direct way," Magerle claims.

To demonstrate the concept, he took a synthetic rubber material called a block copolymer, imaged its surface, "eroded" it with a beam of oxygen atoms, and imaged it again in 12 more steps, each time removing a 100-nanometer-thick layer from the surface. The three-dimensional structure of the sample was determined with a resolution of 10 nanometers—a record for volume imaging in a simple bench top experiment, according to Magerle. What's more, the technique yielded new structural insights. While it was known that the rubber consists of two kinds of polymers (polystyrene and polybutadiene) that reside in separate cylindrical-shaped domains, it was not known how the cylinders link to one another. Close inspection showed that one polystyrene cylinder was connected to four other cylinders—a feature that was not evident from surface views. This result, says Magerle, shows that "volume imaging with SPM offers new information about structures on the nanometer scale that would be difficult, if not impossible, to obtain with existing techniques."

Nanotomography has several advantages, he says. It provides higher spatial resolution than secondary ion mass spectroscopy, a similar approach, especially when studying rough samples. Another competing method, volume imaging through transmission electron microscopy, is limited to materials that are transparent to electrons and can be cut into uniform slices about 50 nanometers thick. That rules out hard materials—such as metals, crystals, semiconductors, and ceramics—that are not readily sectioned into thin slices. Magerle's method also lends itself to full automation, since separate automated machines can already do etching or SPM. A nanotomography device might identify, for example, structural defects in transistors that hadn't been seen before. Designers in the polymers industry could use the technique to examine the internal structure of plastics in an effort to optimize their properties.

For specific applications, says Princeton University's Christopher Harrison, "this approach may be quicker, cheaper, and more straightforward than competing methods." Sample preparation is fast, and pictures can be interpreted with less ambiguity, Harrison adds. "The combination of SPM and etching techniques should support novel observations, while opening up new avenues for discovery."

—Steve Nadis, freelance science writer

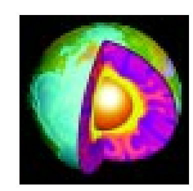
Reference: R. Magerle, Phys. Rev. Lett. 85, 2749 (2000).

Building the Devil's Staircase

Crystal experts don't count the way the rest of us do. To them, a perfect quartz crystal with twelve smooth facets counts as only a two faceted crystal, because the rest are related by symmetry. The most complicated crystals produced in labs have at most six types of facets. But in the 13 March *PRL* a team describes crystals of a "rigid gel" with 60 different facet types, confirming for the first time a prediction from the 1950s, that under ideal conditions, a crystal can show an almost unlimited number of facets on its surface. The work confirms detailed theories on how facets form—a difficult theoretical problem that was solved only recently, and one that is related to other areas of condensed matter physics. (Pawel Pieranski et al., Phys. Rev. Lett. 84, 2409. Complete *Focus* story at http://focus.aps.org/v5/st10.html.)

—David Ehrenstein

Stirring Up a Magnetic Field



Research Systems, Inc.

Molten iron and nickel oozing within the Earth are thought to generate the magnetic field that points compass needles northward. But despite an elaborate theoretical explanation for the field generation process, researchers have been unable to create a so-called fluid dynamo of their own. Now, after 25 years of work, a Latvian-German collaboration reports in the 8 May *PRL* that they have finally created a magnetic field the same way the Earth does, providing clear confirmation of the theory. (Agris Gailitis *et al.*, Phys. Rev. Lett. 84, 4365. Complete *Focus* story at http://focus.aps.org/v5/st20.html.)

—Mark Sincell, freelance science writer

SCIENCE POLICY IN 2000: THE YEAR IN REVIEW

JANUARY: Secretary of Energy Bill Richardson sends Congress a "National Nuclear Security Administration Implementation Plan," and appoints a committee to search for an Under Secretary to head the NNSA. President Clinton delivers a speech at Cal Tech outlining his intention to request an additional 7% in federal funding for scientific and engineering research for the next fiscal year, a move applauded on Capitol Hill. Deputy Under Secretary of Defense (Science and Technology) Delores Etter expresses great concern about defense S&T funding.

FEBRUARY: White House Science Adviser Neal Lane describes Clinton Administration's FY 2001 S&T budget request as "historic," it being the eighth year in a row that the Administration has requested an increase in civilian R&D. First hearings on the S&T requests are positive, one NSF hearing being described as a "love-in." Secretary of State Albright declares "science provides the only sure basis for reaching [foreign policy] agreements that can not only be signed, but implemented...."

MARCH: At a House hearing on the new NNSA, Secretary Richardson disagrees with committee members, but says, "I don't want to get into another fight with you this year." Newly-nominated NNSA Director General John Gordon receives widespread praise on Capitol Hill. Hearings are held on legislation to reauthorize Department of Education programs. Supportive hearings on NASA's budget request reveal some concern about management approach. Strong criticism is leveled at decline in defense R&D funding at congressional hearings. House passes budget resolution calling for $1 billion increase in general science spending. Secretary Richardson states his confidence in the underlying science of the National Ignition Facility, while expressing disappointment in management shortcomings.

APRIL: House appropriations hearing on NSF budget goes well, with Director Rita Colwell telling members that the foundation's plans call for at least a doubling of its budget over five years. Rep. Vern Ehlers (R-MI) introduces a trio of science education reform bills. White House warns that House budget resolution would "dramatically cut" projected S&T spending. Members of Congress continue to worry about NASA's management approach. At Senate S&T Caucus briefing, Nobel Prize winner Richard E. Smalley declares, "The physical sciences . . . need a big boost."

MAY: Allocations for appropriations committees funding NSF and NASA come up short, with Senator Christopher Bond (R-MO) calling it "an impossible situation." Nomination hearing for Mildred S. Dresselhaus to become next Director of DOE's Office of Science goes well, as does nomination hearing for General John Gordon to head NNSA. House appropriations bill for FY 2001 NSF and NASA budgets falls significantly below Administration request.

JUNE: National Research Council issues decadal report on "Astronomy and Astrophysics in the New Millennium." United States and Russia sign agreement on plutonium disposal. Initial indications from Capitol Hill are that FY 2001 defense S&T funding will be at least level, countering decline in the administration request. DOE predicts that National Ignition Project could be about double the original cost, and require an additional four years for completion. New report issued on impacts of global climate change. House appropriators vote to zero out NIST Advanced Technology Program in coming fiscal year.

JULY: Senators Bond and Barbara Mikulski (D-MD) call on their colleagues to double the NSF budget over the next five years, a move supported by former NIH Director Harold Varmus and Kenneth Shine, President of the Institute of Medicine. Commission reports on women and minorities in S&T. Senate rejects amendment to require "operationally-realistic testing against countermeasures for national missile defense." Defense appropriations bill is completed, with a 7.9% increase for defense S&T. Administration nanotechnology initiative plan is sent to Congress.

AUGUST: Office of Science and Technology Policy criticizes R&D funding levels in appropriations bills being considered by Congress. Senate Majority Leader Trent Lott (R-MS) signs letter supporting a doubling of NSF budget.

SEPTEMBER: President Clinton decides to delay deployment decision on limited National Missile Defense System. Moves are made in Congress to increase FY 2001 DOE science budget, a goal supported by university presidents. Senate appropriators vote to increase funding for Advanced Technology Program in the next budget year. Senate bill for NSF and NASA funding provides higher funding than comparable House appropriation. House Science subcommittee hearing demonstrates support for NASA science program. Secretary Richardson declares National Ignition Facility is "back on track" with new cost and schedule baseline. House passes a bill to establish National Institute of Biomedical Imaging and Engineering at NIH.

OCTOBER: Congress completes DOE science appropriation, with budgets up for physics-related programs. Spallation Neutron Source and National Ignition Facility budgets are positive. Glenn Commission issues report on science/math teaching. FY 2001 NSF appropriations bill completed, with 13.6% increase. NASA funding is boosted by 5.0%. House fails to pass one of Rep. Ehlers' science education bills.

NOVEMBER: Concern is expressed about a new polygraphing provision for weapons lab employees in newly signed legislation.

DECEMBER: Effort underway in Senate to increase upcoming administration budget request for DOE science. Clinton Administration establishes research misconduct policy. Report issued on international comparisons in eighth grade science and math achievement. Final appropriations bills are passed: federal support for math/science teacher training appears on track to increase in FY 2001; funding will increase for Advanced Technology Program. President Clinton signs bill to establish a National Institute of Biomedical Imaging and Bioengineering at NIH.

—Richard M. Jones, AIP Public Information Division