INTRODUCTION

Physics News in 2003, a summary of physics highlights for the past year, was compiled from items appearing in AIP’s weekly newsletter Physics News Update. Many of the entries appearing here were also published in Physics Today magazine, where they were edited further by Stephen Benkis. Readers should keep in mind that short items prepared for the way Physics News Update itself is prepared (short items aimed primarily, but not exclusively, at science journalists) and because of limited space in this supplement, some physics fields and certain past contributions to particular research areas might be under-represented in this compendium. Further, entries in the mostly appear as they did during the year, and the events reported therein might have been overaken by newer results and publications which might not be reflected in the reporting. Readers can get a much wider view of the year’s worth of physics by going to the Physics News Update website at http://www.aip.org/physicsnews/update or APS’s Physical Review Focus at http://prfocus.aip.org.

ASTROPHYSICS

A PINPOINT PRECISION MAP OF THE COSMIC MICROWAVE BACKGROUND, reported by scientists associated with the orbiting Wilkinson Microwave Anisotropy Probe (WMAP), brings the early universe into sharper focus. The credibity of WMAP’s pronouncement rests on its location and resolution. The resolution is some 40 times better than that of its microwave predecessor, the Cosmic Background Explorer (COBE); it comprehensively surveyed the entire sky for a whole year (3 more million years after the big bang; the age of the universe is 13.7 billion years; the cosmic microwave background; the orientation of the background is once again a lot of atoms in space. The image shows a microwave picture of the sky as recorded by WMAP. Here are a few of the salient numbers coming out of the WMAP analysis; the time of recombination was 380,000 years after the big bang; the era of the first stars was about 200 million years after the big bang (surprisingly early); the age of the universe is 13.7 billion years; the accounting of matter in the universe is as follows: atomic matter makes up about 4%; dark matter about 23%; and dark energy 73% (13 papers released in February 2003: astro-ph/0302207-09, 13-15, 17, 18, 20, 22-25).

OURL KNOWLEDGE OF THE UNIVERSE HAS BEEN SHARP-ENED thanks to new data from the Sloan Digital Sky Survey (SDSS). Using observations of more than 200,000 galaxies, the SDSS team measured, with small and well-controlled systematic errors, the three-dimensional galaxy power spectrum of the universe. This discovery is the result of 10years of work and is possible because of the strong new constraints—for example, on the matter spectrum—and independent confirmations of the arguments. This marks one of the most significant breakthroughs in modern cosmology. The image, courtesy of the SDSS, shows a 3D image of galaxies on the right, and on the left, displays how the galaxies are fitted into a 2 billion light-year 3D image. When combined with data from the Wilkinson Microwave Anisotropy Probe (WMAP), the new Sloan observations help tamp down uncertainties in several pivotal cosmological numbers. The new best value for the Hubble constant is 0.70 with an uncertainty of about 0.04; the matter density is 0.30, also with an uncertainty of 0.04; the upper limit on neutrino masses is now 0.06 eV. Combining data from SDSS, WMAP, and type Ia supernova surveys, the age of the universe has now been found to be 13.5 billion years with an uncertainty of 0.2 billion years. In a separate project, astronomers from the SDSS have created a new 3D map of the universe that shows features ranging from Earth’s core, through the Solar System and the Milky Way galaxy past the galaxies of the SDSS, and out to the cosmic microwave background. The cosmic cartographers say that the conformal map, which preserves local shapes and structures at every stage, is suitable as an educational tool. (M. Tegmark et al., http://arxiv.org/abs/astro-ph/0310723; J.R. Gott III et al., http://arxiv.org/abs/astro-ph/0310571.)

A VERY LONG LIVED ATOMIC STATE has been measured in an astrophysical source. Most exotic atomic states last much less than a second. The lifetimes of longer-lived states are difficult to measure because collisions between atoms cause deexcitations before the atoms can decay radiatively. With a vacuum far better than any on Earth, outer space provides the laboratory for a long atomic measurement. That’s why Tomas Brage of Lund University (Lund, Sweden), Philip Judge of the High Altitude Observatory (Boulder, Colorado), and Charles Proffitt of Computer Science Corp (Baltimore, Maryland) turned their gaze on the planetary nebula NGC 3198. Amid that wreckage of a dying star, there is enough energy to excite atoms but a low enough density (a few thousand atoms per cubic centimeter) that collisions are not a problem. Using the Hubble Space Telescope, the scientists looked at the emissions from trply ionized nitrogen atoms and found a lifetime of 2500 seconds for one particular hyperfine transition in which a nuclear spin flip induces an electronic transition. The measurement provides important confirmation of earlier calculations, and thus lends support to theoretical studies of both atoms and large-scale, low-density astrophysical sources. (T. Brage, P.G. Judge, C. R. Proffitt, Phys. Rev. Lett. 85, 281101, 2002.)

FIRST SCIENTIFIC RESULTS FROM LIGO (the Laser Interferometer Gravitational-Wave Observatory). Essentially a giant strain gauge to measure the local distortion in spacetime of a passing gravitational wave, LIGO has detectors in Hanford, Washington, and Livingston, Louisiana. (For more on LIGO’s operation, see Physics Today, October 1999, page 44.) The ripples in spacetime, radiated, for example, by the collapsing impiral of two neutron stars are predicted to produce a strain in LIGO of perhaps one part in 10^20, which would change the distance between mirrors some 4 km apart by about 10^-10 meters, a displacement 1000 times smaller than a proton. At the April 2003 APS meeting, the LIGO team reported its first official results from the initial science run, conducted over 17 days in the late summer of 2002. Gary Sanders (Caltech) and Erik Katsavounidis (MIT) reported that, as expected, no gravitational wave events were observed; but new upper limits were set on three of the four prime source categories. For coalescing binaries, no more than 164 events per year are expected from the Milky Way or an equivalent galaxy. The limit for both known and unknown burst sources, at a strain of 10^-12, is 1.4 events per day. Using one pulsar as a test case, LIGO has demonstrated sensitivity to pulsar sources at a strain amplitude of 10^-12, within a factor of 100 of that expected from the Crab pulsar. Finally, LIGO’s limit on stochastic waves that could have arisen in the early universe—expressed as their contribution to the energy density needed to close the universe—has 0 magnitudes as less than 72.4, a bit higher than the current best limit of 60. All of these limits are expected to improve dramatically after data from the recently concluded second science run, with its tenfold increase in sensitivity are analyzed.

THE BIG RIP. A new cosmological model takes the present acceleration of the expansion of the universe to extremes. In the wake of observations of distant supernovae (see the article by Saul Perlmutter in Physics Today, April 2003, page 53), cosmologists generally agree that 70% of the universe’s energy inventory is to an enigmatic dark energy. The new relevant parameter, which must be less than 1/3, is the ratio of the dark energy’s average pressure to its energy density. The well-known cosmological-constant and quintessence models explore values of -1/3 and -1. But what if it is less than -1? In that “phantom energy” case, Dartmouth College physical Robert Caldwell with Marc Kamionkowski and Neil Weinberg of Caltech have now determined that eventually all bound objects—galaxies, stars, planets, atoms, nuclei, and nucleons—will be torn apart. Caldwell suggests that deciding between their model and the others might be possible in coming years with much better measurements of the microwave background, supernovae, and galaxies. (R. Caldwell et al., Phys. Rev. Lett. 91, 071301, 2003.)

DIRECT IMAGING OF EXTRASOLAR Planets (sometimes called exoplanets) might be easier than astronomers thought, according to a new study. Evidence for the existence of planets around nearby stars is mostly indirect—tiny Doppler shifts in a star’s spectra or a minute dimming of a star’s emission. Direct imaging of an exoplanet is problematic because of the overwhelming brightness of the nearby star. One proposed way of getting around the glare is to use nulling
interferometry, which combines the light waves from two or more telescopes so as to minimize the total signal. With this technique, a dim object, like a planet, might suddenly emerge from what had been irresolvable glare. Now, William Danchi (NASA Goddard Space Flight Center in Greenbelt, Maryland) and his colleagues have extensively studied the capability of nulling interfering light waves. In particular, they are concerned with how the interferometer’s performance can be an order of magnitude better than conventionally assumed. First, the interferometers’ response decreases quadratically inside the null while the number of signal photons increases exponentially as the planet gets closer to an extremal. An extremal always wins, so the planets signal strength grows quadratically and cannot be suppressed by nulling. Second, the science function depends on the ratio of two IR wavelengths in a way that renders the observation insensitive to fluctuations in the optical pathlength of the system. The astronomers simulated observations of all known exoplanets and found that several could be directly imaged with even a modest instrument—two 0.5-m telescopes set 12.5 m apart—and spectra could be obtained of their atmospheres.

A new optical geometric phase (the first of its kind) has been measured for the first time, by a group of physicists at Colgate University. The new optical geometric phase is associated with light beams carrying orbital angular momentum (OAM), which is an ever-present feature of light, but is still not fully understood. Consider what happens when the photons are sent along different paths through an interferometer. When the single-photon interferometer is double-slit, the result is a pattern of constructive and destructive interference, depending on whether the path lengths are equal or not. The interferometer's ability to measure the phase of the light field allows for the detection of the geometric phase, which is a measure of the change in phase that a quantum system undergoes in going around a closed path in a spatially periodic potential. The geometric phase can be used to study the properties of quantum systems and has applications in quantum computing and quantum information processing.

Less than 100 zeptojoules (10^{-21} J) of energy is required to operate a molecular spintron. If the photon's wavelength is "correct," the entangled photon pairs have a coherence length much longer than for the 2 mm-long cavity also measured. Thus, when the frequency is tuned, the cavity is made from the "on" position when one of its four legs was perpendicular to the copper surface on which it sat, and "off" when the leg was parallel. In a recent experiment, photons from the cavity, measured from the same source, emitted from the cavity for the first time. The polarization of the light field could be controlled by changing the cavity length. The cavity length depends fundamentally on the object's internal structure. For an ensemble of photons, the cavity length can be an order of magnitude better than conventionally assumed. First, the interferometer's performance decreases quadratically inside the null while the number of signal photons increases exponentially as the planet gets closer to an extremal. An extremal always wins, so the planets signal strength grows quadratically and cannot be suppressed by nulling. Second, the science function depends on the ratio of two IR wavelengths in a way that renders the observation insensitive to fluctuations in the optical pathlength of the system. The astronomers simulated observations of all known exoplanets and found that several could be directly imaged with even a modest instrument—two 0.5-m telescopes set 12.5 m apart—and spectra could be obtained of their atmospheres.

The change in phase that a quantum system undergoes in going around a closed path in a spatially periodic potential manifests the orbital angular momentum of the light. This "colored light" might be exploitable for future quantum computing. For instance, recently a group at the University of Vienna used OAM in light to create a three-dimensional entangled state, or "qutrit" (Vaziri et al., Appl. Phys. Lett., 90, 25040, 2007). However, the orbital angular momentum of the light field can be used to follow a closed loop path in space, and thus the distance traveled by the light can be measured. In addition, the distance does not need to be real space. When the "mode" (set of standing waves in the beam) is changed, it can also produce a phase change when the geometry of the path is changed. For instance, the path length at the Colgate University interferometer is about 200 km.

The new measurement of the orbital angular momentum of light opens up a new dimension in quantum optics, where the geometric phase can be measured for the first time. This phase can be used to study the properties of quantum systems and has applications in quantum computing and quantum information processing. However, the orbital angular momentum of the light field can be used to follow a closed loop path in space, and thus the distance traveled by the light can be measured. In addition, the distance does not need to be real space. When the "mode" (set of standing waves in the beam) is changed, it can also produce a phase change when the geometry of the path is changed. For instance, the path length at the Colgate University interferometer is about 200 km.

The research is supported by the National Science Foundation and the Army Research Office.

**Keywords:** orbital angular momentum, geometric phase, quantum interferometry, quantum computing, quantum information processing.
pulses: one to produce pinpoint fluorescence and the other to null or "bleach" the fluores-
time, to a single strand of DNA. The base molecules being added were fluorescently labeled 
at Caltech has used a DNA polymerase enzyme to add complementary base units, one at a 
high linear data-storage density: The base molecules are only about 3.4 Å apart. Now, a group 
with synchronization tomography . In addition, a related synchronization technique may help 
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areas of the brain involved when test subjects perform physical activities, and can show how 
the filaments and the rafts. Divalent ions of 
provided the crucial cross-linking between both 
attempts to a variable time delay . A CCD camera recorded the diffraction pattern at each time delay; from that 
A new brain imaging method pioneered by a 
thetic anatomy of tissue, histologists typically stain it, freeze it, slice it thinly , and sequentially 
biopsies, in which physicians wish to preserve the tissue for future reference. However, the 
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within 1-μm and preserved protein viability. Because the femtosecond technique completely 
3960, 2003.)

THE ACTIVITY OF A SINGLE-ION CHANNEL PROTEIN has been detected with a 
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SYNCHRONIZATION TOMOGRAPHY. A new brain imaging method pioneered by a 
(7-55 µ J pulses

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Biological

USING BUBBLES TO DELIVER DRUGS IS A STEP OR TWO CLOSER TO REALITY. 
Claus-Dieter Ohl and Roy Ickink (University of Twente, the Netherland) found that tiny bubbles 
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ULTRA-LOW-ENERGY ELECTRONS CAN BREAK UP URACIL, a new study shows. How injurious is radiation (alpha, beta, and gamma rays or heavy ions) to living cells? This important question has been addressed in many ways. Much attention has centered on the secondary particles produced in the wake of the primary radiation, especially electrons (α, β, and γ). The electrons are produced in each MeV of energy deposited with typical energies of tens of electron volts. Many of these secondary particles quickly lose their energy and become attached (solvated) to water molecules. This effect of secondary electrons below 20 eV/µA report from three years ago (Boudaifa et al., Science 287, 1658, 2000) showed that electrons in the 3-20 eV range are able to produce substantial genotoxic damage, including breaking single- and double-stranded DNA. What about secondary electrons with even smaller energies? To look at this energy range for the first time, this collaboration at the University Innsbruck (Austria) and the University Claude Bernard Lyon (France) scattered a beam of sub-eV electrons from a beam of gaseous uracil molecules. Uric acid is one of the base units of RNA molecules, and is thus a crucial component in these cells. These scientists found that uracil is efficiently fragmented by electrons with energies as small as milli-electron volts. Is not the electron charge, which changes the uracil’s internal potential energy environment. Furthermore, in the process a very mobile atomic hydrogen can be freed, which on its own, as a radical (a free chemical unit by itself), can do damage to biomolecules. Mark says this low-energy damage seems to be a general result since his group has since performed similar work with thymine (a DNA base) and have seen similar fragmentation. (Hand et al., Phys. Rev. Lett. 90, 188104, 2003.)

CONDENSED MATTER/MATERIALS PHYSICS

CARBON NANOTUBE RESONANCE FREQUENCIES can be tuned by a factor of 10 in a field-emission microscope (FEM). A group of physicists at the University of Lyon, France, saw several multwall nanotubes (MWNTs) on a nickel support tip, then placed it in an FEM. With a static voltage applied between the nanotubes and the nickel emitter electrodes, electrons are sprayed out of the MWNTs onto a detection screen. Each MWNT has unique resonant frequencies at which it oscillates with large amplitudes. The vibration is excited by applying an additional sinusoidal voltage of the correct frequency to one of the electrodes (see figure). By varying the applied voltage and watching the screen, the researchers not only measured the natural frequencies of the MWNTs—permitting a measure of the MWNT stiffness—but also found that the voltage effectively “pushes” the tip toward the surface, increasing the tension on a guitar string. According to group member Stephen Purcell, carefully excited and tuned MWNTs may act as a core element for future nanometric oscillator circuits, nanobiology, or nanoforce sensors. For more on carbon nanotubes, see articles in Physics Today by Thomas Ebbesen (Physics Today, June 1996, page 26) and by Ceek Dekker (May 1999, page 22). (S. T. Purcell et al., Phys. Rev. Lett. 89, 276103, 2002.)

THE GIANT PLANAR HALL EFFECT is a new type of magnetoresistance (MR) seen in a ferromagnetic semiconductor by a team of physicists from Caltech and the University of California, Santa Barbara. In the Hall effect, current flowing along a planar conductor is slightly deflected in one direction when a magnetic field is applied perpendicular to both the current and the plane, is turned on. In the new experiment, the applied magnetic field lies in the conducting plane, at some angle to the current. The physicists found that, for all nonzero angles—except those aligned with axes of high crystalline symmetry—there were always large angular jumps in the Hall voltage as the magnetic field strength was varied. This type of anisotropic MR switching behavior was previously seen in magnetic metals, but the effect in the magnetic semiconductor (GaMnAs) is a factor of 104 stronger. MR effects are This type of anisotropic MR switching behavior was previously seen in magnetic metals, but not the current. In contrast, noncontact friction is similar to the van der Waals interaction between atoms of different materials—a solid polymer. In condensed matter systems, adja-

ENTANGLED PROTONS IN A SOLID POLYMER, cemented by nuclear cohesion, can be tuned by a factor of 10 in a field-emission microscope (FEM). A group of physicists at the University of Lyon, France, saw several multwall nanotubes (MWNTs) on a nickel support tip, then placed it in an FEM. With a static voltage applied between the nanotubes and the nickel emitter electrodes, electrons are sprayed out of the MWNTs onto a detection screen. Each MWNT has unique resonant frequencies at which it oscillates with large amplitudes. The vibration is excited by applying an additional sinusoidal voltage of the correct frequency to one of the electrodes (see figure). By varying the applied voltage and watching the screen, the researchers not only measured the natural frequencies of the MWNTs—permitting a measure of the MWNT stiffness—but also found that the voltage effectively “pushes” the tip toward the surface, increasing the tension on a guitar string. According to group member Stephen Purcell, carefully excited and tuned MWNTs may act as a core element for future nanometric oscillator circuits, nanobiology, or nanoforce sensors. For more on carbon nanotubes, see articles in Physics Today by Thomas Ebbesen (Physics Today, June 1996, page 26) and by Ceek Dekker (May 1999, page 22). (S. T. Purcell et al., Phys. Rev. Lett. 89, 276103, 2002.)

LEFT-HANDED MATERIALS ARE NOW BEING EXPERIMENTALLY REALIZED. LHMs—which do not exist in nature—have negative index of refraction, n < 0, meaning that light entering such a material at an angle is refracted on the same side of the normal as its incidence. In principle, an LHM with n = -1 can perfectly focus light without any curved surfaces. The first com-

SUPER-TOUGH AND LONG COMPOSITE FIBERS MADE OF CARBON NANOTUBES. Scientists at the University of Texas at Dallas injected a dispersion of single-wall carbon nanotubes into a polyaniline solution to spin 100-m-long gel fibers, which were then converted into solid fibers having a tensile strength of 1.8 gigapascals. Tougher than spider silk, Kevlar, or graphite fibers, the 50-µm-diameter composite fibers are 60% CNT by weight. The research team made their fiber into a “supercapacitor” and incorporated it into a woven fabric. (A. B. Dalton et al., Nature 423, 703, 2003.)

AN ENERGY-FILTERED SCANNING TUNNELING MICROSCOPE (EF-STM). A new type of scanning tunneling microscope is able to map the local electronic states of various materials. Their EF-STM works by effectively suppressing tunneling in a range of energies within the “projected bandgap” along the Fermi level. The tunneling current on the tip shifts the gap relative to the sample states and allows electrons with different energies to tunnel. On a silicon surface, the researchers separately mapped damped bonds from both the silicon atoms, which have electron energy close to 0 eV, and from the silicon oxide, which has electron energy further below 0 eV. Shown is an energy-filtered image which captures both atomic and electronic structure on a silicon surface. New form of scanning tunneling microscopy which would ordinarily be obscured by normal scanning methods. The group foresees the ability to map the local composition of semiconductor alloys. (P. Sutter et al., Phys. Rev. Lett. 90, 166101, 2003.)

HOW INJURIOUS IS RADIATION (ALPHA, BETA, AND GAMMA RAYS OR HEAVY IONS) TO LIVING CELLS? This important question has been addressed in many ways. Much attention has centered on the secondary particles produced in the wake of the primary radiation, especially electrons (α, β, and γ). The electrons are produced in each MeV of energy deposited with typical energies of tens of electron volts. Many of these secondary particles quickly lose their energy and become attached (solvated) to water molecules. What about electrons with even smaller energies? To look at this energy range for the first time, this collaboration at the University Innsbruck (Austria) and the University Claude Bernard Lyon (France) scattered a beam of sub-eV electrons from a beam of gaseous uracil molecules. Uric acid is one of the base units of RNA molecules, and is thus a crucial component in these cells. These scientists found that uracil is efficiently fragmented by electrons with energies as small as milli-electron volts. Is not the electron charge, which changes the uracil’s internal potential energy environment. Furthermore, in the process a very mobile atomic hydrogen can be freed, which on its own, as a radical (a free chemical unit by itself), can do damage to biomolecules. Mark says this low-energy damage seems to be a general result since his group has since performed similar work with thymine (a DNA base) and have seen similar fragmentation. (Hand et al., Phys. Rev. Lett. 90, 188104, 2003.)

OPTICAL NEAR-FIELD RAMAN MICROSCOPY of single-walled carbon nanotubes has been done. Scientists from the University of Arkansas, for example, and Harvard University and the University of Lyon, France, have used an optical near-field microscope to study the bizarre properties of such materials. According to group member Stephen Purcell, carefully excited and tuned MWNTs may act as a core element for future nanometric oscillator circuits, nanobiology, or nanoforce sensors. For more on carbon nanotubes, see articles in Physics Today by Thomas Ebbesen (Physics Today, June 1996, page 26) and by Ceek Dekker (May 1999, page 22). (S. T. Purcell et al., Phys. Rev. Lett. 89, 276103, 2002.)
now, all LHMs have been so-called metamaterials composed of rods and split-ring resonators mounted on boards (see Physics Today, May 2000, page 17, and the second correction in July 2000, page 77). Now, physicists at the National Renewable Energy Laboratory in Golden, Colorado, have found that LHMs made from bicyclics that display a certain “domain twin” structure. Such a structure occurs in both naturally and easily engineered ferromagnetic solids and is shown here in an electron microscopy image (b). The O2P074 concentrator was made with copper-platinum ordering. The researchers used a single YO2 bicyclic to demonstrate, depending on the angle of incidence, both positive and negative refraction (see image). It makes light weaves so that LHMs can be used for ballistic electrons. The devices are better designed for high-speed signals, especially for ballistic electronics, as well as for light and suffer no losses to reflection at the interface. (Y. Zhang, B. Fluegel, A. Macrignese, Phys. Rev. Lett. 83, 157404, 2003.)

HIGH-PRESSURE PHOSPHORUS COULD BE USEFUL FOR SPIRACTRONICS. Found in teeth and bones as well as in fertilizers and DNA, phosphorus is an insulator at room temperature. However, at very high pressures, a series of phase transitions occurs. At 10 GPa, phosphorus is a metallic superconductor at about 10 K. At 262 GPa, it becomes a hard, almost ab-centric-body (bcc) crystal structure. Now, Sergey Ostanin of the University of Warwick in the UK and his colleagues have studied the high-pressure phase diagram of phosphorus, and it turns out that phosphorus has several superconducting phases at higher pressures, somewhere around 20 K. Furthermore, they found that the bcc phase might be stabilized in thin films grown at ambient pressure on some other bcc material. Such a phosphorus film, perhaps sandwiched between films of iron, might be very useful in spintronics applications. For example, a superconducting spin switch could flip-flop from spinor to superconductor depending on the spin state of the iron films. (S. Ostanin et al., Phys. Rev. Lett. 83, 087002, 2003.)

SHOCKING COLOR EFFECTS. A photonic crystal is a lattice of structures (sometimes an arrangement of rods or a solid filled with a pattern of holes) with a periodic alteration in the index of refraction. In such a material with waves only with a select band of frequencies may propagate. What happens when a shock wave moves through the lattice, momentarily compressing or expanding the characteristic spacing? A new “computational experiment” (detailed computer simulation) provides an intriguing answer. Evan, Reeder, Marin Soljacic, and John Ioannopolous at MIT determine that a light beam moving in a shock-modified photonic crystal will undergo two unexpected changes: A Doppler shifting hundreds or even 10,000 times bigger than usual and a bandwidth narrowing. There are plenty of phenomena that can broaden a signal’s bandwidth but none yet known that would narrow the bandwidth of an abnormally small signal in this way (and by factors of 4 or 5 of those that only change the frequency of the light owing to its reflection from a moving target), the light reflecting from the shock wave will be “up converted” (e.g., turned from red light into green light) with an efficiency that should match or exceed what’s possible in conventional nonlinear optical materials. Furthermore, the shock conversion process is tunable and independent of light intensity. According to Evan Reeder, the MIT research should generate great surprise and interest among those who work with photonic crystals. The next step will be to implement the computational results in the laboratory with samples to determine if the new nonlinear optical effects are found. They expect that frequency conversion and signal modulation) future modifications in photonic crystals will be practical and that fundamental, optical and electrical signals might be actuated with some kind of MEMS (microelectromechanical systems) device. (Reed et al., Phys. Rev. Lett. 90, 203903, 2003; website http://lab-initio.mit.edu)

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PHOTONIC CRYSTAL MODULATIONS MIGHT EVEN BE ACTUATED WITH SOME KIND OF MEMS NOT HAVE TO BE INITIATED WITH GUNS OR LASER PULSES BUT WITH LESS Destructive acousto optic effects (frequency conversion and signal modulation) future modifications in photonic crystals will be tunable and independent of light intensity. According to Evan Reed, the photonic crystal modulations might even be actuated with some kind of MEMS (microelectromechanical systems) device. (Reed et al., Phys. Rev. Lett. 90, 203903, 2003; website http://lab-initio.mit.edu)

THE TWISTED ORIGIN OF SPHEROMAKS. Researchers at the California Institute of Technology have made important progress in solving a long-standing mystery concerning the formation of spheromaks, which some speculate may be the key to harnessing the energy locked up in the magnetic fields of stars and planets. Researchers at the California Institute of Technology have made important progress in solving a long-standing mystery concerning the formation of spheromaks, which some speculate may be the key to harnessing the energy locked up in the magnetic fields of stars and planets. Researchers at the California Institute of Technology have made important progress in solving a long-standing mystery concerning the formation of spheromaks, which some speculate may be the key to harnessing the energy locked up in the magnetic fields of stars and planets.

FIRST FUSION AT THE Z MACHINE was announced at the April 2003 meeting of the American Physical Society in Philadelphia. For the first time, Sandia National Laboratories’ Z facility in New Mexico, created a hot dense plasma that produces neutrons associated with nuclear fusion reactions (for example, a proton and a neutron to form a deuteron). Accurate fusion reactions are the result of combining the hydrogens, such as protons or neutrons) or two quarks (mesons such as pions or kaons). Although not forbidden by the standard model of particle physics, other quark combinations have not been found until now. But a larger quark grouping was hypothesized by theorists at the Petersburg Nuclear Physics Institute in Russia. They predicted that a five-quark state might exist, humanity, because, when a shock wave moves through the lattice, momentary compressing or expanding the characteristic spacing? A new “computational experiment” (detailed computer simulation) provides an intriguing answer. Evan, Reeder, Marin Soljacic, and John Ioannopolous at MIT determine that a light beam moving in a shock-modified photonic crystal will undergo two unexpected changes: A Doppler shifting hundreds or even 10,000 times bigger than usual and a bandwidth narrowing. There are plenty of phenomena that can broaden a signal’s bandwidth but none yet known that would narrow the bandwidth of an abnormally small signal in this way (and by factors of 4 or 5 of those that only change the frequency of the light owing to its reflection from a moving target), the light reflecting from the shock wave will be “up converted” (e.g., turned from red light into green light) with an efficiency that should match or exceed what’s possible in conventional nonlinear optical materials. Furthermore, the shock conversion process is tunable and independent of light intensity. According to Evan Reeder, the MIT research should generate great surprise and interest among those who work with photonic crystals. The next step will be to implement the computational results in the laboratory with samples to determine if the new nonlinear optical effects are found. They expect that frequency conversion and signal modulation) future modifications in photonic crystals will be practical and that fundamental, optical and electrical signals might be actuated with some kind of MEMS (microelectromechanical systems) device. (Reed et al., Phys. Rev. Lett. 90, 203903, 2003; website http://lab-initio.mit.edu)

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The evidence for this collection of five quarks would be an excess of events (a peak) on a plot of position vs. momentum. If this were the case, it would provide spectacular evidence of the existence of various combinations of particles, including a short lived state in which one proton and one neutron to form a deuteron and a neutral pion (A. K. Opper et al., Phys. Rev. Lett. 91, 212302, 2003) The experiment—a collaboration at the TRUMF cyclotron in Canada—produced a peak in the plot of position vs. momentum. However, all LHMs have been so-called metamaterials composed of rods and split-ring resonators mounted on boards (see Physics Today, May 2000, page 17, and the second correction in July 2000, page 77). Now, physicists at the National Renewable Energy Laboratory in Golden, Colorado, have found that LHMs made from bicyclics that display a certain “domain twin” structure. Such a structure occurs in both naturally and easily engineered ferromagnetic solids and is shown here in an electron microscopy image (b). The O2P074 concentrator was made with copper-platinum ordering. The researchers used a single YO2 bicyclic to demonstrate, depending on the angle of incidence, both positive and negative refraction (see image). It makes light weaves so that LHMs can be used for ballistic electrons. The devices are better designed for high-speed signals, especially for ballistic electronics, as well as for light and suffer no losses to reflection at the interface. (Y. Zhang, B. Fluegel, A. Macrignese, Phys. Rev. Lett. 83, 157404, 2003.)

SHOCKING COLOR EFFECTS. A photonic crystal is a lattice of structures (sometimes an arrangement of rods or a solid filled with a pattern of holes) with a periodic alteration in the index of refraction. In such a material with waves only with a select band of frequencies may propagate. What happens when a shock wave moves through the lattice, momentarily compressing or expanding the characteristic spacing? A new “computational experiment” (detailed computer simulation) provides an intriguing answer. Evan, Reeder, Marin Soljacic, and John Ioannopolous at MIT determine that a light beam moving in a shock-modified photonic crystal will undergo two unexpected changes: A Doppler shifting hundreds or even 10,000 times bigger than usual and a bandwidth narrowing. There are plenty of phenomena that can broaden a signal’s bandwidth but none yet known that would narrow the bandwidth of an abnormally small signal in this way (and by factors of 4 or 5 of those that only change the frequency of the light owing to its reflection from a moving target), the light reflecting from the shock wave will be “up converted” (e.g., turned from red light into green light) with an efficiency that should match or exceed what’s possible in conventional nonlinear optical materials. Furthermore, the shock conversion process is tunable and independent of light intensity. According to Evan Reeder, the MIT research should generate great surprise and interest among those who work with photonic crystals. The next step will be to implement the computational results in the laboratory with samples to determine if the new nonlinear optical effects are found. They expect that frequency conversion and signal modulation) future modifications in photonic crystals will be practical and that fundamental, optical and electrical signals might be actuated with some kind of MEMS (microelectromechanical systems) device. (Reed et al., Phys. Rev. Lett. 90, 203903, 2003; website http://lab-initio.mit.edu)
VIBRATIONS HELP A FROG LOCATE TASTY PREY. Living in southern Africa, the aquatic clawed frog Xenopus laevis finds insects by localizing their vibrations on the water's surface. Hunting at night and unable to see well, the frog gets a wealth of information from about 180 sensory organs (the white "stickers" in the photo, collectively called the lateral-line system) on its skin. As an insect strolls around, the moving water triggers signals in hair cells attached to the organ, allowing researchers working at the University of Vienna (Technical University of Munich), have developed a simple model, with a minimal set of assumptions, that explains how the lateral-line system works. Striking the model suggests the frog can both reconstruct the waveform of the water disturbance and determine its direction. The model thus explains the frog's ability to distinguish between two different water disturbances coming simultaneously from insects—one of which might be indistinct—in different directions. The model also agrees with experiments in showing that the sensory system can operate even if some of the lateral-line organs do not function properly. The simple model may also be applicable to the mechanosensory systems of other animals, such as fish and crocodiles, which have similar receptor organs. (J. P. Franosch et al., Phys. Rev. Lett. 91, 158101, 2003.)

WHY DON'T ALCOHOL AND WATER MIX VERY WELL? A US-Swedish collaboration has obtained new molecular-level details of mixtures of water and methanol, the simplest alcohol. At Lawrence Berkeley National Laboratory's Advanced Light Source, the researchers (led by Anthony J. Leggett, University of Illinois, Urbana Champaign) have reported using a technique called synchrotron X-ray crystallography to determine for the first time the arrangement of ordinary salt grains. The salt, made of both six and eight methanol molecules, when the methanol and water were mixed, the molecules remained intact. As the figure shows, the CH₃OH molecules, however, are selectively deposited at certain locations. (H. Gu et al., Phys. Rev. Lett. 91, 157401, 2003.)

THE 2003 PHYSICS NOBEL PRIZE went to Alexei A. Abrikosov (Institute for Physical Problems in Moscow and now at Argonne National Laboratory near Chicago), Vitaly I. L'vov (Laboratory of Physical Institute of Moscow) and Anthony J. Leggett (University of Illinois, Urbana Champaign). The award recognized work done on systems that operate under two regimes very far from human experience: the quantum realm and the low temperature realm. In superconductivity, a current of electrons flowing through a material undergoes a change in behavior: normally reluctant to associate with each other, the electrons at low temperatures can form pairs. These pairs act like particles and are so energetic that they can enter into a single unified quantum state. In this state the electron pairs are no longer just a current, but a wave function that permeates the whole sample. This uniform wave function is a quantum state of coherence. The practical benefit is that energy loss through dissipation can be eliminated. An additional feature is that much higher currents can flow through some superconductor materials than through normal metal wires. The price to pay for producing the weird quantum state of superconductivity is that the first place is having to chill to extremely low temperatures. To achieve absolute zero, which usually means about 4 K. Practical applications of wire made from superconducting material include medical scanners (this year's Nobel for medicine rewards MRI research; here potent magnetic fields inside the scanner are usually produced with superconducting cables, levitated trains (still at an early stage of deployment), and the chilling of some components in cell phone networks. In some superconductors (type I) magnetic fields are anathema to the superconducting state. In other superconductors (type II), magnetic fields are like a sword to a superconductor. They create a lossless current in a superconductor, and no other possible applications the just mentioned. Abrikosov and Greinberg are being recognized for their work in explaining how type II superconductors work. When a sample of helium-3 atoms is chilled to very low temperatures, the helium-4 atoms can pair up, and the pairs in turn may enter into a single quantum state in which (analogous to the loss flow of supercurrents in superconductors) the fluid will flow without losing energy via friction. Just as superconductors have no electrical resistance, so superfluids have no viscosity, and can flow freely in a totally frictionless state in explaining He-3 superfluidity. More information on the prize can be found at www.nobel.se and in the December 2003 issue of Physics Today.

THE 2003 NOBEL PRIZE IN PHYSIOLOGY/MEDICINE went to Paul C. Lauterbur of the University of Illinois at Urbana Champaign and Peter M. Mansfield of the University of Nottingham for their work in developing magnetic resonance imaging, or MRI. In the medical world, MRI has become a major imaging technique, but its roots lie in the most basic of physics. The nucleus of every atom and molecule, taking advantage of the fact that the body is two-thirds water, MRI obtains images of the hydrogen nuclei in water molecules inside our bodies. In the early 1970s while working at the State University of New York at Stony Brook, Lauterbur exploited the magnetic properties of atomic nuclei to yield a two dimensional image of matter, by introducing gradients in the external magnetic field that surrounds the object to be imaged. Shortly thereafter, Peter Mansfield helped to make MRI a practical imaging process. In the late 1970s and early 1980s, Mansfield was awarded the 1985 Nobel prize in chemistry for developing the spectrometric methods for determining protein structures. The origins of MRI go back further, to the late 1930s, when physicist I. Rabi of Columbia University showed that one could obtain information about lithium chloride molecules by manipulating the magnetic "spins" of the molecules' nuclei (Nobel Prize, 1944). Later, physicists E.M. Purcell (Harvard) and Felix Bloch (Stanford) developed nuclear magnetic resonance (NMR) in hydrogen (Nobel Prize, 1952). Two Nobel Prizes in Chemistry (1991) and (1992) have been awarded for advancements in nuclear magnetic resonance. MRI has been so successful that the original technique has spawned numerous offshoots, such as functional MRI (fMRI), which measures brain activity by detecting oxygen levels in specific brain areas. MRI advances continue at a feverish pace. (See www.nobel.se and the December 2003 issue of Physics Today for more information on this year's prize.)

DETECTING ELECTRIC EXPLOSIVES IN AIR. At the per-attoseconds level has been achieved. Explosive compounds such as PETN and RDX are easy to melt, remain stable when detonated, and have no particular smell. Now, researchers at the Oak Ridge National Laboratory and the University of Tennessee, Knoxville, have reported using commercially available atomic force microscope cantilevers for detecting PETN and RDX with great sensitivity. The tip of the cantilever was coated with a monolayer of 4-mercaptobenzoic acid, which can bind to both PETN and RDX. As the binding occurs, the cantilever bends significantly due to differential stress. The researchers estimate that a sensor based on their technique could detect the explosives at a level of 14 parts per trillion after only a second contact and 30 sec. Such a sensor could be used in the air and easy to mass-produce. (L. A. Pinnaduwage et al., Appl. Phys. Lett. 83, 1441, 2003.)

NANOSCOPIC THERMOMETER. A nanoscopic thermometer, consisting of a mag- nesium oxide nanotube filled with gallium metal, may dramatically increase the temperature range over which thermometers work. Researchers at the University of California, Los Angeles, first demonstrated the creation of a carbon nanotube thermometer last year, but the device had at least one shortcoming: nanoscopic carbon tubes rapidly degrade in air at temperatures of about 1000 degrees Celsius. The new nanotubes are made of magnesium oxide cylinders with inner diameters much smaller than the thickness of a human hair. Magnesium oxide nanotubes, in contrast to carbon versions, can withstand high temperatures. Often, there is gas in a nanotube gallium filling, and because gallium expands as its heated, the temperature of the thermometer is read out by measuring changes in the gap between instrument components as the temperature of the thermometer is expected to function well up to about 1000 degrees Celsius. Eventually, miniature thermometers such as these could be important for measuring temperature in the nanoscopic devices and other devices. (Y. B. Li; Y. Bandow, D. Golberg, and Z. W. Liu, Appl. Phys. Lett. 83, 4414, 2003.)

WHEN A "WATER HACKER" POWERS UP SONOLUMINESCENCE. In household plumbing, a water hammer can occur when a sudden slowdown of the water's flow generates a turbulent shock wave, which is tolerated as long as the tube is relatively thick and steady. Not so, however, a research team at the University of California, Davis (under the leadership of Andrew Dally) has found that the water hammer can cause the water's flow down the icicle shaft. A portion of the flowing water freezes and the rest drips from the icicle tip. But researchers at Hokkaido University's Institute of Low Temperature Sciences (in Japan) have developed a theoretical model that explains the surprisingly universal structure of icicles. According to the new model, two effects are important as an icicle grows. The first is the Laplace instability, which is related to the latent heat released from an icicle's growth. The second is the fluid effect. Flow in the thin water layer decreases the temperature distribution along the layer, making uniform and thus inhibiting the icicle instability. As this happens, these two competing effects ensure that all icicle ripples have the same wavelength, although the ripple height can vary from one icicle to another. This second effect is important: as the speed that the icicle grows a prediction the researchers hope will soon be verified experimentally. In addition the researchers expect that their model should be helpful in explaining the structures of mineral stalagmites commonly found in limestone caves. (N. Ogawa and Y. Furukawa, Physical Review E, 66, 041202, 2002.)

QUANTUM MEASUREMENT: THE MOVIE. THE MOVIE: THE MOVIE: THE MOVIE: THE MOVIE: THE MOVIE. (about a hundred times more than earlier SL experiments). That emission corresponds to a single quantum state in which a molecule's electron is promoted to a higher quantum state. The practical benefit is that energy loss through dissipation can be eliminated. An additional feature is that much higher currents can flow through some superconductor materials than through normal metal wires. The price to pay for producing the weird quantum state of superconductivity is that the first place is having to chill to extremely low temperatures. To achieve absolute zero, which usually means about 4 K. Practical applications of wire made from superconducting material include medical scanners (this year's Nobel for medicine rewards MRI research; here potent magnetic fields inside the scanner are usually produced with superconducting cables, levitated trains (still at an early stage of deployment), and the chilling of some components in cell phone networks. In some superconductors (type I) magnetic fields are anathema to the superconducting state. In other superconductors (type II), magnetic fields are like a sword to a superconductor. They create a lossless current in a superconductor, and no other possible applications the just mentioned. Abrikosov and Greinberg are being recognized for their work in explaining how type II superconductors work. When a sample of helium-3 atoms is chilled to very low temperatures, the helium-4 atoms can pair up, and the pairs in turn may enter into a single quantum state in which (analogous to the loss flow of supercurrents in superconductors) the fluid will flow without losing energy via friction. Just as superconductors have no electrical resistance, so superfluids have no viscosity, and can flow freely in a totally frictionless state in explaining He-3 superfluidity. More information on the prize can be found at www.nobel.se and in the December 2003 issue of Physics Today.