Physics News in 2005

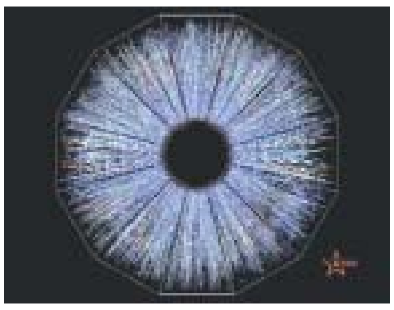
A Supplement to *APS News*

Edited by Phillip F. Schewe, Ben Stein and Ernie Tretkoff

INTRODUCTION

Physics News in 2005, a summary of physics highlights for the past year, was compiled from items appearing in AIP's weekly newsletter *Physics News Update*, written by Phil Schewe and Ben Stein. The items in this supplement were compiled by Ernie Tretkoff of the American Physical Society. The items below are in no particular order. Because of limited space in this supplement, some physics fields and certain contributions to particular research areas might be underrepresented in this compendium. These items mostly appear as they did during the year, and the events reported therein may in some cases have been overtaken by newer results and newer publications which might not be reflected in the reporting. Readers can get a fuller account of the year's achievements by going to the *Physics News Update* website at http://www.aip.org/physnews/update and *APS's Physical Review Focus* website at http://focus.aps.org/.

AN OCEAN OF QUARKS



Courtesy of Brookhaven National Laboratory

Nuclear physicists have demonstrated that the material essence of the universe at a time mere microseconds after the big bang consists of a ubiquitous quark-gluon liquid. This insight comes from an experiment carried out over the past five years at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab, where scientists have created a toy version of the cosmos amid high-energy collisions. RHIC is, in effect, viewing a very early portion of the universe, before the time when protons are thought to have formed into stable entities (ten microseconds after the big bang).

In our later, cooler epoch quarks conventionally occur in groups of two or three, held together by gluons. Could a nucleus be made to rupture and spill its innards into a common swarm of unconfined quarks and gluons? This is what RHIC set out to show.

In the RHIC accelerator two beams of gold ions are clashed at several interaction zones around the ring-shaped facility. Every nucleus is a bundle of 197 protons and neutrons, each of which shoots along with an energy of up to 100 GeV. When the two gold projectiles meet in a head-on "central collision" event, the total collision energy is 40 TeV. Of this, typically 25 TeV serves as a stock of surplus energy–call it a fireball–out of which new particles can be created. Indeed in many gold-gold smashups as many as 10,000 new particles are born of that fireball.

The outward-streaming particles provided the tomographic evidence for determining the properties of the fireball. The recreation of the frenzied quark era lasts only a few times 10^{-24} seconds. The size of the fireball is about 5 femtometers, its density about 100 times that of an ordinary nucleus, and its temperature about 2 trillion degrees Kelvin or 175 MeV. But was it the much-anticipated quark-gluon plasma? The data unexpectedly showed that the fireball looked nothing like a gas. For one thing, potent jets of mesons and protons expected to be squirting out of the fireball were being suppressed.

For the first time since starting nuclear collisions at RHIC in the year 2000 and with plenty of data in hand, all four detector groups operating at the lab have converged on a consensus opinion. They believe that the fireball is a liquid of strongly interacting quarks and gluons rather than a gas of weakly interacting quarks and gluons. The liquid is dense but seems to flow with very little viscosity, approximating an ideal fluid. The RHIC findings were reported at the April meeting of the American Physical Society in Tampa.

Papers published concurrently by the four groups: BRAHMS: *Nucl.Phys. A* 757 (2005) PHENIX: 1-27, *Nucl.Phys. A* 757 (2005) 28-101, PHOBOS: *Nucl.Phys. A* 757 (2005) 102-183, STAR *Nucl. Phys. A* 757 (2005) 184-283

THE MOST DISTANT CRAFT LANDING IN THE SOLAR SYSTEM

The Huygens probe, given long passage by the Cassini spacecraft into the middle of Saturn's minor planetary system, has successfully parachuted onto the surface of Titan, the only moon with a considerable atmosphere. Pictures taken from miles above the surface during the descent and pictures taken on the surface itself suggest the presence of boulders or ice chunks and some kind of shoreline, perhaps of a hydrocarbon lake or sea. The data gained so far include a sort of acoustic sampling of the atmosphere during the descent and some color photographs. The Titan probe is named for Christiaan Huygens, who first spotted Titan and who also was the first to provide the proper interpretation of Saturn's ring system. (http://www.esa.int/SPECIALS/Cassini-Huygens/)

THE BIGGEST SPLASH OF LIGHT FROM OUTSIDE THE SOLAR SYSTEM

Credit: G.B. Taylor, NRAO/AUI/NSF)

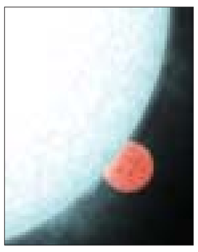
The biggest splash of light from outside the solar system to be recorded here at Earth occurred on December 27, 2004. The light came from an object called SGR 1806-20, about 50,000 light years away in our own galaxy. SGR stands for "soft gamma repeater," a class of neutron star possessing a gigantic magnetic field. Such "magnetars" can erupt violently, sending out immense bolts of energy in the form of gamma rays and light at other wavelength regions of the electromagnetic spectrum. The eruption was first seen with orbiting telescopes at the upper end of the spectrum over a period of minutes and then by more and more telescopes; at radio wavelengths emissions were monitored for months. For an instant the flare was brighter than the full moon. (NASA press conference, 18 February; www.nrao.edu/pr/2005/sgrburst/; many telescopes participated in the observations, reports appeared in the 28 April 2005 issue of *Nature*.)

SUPERFLUID SOLID HYDROGEN

Last year Moses Chan (Penn State) announced the results of an experiment in which solid helium-4 was revolved like a merry-go-round. It appeared that when the bulk was revolved at least part of the solid remained stationary. In effect part of the solid was passing through the rest of the solid without friction. Chan interpreted this to mean that a fraction of the sample had become superfluid.

Now, Chan sees evidence for superfluid behavior in solid hydrogen as well. Speaking at the March meeting of the American Physical Society in Los Angeles, Chan said that his hydrogen results are preliminary and that further checks are needed before ruling out alternative explanations. The concept of what it means to be a solid, Chan said, needs to be re-examined.

DIRECT DETECTION OF EXTRASOLAR PLANETS



Credit:: NASA/JPL-Caltech/R. Hurt (SSC))

Direct detection of extrasolar planets has been achieved for the first time. Previously the existence of planets around other suns has been inferred from subtle modulation of the light emitted by the star. Now light from the planet itself has been recorded directly at infrared wavelengths by the Spitzer Space Telescope (www.spitzer.caltech.edu).

The planets, one with the prosaic name of HD 209458b (153 light years away), the other TrES-1 (489 light years away), orbit their stars more tightly than does Mercury around our sun. This makes the Jupiter-sized planets hot enough to be viewed by Spitzer. (NASA press conference, 23 March; report published in *Nature*, 7 April.)

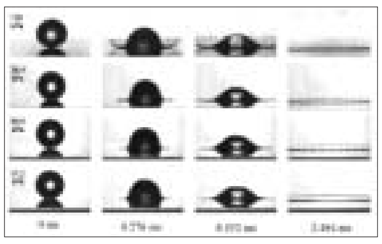
ZEPTOGRAM MASS DETECTION–WEIGHING MOLECULES

Michael Roukes and his Caltech colleagues have performed mass measurements with nearly zeptogram (zg) sensitivity, that is, with an uncertainty of only a few times 10^{-21} grams. At this level one can start to weigh molecules one at a time. In experiments, the presence of xenon accretions of only about 30 atoms (7 zg, or about 4 kilodaltons, or the same as for a small protein) have been detected in real time.

Minuscule masses are measured through their effect on an oscillating doubly clamped silicon carbide beam, which serves as the frequency-determining element in a tuned circuit. In practice, the beam would be set to vibrating at a rate of more than 100 MHz and then would be exposed to a faint puff of biomolecules. Each molecule would strike the beam, where its presence (and its mass) would show up as a changed resonant frequency.

After a short sampling time, the molecule would be removed and another brought in. Through this kind of miniaturization and automation, the NEMS approach to mass spectroscopy could change the way bioengineering approaches its task, especially in the search for cancer and its causes. The Roukes group reported its findings at the APS March Meeting in Los Angeles.

NO SPLASH ON THE MOON



Sidney Nagel's lab at the University of Chicago has explored the behavior of liquid drops when they fall from a faucet. At the APS March meeting, Nagel's graduate student, Lei Xu, revealed a surprising discovery concerning one of the commonest physical effects: the splash a liquid drop makes when it strikes a flat surface.

Under ordinary atmospheric conditions a liquid drop will flatten out on impact, splay sideways, and also raise a tiara-like crown of splash droplets. Remove some of the ambient atmosphere, and surprisingly the splash becomes less. At about one-fifth atmosphere the splash disappears altogether, leaving the outward going splat but no upwards splash. Apparently it is the presence of the air molecules that give the impacting liquid something to push off of; remove the surrounding atmosphere, and the splash disappears. (Lei Xu, Wendy W. Zhang, and Sidney R. Nagel, *Phys. Rev. Lett.* 94, 184505, 2005)

PYROFUSION: A ROOM-TEMPERATURE, PALM-SIZED NUCLEAR FUSION DEVICE

A room-temperature, palm-sized nuclear fusion device has been reported by a UCLA collaboration, potentially leading to new kinds of fusion devices and other novel applications such as microthrusters for MEMS spaceships.

The key component of the UCLA device is a pyroelectric crystal, a class of materials that includes lithium niobate, an inexpensive solid that is used to filter signals in cell phones. When heated, a pyroelectric crystal polarizes charge, segregating a significant amount of electric charge near a surface, leading to a very large electric field there. In turn, this effect can accelerate electrons to relatively high (keV) energies.

The UCLA researchers (Brian Naranjo, Jim Gimzewski, Seth Putterman) take this idea and add a few other elements to it. In a vacuum chamber containing deuterium gas, they place a lithium tantalate ($LiTaO_3$) pyroelectric crystal so that one of its faces touches a copper disc which itself is surmounted by a tungsten probe. They cool and then heat the crystal, which creates an electric potential of about 120 kilovolts at its surface.

The electric field at the end of the tungsten probe tip is so high (25 V/nm) that it strips electrons from nearby deuterium atoms. Repelled by the positively charged tip, and crystal field, the resulting deuterium ions then accelerate towards a solid target of erbium deuteride (ErD_2), slamming into it so hard that some of the deuterium ions fuse with deuterium in the target. Each deuterium-deuterium fusion reaction creates a helium-3 nucleus and a 2.45 MeV neutron, the latter being collected as evidence for nuclear fusion. In a typical heating cycle, the researchers measure a peak of about 900 neutrons per second, about 400 times the “background” of naturally occurring neutrons. During a heating cycle, which could last from 5 minutes to 8 hours depending on how fast they heat the crystal, the researchers estimate that they create approximately 10^{-8} joules of fusion energy. By using a larger tungsten tip, cooling the crystal to cryogenic temperatures, and constructing a target containing tritium, the researchers believe they can scale up the observed neutron production 1000 times, to more than 10^6 neutrons per second. (Naranjo, Gimzewski, Putterman, *Nature*, 434, 1115).

MOST PRECISE MASS CALCULATION FOR LATTICE QCD

A team of theoretical physicists have produced the best prediction of a particle’s mass, using lattice QCD, a computational approach to understanding how quarks interact. Within days of their paper being submitted to Physical Review Letters, that very particle’s mass was accurately measured at Fermilab, providing striking confirmation of the predicted value.

In a lattice QCD computation, quarks are placed at the interstices of a crystal-like structure. The quarks interact with each other via the exchange of gluons along the links between the quarks. From this sort of framework the mass of the known hadrons can be calculated.

Until recently, however, the calculations were marred by a crude approximation. A big improvement came in 2003, when uncertainties in mass predictions went from the 10% level to the 2% level. Progress has come from a better treatment of the light quarks and from greater computer power. The improvements provide the researchers with a realistic treatment of the “sea quarks,” the virtual quarks whose ephemeral presence has a noticeable influence over the “valence” quarks that are considered the nominal constituents of a hadron. Now, for the first time, the mass of a hadron has been predicted with lattice QCD.

Andreas Kronfeld and his colleagues at Fermilab, Glasgow University, and Ohio State report a mass calculation for the charmed B meson Bc, consisting of an anti-bottom quark and a charmed quark). The value they predict is 6304 +/- 20 MeV. A few days after they submitted their Letter for publication, the first good experimental measurement of the same particle was announced: 6287 +/- 5 MeV. This successful confirmation is exciting because it bolsters confidence that lattice QCD can be used to calculate many other properties of hadrons. (Allison et al., *Phys. Rev. Lett.* 94, 172001, 2005)

PRECISE MEASUREMENT OF THE WEAK NUCLEAR FORCE

Physicists at the SLAC accelerator have measured, with much greater precision than ever before, the variation in the weak nuclear force over an enormous size scale (a distance of more than ten proton diameters) for so feeble a force. Although the results were not surprising (the weak force diminished with distance as expected) this new quantitative study of the weak force helps to cement physicists’ view of the sub-nuclear world.

Physicists at SLAC extract weak effects from the much larger electromagnetic effects involved when two electrons interact. In the case of their present experiment (E158), a powerful electron beam scatters from electrons bound to hydrogen atoms in a stationary target. By using electrons that have been spin polarized–the weak force can be studied by looking for subtle asymmetries in the way electrons with differing polarizations scatter from each other.

One expects an intrinsic fall off in the weak force with the distance between the electrons. It should also fall off owing to the cumbersome mass possessed by the Z boson. Finally, the weak force weakens because the electron’s “weak charge” becomes increasingly shielded owing to a polarization of the vacuum–with virtual quarks, electrons, and W and Z bosons needing to be taken into account.

Previously, the weak charge has been well measured only at a fixed distance scale, a small fraction of the proton’s diameter. The SLAC result over longer distances confirms the expected falloff. According to E158 researcher Yury Kolomensky, the result is precise enough to rule out certain theories that invoke new types of interactions, at least at the energy scale of this experiment. (Anthony et al., *Phys. Rev. Lett*. 95, 081601, 2005)

SUPERFLUIDITY IN AN ULTRACOLD GAS OF FERMION ATOMS

Superfluidity in an ultracold gas of fermion atoms has been demonstrated in an experiment at MIT, where an array of vortices has been set in motion in a molecular Bose Einstein condensate (BEC) of paired lithium-6 atoms. There have been previous hints of superfluidity in Li-6, but the presence of vortices observed in the new experiment clinches the case since vortices manifest the most characteristic feature of superfluidity, namely persistent frictionless flow.

Wolfgang Ketterle and his MIT colleagues use laser beams to hold the chilled atoms in place and separate laser beams to whip up the vortices. Gaseous Li-6 represents only the second known superfluid among fermi atoms, the other being liquid helium-3. There are great advantages in dealing with a neutral superfluid in dilute gas form rather than in liquid form: in the gas phase (with a material density similar to that of the interstellar medium), inter-atomic scattering is simpler; furthermore, the strength of the pairing interaction can be tuned at will using an imposed external magnetic field.

The ultracold lithium gas represents, in a narrow sense, the first “high-temperature” superfluid. Consider the ratio of the critical temperature (T_c) at which the superfluid transition takes place to the fermi temperature (T_f), the temperature (or energy, divided by Boltzmann’s constant) of the most energetic particle in the ensemble. For ordinary superconductors, T_c/T_f is about 10^{-4}; for superfluid helium-3 it is 10^{-3}; for high-temperature superconductors 10^{-2}; for the new lithium superfluid it is 0.3. (Zwierlein et al., *Nature*, 23 June 2005)

ULTRAVIOLET FREQUENCY COMB

Physicists at JILA, the joint institute of NIST and the University of Colorado, have created a new optical process to extend the production of coherent radiation into the extreme ultraviolet region of the electromagnetic spectrum. This process takes advantage of the fact that ultrafast laser pulses of femtosecond widths, separated by nanoseconds, manifest themselves as a superposition of light at different frequencies over a wide spectral band.

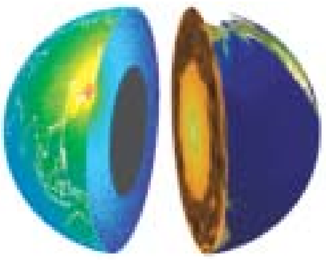
The Fourier transform of these short pulses is a long series of evenly spaced spikes that look like the tines of a comb. The JILA researchers have pushed the coverage of the frequency comb into the extreme ultraviolet by generating a series of high harmonics of the original, near-infrared laser frequency comb. (A comparable result has also been achieved by Ted Hänsch’s group in Munich.)

In the JILA experiment, 50-femtosecond-long pulses, spaced 10 nanoseconds apart, are sent into a coherent storage device–an optical buildup cavity. The cavity length is determined so that each tine of the incoming frequency comb is matched to a respective cavity resonance mode. In other words, the pulse train is matched exactly into the cavity such that a pulse running around inside the cavity is reinforced by a steady stream of incoming pulses. After a thousand roundtrips through the cavity, the infrared laser light becomes sufficiently energized to directly ionize xenon atoms inside the cavity. The quick repatriation of the xenon electrons to their home atoms produces light pulses of high frequency harmonics. Coherent high harmonic generation has been achieved with other techniques, typically involving single, actively amplified, ultrashort laser pulses.

The new approach demonstrated in the JILA work has drastically improved the spectral resolution of these high harmonic generated light sources by many orders of magnitude and will also permit an important increase of the efficiency of the harmonic generation process. Moreover, the buildup of intense UV happened without the need for expensive or bulky amplifying equipment.

Optical frequency combs have led to demonstrations of optical atomic clocks and are furthering research in extreme nonlinear optics, precision spectroscopy, and laser pulse manipulation and control. Jun Ye and his colleagues believe that the new ultraviolet frequency comb promises to provide an important tool for ultrahigh resolution spectroscopy and precision measurement in that spectral domain. It will open the door to unprecedented spectral resolution, making it possible for scientists to study the fine structure of atoms and molecules with coherent XUV light. (Jones et al., *Phys. Rev. Lett*. 94, 193201, 2005)

GEONEUTRINOS DETECTED



Neutrinos have very little mass and interact rarely, but are made in large numbers inside the sun as a byproduct of fusion reactions. They are also routinely made in nuclear reactors and in cosmic ray showers. Terrestrial detectors (usually located underground to reduce the confusing presence of cosmic rays) have previously recorded these various kinds of nu’s.

Now, a new era in neutrino physics has opened up with the detection of electron antineutrinos coming from radioactive decays inside the Earth. The Kamioka liquid scintillator antineutrino detector (KamLAND) in Japan has registered the presence of candidate events of the right energy; uncertainty in the model of the Earth’s interior makes the exact number vague, but it might be dozens of geo-nu’s.

The neutrinos presumably come from the decays of U-238 or Th-232. They are sensed when they enter the experimental apparatus, where they cause a 1000-ton bath of fluid to sparkle. Scientists believe the Earth is kept warm, and tectonic plates in motion, by a reservoir of energy deriving from two principal sources: residual energy from the Earth’s formation and additional energy from subsequent radioactive decays. The rudimentary inventory of geoneutrinos observed so far is consistent with the theory. (Araki et al., *Nature* 436, 499-503 (28 July 2005)

ATOM-MOLECULE DARK STATES

Physicists at the University of Innsbruck have demonstrated that atom pairing in Bose-Einstein condensates (BECs) using photoassociation is coherent. Coherent pairing of atoms has been observed before using a tuned magnetic condition–a Feshbach resonance–between the atoms. But molecules made that way are only feebly attached. By contrast the process of photoassociation–i.e. using light to fuse two atoms into one molecule–allows more deeply bound molecule states to be established. The trouble is that the same laser light can also be absorbed to dissociate the molecules. The countermeasure used by the Innsbruck researchers is to create a “dark state” in which the light cannot be absorbed. A dark state is a special quantum condition: it consists of three quantum energy levels, two stable ground states and one excited level. If laser light at the two frequencies needed for the transitions from both the ground states to the excited state are present simultaneously, the two excitations (from the two lower energy states) can destructively interfere with each other if there is phase coherence between the ground states. The consequence is that no light gets absorbed and the molecules are stable. Such “electromagnetically induced transparency” has been observed before for transitions within atoms, but the Innsbruck scientists are the first to use it for a transition between a BEC of atoms and molecules. In their experiments, the same (two-color) laser light that creates the dark state is also the light that photoassociates rubidium atoms into molecules. Johannes Hecker Denschlag says that atom-molecule dark states are a convenient tool to analyze the atom-molecule system and to optimize the conversion of atomic into molecular BECs. BECs of ultracold molecules represent, because of their many internal degrees of freedom (vibrational and rotational), a new field of research beyond atomic BECs. (Winkler et al., *Phys. Rev. Lett*. 95, 063202, 2005)

HOW EFFECTIVE WILL FLU VACCINE BE?

A new way of predicting the flu vaccine's efficacy by using the tools of statistical physics was described by Michael Deem of Rice University at the APS March Meeting.

To predict efficacy, researchers examine each strain's hemagglutinin (H) protein, the major protein on the surface of influenza A virus that is recognized by the immune system.

In one standard approach, researchers study all the mutations in the entire H protein from one season to the next. In another approach, researchers study the ability of antibodies produced in ferrets to recognize either the vaccine strain or the mutated flu strain, which had been thought to be a good method for predicting flu vaccine efficacy in humans.

However, these approaches are only modestly reliable indications of the vaccine's efficacy. Deem and his Rice University colleagues point out that each H protein has 5 "epitopes," antibody-triggering regions mutating at different rates. The Rice team refers to the one that mutates the most as the "dominant" epitope. Drawing upon theoretical tools originally developed for nuclear and condensed-matter physics, the researchers focus on the fraction of amino acids that change in the dominant epitope from one flu season to the next.

Analyzing 35 years of epidemiological efficacy data, the researchers believe that their focus on epitope mutations correlates better with vaccine efficacy than do the traditional approaches. Deem and his colleagues Vishal Gupta and Robert Earl believe that this new measure may prove useful in designing the annual flu vaccine and in interpreting vaccine efficacy studies.

DID YOU SAY HYDROPHOBIC WATER?

Hydrophobic water sounds like an impossibility. Nevertheless, scientists at Pacific Northwest National Lab have produced and studied monolayers of water molecules (resting on a platinum substrate) which prove to be poor templates for subsequent ice growth. Picture the following sequence: at temperatures below 60 K, isolated water molecules will stay put when you place them on a metallic substrate. At higher temperatures, the molecules become mobile enough to begin forming into tiny islands of two-dimensional ice. New molecules landing on the crystallites will fall off the edges into the spaces between the islands. In this way the metal surface becomes iced over completely with a monolayer. But because the water molecules' four bonds are now spoken for (1 to the Pt substrate and 3 to their neighboring water molecules), the addition of more water does not result in layer-by-layer 3D ice growth. Only when there is an amount of overlying water equivalent to about 40 or 50 layers does 3D crystalline ice completely cover the hydrophobic monolayer. The PNL researchers are the first to observe this effect. For the novel hydrophobic property to show itself, the water-substrate bond has to be strong enough to form a stable monolayer. Weaker bonding results in a "classic" hydrophobic state, in which the water merely balls up immediately; in other words, not even a first monolayer of ice forms. This research should be of interest to those who, for example, study the seeding of clouds, where ice is nucleated on particles in the atmosphere. (Kimmel et al. *Phys. Rev. Lett*. 95, 166102, 2005)

THE 2005 NOBEL PRIZE IN PHYSICS

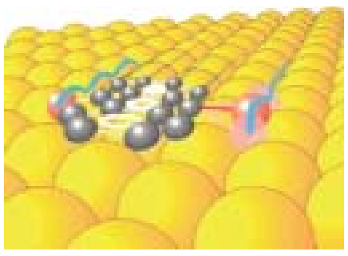
The 2005 Nobel Prize in Physics was devoted to optics, with half of the prize going to Roy J. Glauber of Harvard University for his quantum theory of optical coherence, and one-quarter each going to John L. Hall (JILA, University of Colorado and National Institute of Standards and Technology, Boulder, CO) and Theodor W. Hänsch (Max Planck Institute for Quantum Optics, Garching, Germany; Ludwig-Maximilians-University, Munich, Germany), for their development of ultra-high-precision measurements of light.

Glauber described optical coherence and the detection of laser light in the language of quantum mechanics. Glauber's theory provided understanding of quantum "noise," jittery and unavoidable fluctuations in the properties of light. This in turn provides information on the limits of measuring light, as well on the as understanding of optical detectors that count single photons at a time. Single-photon detectors are important for applications such as quantum cryptography.

Meanwhile, Hall and Hänsch developed techniques for measuring the frequency of light to what is currently 15 digits of accuracy. These frequency-measurement techniques helped scientists to devise fundamental definitions of physical units (for example, Hall and others helped to redefine one meter as the distance that light travels in 1/299,792,458 seconds). Measuring optical frequency has also helped to test Einstein's theory of special relativity to record-breaking levels of precision. In addition, optical-frequency measurements have made possible tabletop experiments that search for new physics, such as the question of whether the fine structure constant, the quantity that determines the inherent strength of the electromagnetic force, is changing over time.

Hall and Hänsch are cited in particular for the recent development of the "optical frequency comb technique," in which ultrashort pulses of light create a set of equally spaced frequency peaks resembling a comb. The combs can be used to measure other optical frequencies with unprecedented precision and ease (and with much smaller equipment than previously possible). They enable better atomic clocks which in turn can make the Global Positioning System more precise.

WALKING MOLECULES



A single molecule has been made to walk on two legs. Ludwig Bartels and his colleagues at the University of California at Riverside, guided by theorist Talat Rahman of Kansas State University, created a molecule–called 9,10-dithioanthracene (DTA)–with two "feet" configured in such a way that only one foot at a time can rest on the substrate.

Activated by heat or the nudge of a scanning tunneling microscope tip, DTA will pull up one foot, put down the other, and thus walk in a straight line across a flat surface. The planted foot not only supplies support but also keeps the body of the molecule from veering or stumbling off course.

In tests on a standard copper surface, such as the kind used to manufacture microchips, the molecule has taken 10,000 steps without faltering. According to Bartels, possible uses of an atomic-sized walker include guidance of molecular motion for molecule-based information storage or even computation.

DTA moves along a straight line as if placed onto railroad tracks without the need to fabricate any nano-tracks; the naturally occurring copper surface is sufficient. The researchers now aim at developing a DTA-based molecule that can convert thermal energy into directed motion like a molecular-sized ratchet. (Kwon et al. *Phys. Rev. Lett.* 95, 166101, 2005)

PARTICLES OF HEAT

The phonon Hall effect, the acoustic equivalent of the electrical Hall effect, has been observed by physicists at the Max Planck Institut für Festkörperforschung (MPI) and the Centre National de la Recherche Scientifique (CNRS) in France.

In the electrical Hall effect, when an electrical current being driven by an electric field is subjected to an external magnetic field, the charge carriers will feel a force perpendicular to both the original current and the magnetic force, causing the electrical current to be deflected to the side. A "current" of heat can consist of free electrons carrying thermal energy or it can consist of phonons, which are vibrations rippling through the lattice of atoms of the sample.

Previously, some scientists believed that in the absence of free electrons, a magnetically induced deflection of heat could not be possible. The MPI-CNRS researchers felt, however, that a magnetic deflection of phonons was possible, and have demonstrated it experimentally in insulating samples of Terbium Gallium Garnet (a material often used for its magneto-optical properties) where no free charges are present. The sample was held at a temperature of 5 degrees Kelvin and was warmed at one side, creating the thermal equivalent of an applied voltage. Application of a magnetic field of a few Tesla led to an extremely small (smaller than one thousandth of a degree), yet detectable temperature difference. (Strohm et al., *Phys. Rev. Lett*. 95, 155901, 2005)

HYPER-ENTANGLED PHOTON PAIRS

Physicists at the University of Illinois at Urbana-Champaign have demonstrated for the first time the entanglement of two objects not merely in one aspect of their quantum natures, such as spin, but in a multitude of ways.

In the Illinois experiment, two photons are produced in a "down-conversion" process whereby one photon enters an optical crystal and sunders into two lesser-energy correlated daughter photons. The two daughter photons are entangled not just in terms of polarization, but also in a number of other ways: energy, momentum, and orbital angular momentum.

The photon pair can be produced in either of two crystals, and the uncertainty in the production details of the individual photons is what provides the ability to attain entanglement in all degrees of freedom.

Is it better to entangle two particles in ten ways or ten particles in two ways? They're probably equivalent, says Paul Kwiat, leader of the Illinois group, but for the purpose of quantum computing or communication it might be of some advantage if multiple quantum bits (or qubits) of information can be encoded in a single pair of entangled particles. Kwiat says that his lab detects a record two million entangled photon pairs per second with ample determination of numerous properties, allowing a complete characterization of the entanglement produced. (Barreiro et al, *Phys. Rev. Lett*. 95, 260501, 2005)

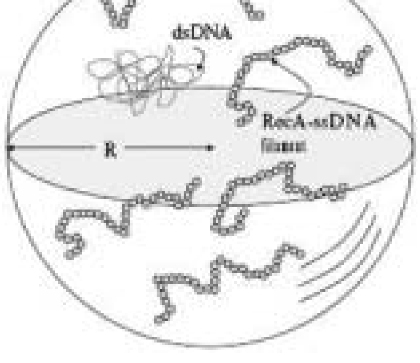
SUPER LENSING IN THE MID-INFRARED

Physicists at the University of Texas at Austin have made a "super lens," a plane-shaped lens that can image a point source of light down to a focal spot only one-eighth of a wavelength wide. This is the first time such super lensing has been accomplished in a functional device in the mid-infrared range of the electromagnetic spectrum.

Historically, lensing required a lens-shaped optical medium for bringing the diverging rays coming from a point source into focus on the far side of the lens. But in recent years, researchers have found that in "negative permittivity" materials, in which a material's response to an applied electric field is opposite that of most normal materials, light rays can be refracted in such a way as to focus planar waves into nearly a point–albeit over a very truncated region, usually only a tenth or so of the wavelength of the light.

Such near-field optics are not suitable for such applications as reading glasses or telescopes, but have become an important technique for certain kinds of nanoscale imaging of large biological molecules than can be damaged by UV light. The micron-sized Texas lens, reported in October at the Frontiers in Optics meeting of the Optical Society of America, consists of a silicon carbide membrane between layers of silicon oxide. It focuses 11-micron-wavelength light, but the researchers hope to push on into the near-infrared range soon. Furthermore, the lensing effect seems to be highly sensitive to the imaging wavelength and to the lens thickness. Possible applications of the lens include direct laser nanolithography and making tiny antennas for mid-IR-wavelength free-space telecommunications.

UNCOVERING NEW SECRETS IN A DNA HELPER



The protein RecA performs some profoundly important functions in bacteria. Two independent papers shed light on how the bacterial protein helps (1) identify and (2) replace damaged DNA while making few mistakes. Error-correction mechanisms keep DNA fidelity during replication to within an average of one error per billion "letters" or base pairs. This research may provide insight on how damage to existing DNA from processes such as UV radiation can be detected and repaired efficiently in living organisms, including humans, who carry evolutionary cousins of RecA. When the double-helix DNA is seriously damaged, single-stranded DNA is exposed and RecA polymerizes (bonds) onto it, activating a biochemical SOS signal.

To do this, Tsvi Tlusty and his colleagues at the Weizmann Institute and Rockefeller University suggest that RecA performs "kinetic proofreading" in which RecA can precisely identify a damaged strand and its length by using ATP (the energy-delivering molecule in cells) to inspect (proofread) the DNA's binding energy and to detach after a certain time delay (the "kinetic" part) if the DNA has the "wrong" binding energy.

The researchers argue that the RecA performs the precise binding and unbinding actions that are necessary for kinetic proofreading through “assembly fluctuations,” a protein’s structural changes brought about by constant bonding and dissociation of RecA from its target. According to the authors, this is the first known biological process in which kinetic proofreading and assembly fluctuations are combined (Tlusty et al., *Physical Review Letters*, 17 December 2004, *Phys. Rev. Lett*. 93, 258103 (2004)).

Meanwhile, researchers at L’Institut Curie in France (Kevin Dorfman and Jean-Louis Viovy) have studied how RecA exchanges a damaged strand with a similar copy. In bacteria, RecA protein catalyzes this process by binding to a healthy single DNA strand to form a filament that “searches” for damaged double-stranded DNA (dsDNA). At odds with the conventional view, they propose that the dsDNA which needs to be repaired is the more active partner in this mutual search. Unbound, it first diffuses towards the more rigid and thus less mobile filament. In a second step, local fluctuations in the structure of the dsDNA, caused only by thermal motion, allow the base pairs of the filament to align and pair with the strand of replacement DNA. (Dorfman et al, Phys. Rev. Lett. 93, 268102, 2004)

ELECTRON CLOUDS CAN FREEZE INTO AN “ORBITAL GLASS”

Electron clouds can freeze into an “Orbital Glass” at low temperatures. In the modern picture of quantum mechanics, electrons take the form of “clouds” within the atoms and molecules in which they inhabit. The clouds, which have various shapes such as spheres or dumbbells, represent the general boundaries within which one may find an electron at any one measurement in time. Typically, processes involving electron clouds (more formally known as “orbitals”) are blazingly fast. In the order of a femtosecond (10^{-15} s), for example, an electron orbital can make transitions between degenerate states (those containing the same amount of energy), transforming from a vertical dumbbell to a horizontal one with respect to some axis.

Now, scientists have found evidence that these and other orbital processes can slow down dramatically–to as long as 0.1 seconds, a slowing by 14 orders of magnitude–for electrons in low-temperature FeCr2S4, a spinel (class of mineral) with a relatively simple crystalline structure. The researchers, from the Center for Electronic Correlations and Magnetism at the University of Augsburg in Germany (Peter Lunkenheimer) and the Academy of Sciences of Moldova, consider these frozen electron orbitals in spinels to constitute a new class of material which they have dubbed an orbital glass. By measuring the response of the material to alternating-current electric fields in the audio- to radio-frequency range, they found that processes involving non-spherical orbitals dramatically slow down at low temperatures to form a glass-like state, in a manner very similar to the arrest of molecular motion that occurs when glass blowers perform their craft.

It’s not just the orbitals that slow down; the neighboring atomic nuclei that surround the electrons also distort more slowly in response to the glacially changing orbitals. In contrast to conventional glasses, a complete “freeze” of the electron clouds does not occur at the lowest temperatures. Completely frozen orbitals are prevented by quantum-mechanical tunneling: the clouds keep themselves moving by making transitions between different low-energy cloud configurations even without the energy they normally require. (Fichtl et al., *Phys. Rev. Lett*. 94, 027601, 2005)

COMPLEX HYBRID STRUCTURES

Complex hybrid structures, part vortex ring and part soliton, have been observed in a Bose-Einstein condensate (BEC) at the Harvard lab of Lene Vestergaard Hau. Hau previously pioneered the technique of slowing and then stopping a light pulse in a BEC consisting of a few million atoms chilled into a cigar shape about 100 microns long.

In the new experiment, two such light pulses are sent into the BEC and stopped. The entry of these pulses into the BEC set in motion tornado-like vortices. These swirls are further modulated by solitons, waves which can propagate in the condensate without losing their shape. The resultant envelope can act to isolate a tiny island of superfluid BEC from the rest of the sample.

The dynamic behavior of the structures can be imaged with a CCD camera by shining a laser beam at the sample. Never seen before, these bizarre BEC excitations sometimes open up like an umbrella. Two of the excitations can collide and form a spherical shell (the vortex rings taking up the position of constant latitudes). Two such rings, circulating in opposite directions, will co-exist for a while, but after some period of pushing and pulling, they can annihilate each other as if they had been a particle-antiparticle pair.

Hau and her colleagues, graduate student Naomi Ginsberg and theorist Joachim Brand (at the Max Planck Institute for the Physics of Complex Systems, Dresden), have devised a theory to explain the strange BEC excitations and believe their new work will help physicists gain new insights into the superfluid phenomenon and into the breakdown of superconductivity. (Ginsberg, Brand, Hau, *Phys. Rev. Lett.* 94, 040403, 2005)

EVIDENCE FOR QUANTIZED DISPLACEMENT

Physicists at Boston University have found evidence for quantized displacement in nanomechanical oscillators. They performed an experiment in which tiny silicon paddles, sprouting from a central stick of silicon like the vanes from a heat sink, seem to oscillate together in a peculiar manner: the paddles can travel out to certain displacements but not to others. The setup for this experiment consists of a lithographically prepared structure looking like a double-sided comb.

Next, a gold-film electrode is deposited on top of the spine. Then a current is sent through the film and an external magnetic field is applied. This sets the structure to vibrating at frequencies as high as one gigahertz. This makes the structure the fastest man-made oscillator. At relatively warm temperatures, this rig behaves according to the dictates of classical physics. The larger the driving force (set up by the magnetic field and the current moving through the gold electrode) the greater the excursion of the paddles.

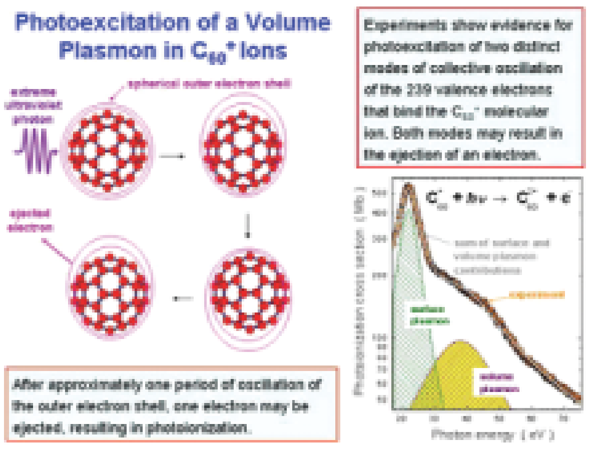
At millikelvin temperatures, however, quantum mechanics takes over. In principle, the energies of the oscillating paddles are quantized, and this in turn should show up as a propensity of the paddles (500 nm long and 200 nm wide) to displace only by discrete amounts. The Boston University experiment sees signs of exactly this sort of behavior. (Gaidarzhy et al., *Phys. Rev. Lett*. 94, 030402, 2005)

LIQUID CARBON CHEMISTRY

The chemistry of carbon atoms, with their gregarious ability to bond to four other atoms, is a major determinant of life on Earth. But what happens when carbon is heated up to its melting temperature of 5000 K at pressures greater than 100 bars? Although liquid carbon may exist inside the planets Neptune and Uranus, the main interest in studying liquid carbon here on Earth might be in the indirect information provided about bonding in ordinary solid carbon or in hypothetical novel forms of solid carbon. A new experiment creates liquid carbon by blasting a solid sheet of carbon with an intense laser beam. Before the liquid can vaporize, its structure is quickly probed by an x-ray beam. At low carbon density, two bonds seem to be the preferential way of hooking up, while at higher density, three and four bonds are typical.

This is not to say that complex organic molecules (carbon bonded to other atoms such as hydrogen or oxygen) could survive at 5000 K, but carbon bonds are tougher and can persist. The experiment was performed by physicists from UC Berkeley, the Paul Scherrer Institute (PSI) in Switzerland, Lawrence Berkeley National Lab, Kansas State, and Lawrence Livermore National Lab. A team member, Steve Johnson, says that one next step will be to study carbon, as well as other materials, at even higher temperatures in order to look at “warm dense matter,” a realm of matter too hot to be considered by conventional solid-state theory but too dense to be considered by conventional plasma theory. (Johnson et al., *Phys. Rev. Lett*. 94, 057407, 2005)

240 ELECTRONS SET IN MOTION



Photoexcitation of a Volume Plasmon in C_{60}^{+} Ions

Experiments show evidence for photoexcitation of two distinct modes of collective oscillation of the 239 valence electrons that bind the C_{60}^{+} molecular ion. Both modes may result in the ejection of an electron.

After approximately one period of oscillation of the outer electron shell, one electron may be ejected, resulting in photoionization.

A soccerball-shaped carbon-60 molecule, possessing a mobile team of up to about 240 valence electrons holding the structure together, is sort of halfway between being a molecule and a solid. To explore how all those electrons can move as an ensemble, a team of scientists working at the Advanced Light Source synchrotron radiation lab in Berkeley, turned the C-60 molecules into a beam (by first ionizing them) and then shot ultraviolet photons at them. When a photon is absorbed, the energy can be converted into a collective movement of the electrons referred to as a plasmon.

Previously a 20-electron-volt “surface plasmon” was observed: the absorption of the UV energy resulted in a systematic oscillation of the ensemble of electrons visualized as a thin sphere of electric charge. Now a new experiment has found evidence of a second resonance at an energy of 40 eV. This second type of collective excitation is considered a “volume plasmon” since the shape of the collective electron ensemble is thought to be oscillating with respect to the center of the molecule.

The collaboration consists of physicists from the University of Nevada, Reno, Lawrence Berkeley National Lab, Justus-Liebig-University (Giessen, Germany), and the Max Planck Institute (Dresden). (Scully et al., *Phys. Rev. Lett*. 94, 065503, 2005)

DEGENERATE GAS STUCK IN OPTICAL LATTICE

Physicists at the ETH lab in Zurich have, for the first time, not only made a quantum degenerate Fermi gas but have been able to load the atoms into the criss-cross interstices of an optical lattice, an artificial 3D crystal in which atoms are held in place by the electric fields of well-aimed laser beams.

By adjusting an external magnetic field, the pairs of atoms lodged in their specified sites can be made to interact (courtesy of the “Feshbach resonance”) with a varying strength. According to Tilman Esslinger, it is this ability to put atoms where you want them in a crystal-like scaffolding, and then to make them interact with a strength that you can control, that makes this setup so useful. It might be possible to test various condensed matter theories, such as those that strive to explain high-temperature superconductivity, on a real physical system. (Kohl et al., *Phys. Rev. Lett*. 94, 080403, 2005)

USING THE LHC TO STUDY HIGH ENERGY DENSITY PHYSICS?

The Large Hadron Collider (LHC) will be the most powerful particle accelerator around when, according to the plans, it will start operating in the year 2007. Each of its two 7-TeV proton beams will consist of 2808 bunches and each bunch will contain about 100 billion protons, for a total energy of 362 megajoules, enough to melt 500 kg of copper. What if one of these full-power beams were to accidentally strike a solid surface, such as a beam pipe or a magnet?

To study this possibility, scientists have now simulated the material damage the beam would cause. (In the case of an actual emergency, the beam is extracted and led to a special beam dump.) The computer study showed, first of all, that the proton beam could penetrate as much as 30 m of solid copper, the equivalent of two of LHC’s giant superconducting magnets. It is also indicated that the beam penetrating through a solid material would not merely bore a hole but would create a potent plasma with a high density (10 percent of solid density) and low temperature (about 10 eV).

Such plasmas are known as strongly coupled plasmas. One way of studying such plasmas would therefore be to deliberately send the LHC beam into a solid target to directly induce states of high-energy-density (HED) in matter, without using shock compression. This is a novel technique and could be potentially a very efficient method to study this venerable subject. (Tahir et al., *Phys. Rev. Lett*. 94, 135004, 2005)

NICKEL-78, THE MOST NEUTRON-RICH OF THE DOUBLY-MAGIC NUCLEI

Nickel-78, the most neutron-rich of the doubly-magic nuclei, has had its lifetime measured for the first time, which will help us better understand how heavy elements are made.

Physicists believe gold and other heavy elements (beyond iron) were built from lighter atoms inside star explosions billions of years ago. In the "r-process" (r standing for rapid) unfolding inside the explosion, a succession of nuclei bulk up on the many available neutrons.

This evolutionary buildup is nicely captured in a movie simulation showing all the species in the chart of the nuclides being made one after the other. In some models the buildup can slow down at certain strategic bottlenecks. Nickel-78 is one such roadblock. This is because Ni-78 is a "doubly magic" nucleus. It has both closed neutron and proton shells; it is "noble" in a nuclear sense in the way that a noble gas atom is noble in the chemical sense owing to its completely filled electron shell.

This crucial nuclide is very rare and hard to make artificially. Nevertheless, scientists at the National Superconducting Cyclotron (NCSL) at Michigan State University have now culled 11 specimens of Ni-78 from among billions of high-energy collision events recorded. In effect, the NCSL is a factory for reproducing supernova conditions here on Earth. Hendrik Schatz, speaking at the April APS meeting in Tampa, reported that from the available Ni-78 decays recorded, a lifetime of 110 milliseconds could be deduced.

This is some 4 times shorter than previous theoretical estimates, meaning that the bottleneck nucleus lived shorter than was thought, which in turn means that the obstacle to making heavier elements was that much less. So far the exact conditions and site for the r-process are still unknown. With the new measurement model conditions have to be readjusted to produce the observed amounts of precious metals in the universe. This will provide a better idea of what to look for when searching for the site of the r-process. (See also Hosmer et al., *Phys. Rev. Lett*. 94, 112501, 2005)

THE FIRST DIRECT MEASUREMENT OF RECOIL MOMENTUM

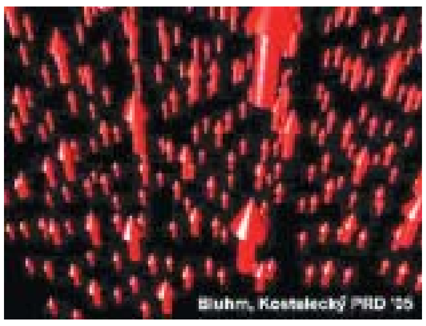
The first direct measurement of recoil momentum for single atoms struck by light in an absorptive medium has been made by Gretchen Campbell, Dave Pritchard, Wolfgang Ketterle and their colleagues at MIT. Photons do not possess mass, but a beam of light does carry momentum. In general, when light strikes a mirror, the mirror will recoil ever so slightly, and this recoil has previously been measured. But what about a single photon striking a single atom in a dilute gas?

The momentum of a photon equals h/lambda, where h is Planck's constant and lambda is the wavelength of the light in vacuum. In a dispersive medium, the index of refraction for the medium, n, comes into play: an object absorbing the photon will recoil with a momentum equal to nh/lambda. This is what has been measured for the first time on an atomic basis.

The MIT team used laser beams sent into a dilute gas; a beat note between recoiling atoms and atoms at rest provided the momentum measurement of selected atoms. The fact that the recoil momentum should be proportional to the index of refraction came as something of a surprise to the experimenters. You might expect that in isolated encounters, when an individual atom absorbs a single photon, that the recoil of the atom should not depend on n. That's because the atoms in the sample–in this case a Bose-Einstein condensate of Rb atoms–-is extremely dilute, so dilute that each atom essentially resides in a vacuum.

Nevertheless, the interaction of the light with all the atoms has to be taken into account, even if the specific interaction being measured, in effect, is that of single atoms. The atoms "sense" the presence of the others and act collectively, and the extra factor, the index of refraction, is applicable after all. Ketterle believes that this new insight about what happens when light penetrates a dispersive medium provides an important correction for high-precision measurements using cold atoms. (Campbell et al., *Phys. Rev. Lett*. 94, 170403, 2005)

LIGHT MAY ARISE FROM TINY RELATIVITY VIOLATIONS



Light may arise from tiny relativity violations, according to a new theory. Speaking at the meeting of the Division of Atomic, Molecular, and Optical Physics in Nebraska in May, Alan Kostelecky of Indiana University described how light might exist as a result of breaking Lorentz symmetry. In Lorentz symmetry, the laws of physics stay the same even when you change the orientation of a physical system (such as a barbell-shaped molecule) or alter its velocity.

Broken Lorentz symmetry would give space-time a preferred direction. In its simplest form, broken Lorentz symmetry could be visualized as a field of vectors existing everywhere in the universe.

In such a picture, objects might behave slightly differently depending upon their orientation with respect to the vectors. In a recent paper, the authors propose that the very existence of light is made possible through a vector field arising from broken Lorentz symmetry. In this picture, light is a shimmering of the vector field analogous to a wave blowing through a field of grain.

The researchers have shown that this picture would hold in empty space as well as in the presence of gravity, which is often ignored in conventional theories of light. This theory is in contrast to the conventional view of light, which arises in a space without a preferred direction and as a result of underlying symmetries in particles and force fields. Kostelecky says that the new theory can be tested by looking for minute changes in the way light interacts with matter as the earth rotates (and changes its orientation with respect to the putative vector field). (Bluhm and Kostelecky, *Physical Review D*, 71, 065008, 2005)

NEW SPINTRONIC SPEED RECORD

Spintronics is the science devoted to gaining greater control over digital information processing by exploiting electron spin along with electron charge in microcircuits. One drawback to implementing a scheme of magnetic-based memory cells for computers has been the relatively slower speed of spin transistors. Hans Schumacher of the Physikalisch-Technische Bundesanstalt, Braunscheig, Germany, has now devised the fastest-yet magnetic version of a random access memory (MRAM) cell, one that switches at a rate of 2 GHz, as good as or better than the fastest non-magnetic semiconductor memories.

The MRAM architecture is a sandwich, consisting of two magnetic layers, with a tunneling layer in between. When the magnetic layers are aligned (their spin orientation is the same) resistance in the cell is low; when they are counter-aligned resistance is high. These two conditions establish the binary 1 or 0 states. The speed of writing or reading data to and from the cells has, for MRAMs, been limited to cycle times of 100 MHz by magnetic excitations in the layers. This problem has been overcome, according to Hans Schumacher, through a novel approach referred to as ballistic bit addressing.

In the case of the new MRAM architecture, the influence of magnetic excitations is eliminated through the use of very short (500 picosecond) current pulses for carrying out the write operation. The 2-GHz switching speed (the rate at which writing can be accomplished) is faster than static RAM (or SRAM) memories, currently the fastest memories, can accomplish. Furthermore, the magnetic memories are non-volatile, which means that the status of the memory does not disappear if the computer is shut down. (Schumacher, *Appl. Phys. Lett.* 87, 042504, 2005, *J. Appl. Phys.* 98, 033910, 2005)

A NEW KIND OF NANOPHOTONIC WAVEGUIDE

A new kind of nanophotonic waveguide has been created at MIT, overcoming several long-standing design obstacles. The device might lead to single-photon, broadband and more compact optical transistors, switches, memories, and time-delay devices needed for optical computing and telecommunications.

If photonics is to keep up with electronics in the effort to produce smaller, faster, less-power-hungry circuitry, then photon manipulation will have to be carried out over scales of space, time, and energy hundreds or thousands of times smaller than is possible now. One or two of these parameters (space, time, energy) at a time have been reduced, but until now it has been hard to achieve all three simultaneously. John Joannopoulos and his MIT colleagues have succeeded in the following way. To process a photonic signal, they encrypt it into light waves supported on the interface between a metal substrate and a layer of insulating material. These waves, called surface plasmons, can have a propagation wavelength much smaller than the free-space optical wavelength. This achieves one of the desired reductions: with a shorter wavelength the spatial dimension of the device can be smaller.

Furthermore, a subwavelength plasmon is also a very slow electromagnetic wave. Such a slower-moving wave spends more time "feeling" the nonlinear properties of the device materials, and is therefore typified by a lower device-operational-energy scale, thus achieving another of the desired reductions. Finally, by stacking up several insulator layers, the slow plasmon waves occupy a surprisingly large frequency bandwidth. Since the superposition of waves at a variety of frequencies can add up to a pulse that is very short in the time domain, the third of the desired scale reductions is thereby achieved.

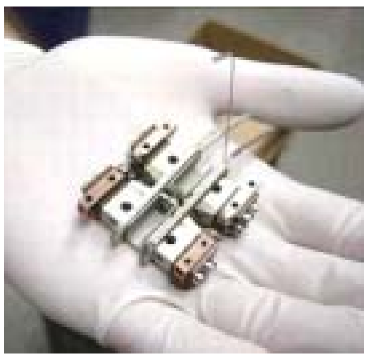
Reducing energy loss is another virtue of the MIT device. The plasmons are guided around on the photonic chip by corrugations on the nano-scale. In plasmonic devices the corrugations have usually been in the metal layer; this has always led to intractable propagation losses. However, in the MIT device they reside in the insulator layer; this, it turns out, allows for a drastic reduction of the losses by cooling. (Karalis et al., *Phys. Rev. Lett*. 95, 063901, 2005)

ROOM-TEMPERATURE ICE IN ELECTRIC FIELDS

Room-temperature ice is possible if the water molecules are submitted to a high enough electric field. Some physicists had predicted that water could be coaxed into freezing at fields around 109 V/m. The fields are thought to trigger the formation of ordered hydrogen bonding needed for crystallization. Now, for the first time, such freezing has been observed, in the lab of Heon Kang at Seoul National University in Korea, at room temperature and at a much lower field than was expected, only 106 V/m. Exploring a new freezing mechanism should lead to additional insights about ice formation in various natural settings, Kang believes.

The field-assisted room-temperature freezing took place in cramped quarters: the water molecules were constrained to the essentially 2-dimensional enclosure between a gold substrate and the gold tip of a scanning tunneling microscope (STM). Nevertheless, the experimental conditions in this case, modest electric field and narrow spatial gap, might occur in nature. Fields of the size of 106 V/m, for example, are thought to exist in thunderclouds, in some tiny rock crevices, and in certain nanometer electrical devices. (Choi et al., *Phys. Rev. Lett*. 95, 085701, 2005)

BEC IN A CIRCULAR WAVEGUIDE



Bose Einstein condensates (BECs), in which trapped, chilled atoms fall into a single corporate quantum state, have been achieved for several elements of the periodic table and in a variety of trap geometries. Physicists at UC Berkeley have now, for the first time, produced a BEC in a ring-shaped trap about 1 millimeter across. By using an extra magnetic field, in addition to those used to maintain the atoms in the trap to start with, the whole trap can be "tilted," so as to accelerate the atoms up to velocities of about 50-150 mm/sec (or equivalently to energies of about 100 pico-electron-volts per nucleon, as compared to the TeV energies sought for particle physics). After this initial "launch" phase, the atoms are allowed to drift around the ring; they do this not in clumps (as you would have with particles in a colliding-beam storage accelerator) but in a continuously expanding stream. However, starting from the BEC state, the atoms are more like coherent atom waves smeared out around the ring; they move ballistically and without emitting synchrotron radiation. According to Dan Stamper-Kurn, potential applications for BEC rings would become possible if parts of the circulating condensate could be made to interfere with other parts. From such an interferometer one could devise gyroscopes or high-precision rotation sensors. Other possible realms of study include quantized circulation, fluid analogues of general relativity, and fluid analogues of SQUID detectors and other superconducting devices. (Gupta et al., *Phys. Rev. Lett.* 95, 143201, 2005)

MAGNETIC BURNING

A new experiment suggests that the fast flipping of the magnetic orientation of some molecules in a solid sample resembles the propagation of a flame front through a material being burned, and that the "magnetic burning" process can be used to study flammable substances without actually having flames present. In a chemical fire–say, the burning of the pages of a book–the flame front marks a dividing point: ahead of the front is intact unburned material, while behind the front is ash, the state of material that has been oxidized in the combustion process. Now, consider the magnetic equivalent as studied by a collaboration of scientists from CUNY-City College, CUNY-Lehman College, the Weizmann Institute, and the University of Florida. A crystal of manganese12-acetate (Mn12-ac) molecules, each with a net spin of 10 units, is quite susceptible to magnetic influence. Turning on a strong external magnetic field opposed to the prevailing magnetic orientation of the crystal can cause a sudden reversal of spins of the molecules. The reversal propagates along a front through the crystal (which can be thought of as a stack of nanomagnets) just as a flame moves through a solid in the case of a conventional combustion. In the magnetic case, much heat will be generated as the spins get flipped (the heat energy being equal to the difference in energy of the before and after spin states), but there will be no destructive burning. The "ash" consists of the molecules in their new spin state. In summary, magnetic burning in molecular magnets has several of the qualities of regular burning (a flame front and combustion) but not the destructiveness. Myriam Sarachik says that magnetic burning might offer a more controlled way of learning how to control and channel flame propagation. (Suzuki et al., *Phys. Rev. Lett*. 95, 147201, 2005)

WHY DO WE RESIDE IN A THREE-DIMENSIONAL UNIVERSE?

Andreas Karch (University of Washington) and Lisa Randall (Harvard) propose to explain why we live in three dimensions and not some other number. Currently, the popular string theory of matter holds that our universe is actually ten-dimensional, including, first of all, the dimension of time, then the three "large" dimensions we perceive as "space," plus six more dimensions that are difficult to see, perhaps because they are hidden in some way. There is reason to believe, therefore, that our common 3D space is but a portion of some membrane or "brane" within a much more complicated higher-dimensional reality. Specifically, Karch and Randall address themselves to the behavior of three-dimensional force laws, including the force of gravity. Having several dimensions rolled up is one way to explain why gravity is so weak.

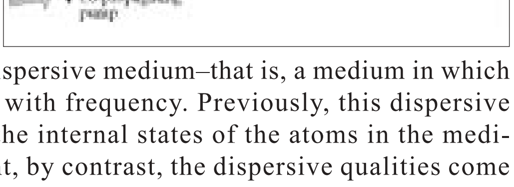
Another view, pioneered by Randall and Raman Sundrum, holds that if gravity is localized on a 3D defect in the larger multi-dimensional universe and if spacetime is sufficiently warped, then the other spatial dimensions might be large after all. But why is our "local gravity" apparently a 3D defect in a 10D universe? Why not a 4D defect or some other dimensionality?

In the present paper, Karch and Randall show that the cosmic evolution of the 10D universe, involving a steady dilution of matter, results in spacetime being populated chiefly by 3D and 7D branes. Several versions of string theories require the existence of 3D and 7D branes; indeed, the particles that constitute matter–such as quarks and electrons–can be considered open strings with one end planted on a 3D brane and the other end planted on a 7D brane. (Karch and Randall, *Phys. Rev. Lett*. 95, 161601, 2005)

NUCLEAR SEISMOLOGY

Physicists at the GSI lab in Darmstadt, Germany, have discovered a new excited nuclear state, one in which a tide of neutrons swells away from the rest of the nucleus. Ordinarily, in its unexcited state, a typical atomic nucleus consists of a number of constituent neutrons and protons bobbing around inside a roughly spherical shape. However, if struck by a projectile from outside, such as a beam particle supplied by an accelerator, the nucleus can be set to spinning, or it might distend. In one kind of excited mode called a dipole resonance, the protons can move slightly in one direction while the neutrons go the other way. In another type of excitation, a nucleus might consist of a stable core blob of nucleons surrounded by a surplus complement of one or two neutrons, which constitute a sort of halo around the core. In the new GSI experiment, yet another nuclear mode has been observed. The nuclei used, two isotopes of tin, are the most neutron-rich among the heavier nuclei that can be produced at this time. Sn-130 and Sn-132 are so top-heavy with neutrons that they are quite unstable and must be made artificially in the lab. At GSI this is done by shooting a uranium beam at a beryllium target. The U-238 nuclei, agitated by the collision, eventually fission in flight, creating a swarm of more than 1,000 types of daughter nuclei, from which the desired tin isotopes can be extracted for study. The tin nuclei are excited when they pass through a secondary target, made of lead. The excited tin states later disintegrate; the debris coming out allows the researchers to reconstruct the turbulent nature of the tin nuclei. The dipole resonance was seen, as expected, but also a new resonance: an excess of neutrons pushing off from the core nucleus. Furthermore, the neutron resonance appears at a lower excitation energy than does the dipole resonance. Team leader Hans Emling says that there was some previous evidence for the existence for the neutron mode in work with lighter nuclei, but not the actual oscillation observed in the present work. (Adrich et al., *Phys. Rev. Lett*. 95, 132501, 2005)

GUIDED SLOW LIGHT



Guided, slow light in an ultracold medium has been demonstrated by Mukund Vengalattore and Mara Prentiss at Harvard.

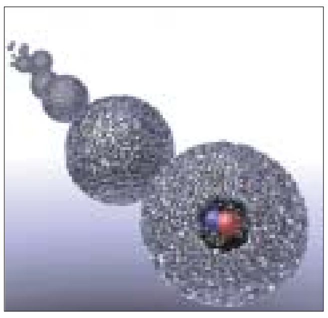
Slowing light pulses in a sample of atoms had been accomplished before by sending light pulses into a highly dispersive medium–that is, a medium in which the index of refraction varies greatly with frequency. Previously, this dispersive quality had come about by tailoring the internal states of the atoms in the medium. In the present Harvard experiment, by contrast, the dispersive qualities come about by tailoring the external qualities of the atoms, namely their motion inside an elongated magnetic trap.

In the lab setup, two pump laser beams can be aimed at the atoms in the trap; depending on the frequency and direction of the pump light, the atomic cloud (at a temperature of about 10 micro-Kelvin) can be made more or less dispersive in a process called recoil-induced resonance, or RIR. If now a separate probe laser beam is sent along the atom trap central axis, it can be slowed by varying degrees by adjusting the pump laser beam. Furthermore, the probe beam can be amplified or attenuated depending on the degree of dispersiveness in the atoms. This process can be used as a switch for light or as a waveguide.

According to Mukund (now working at UC Berkeley), slowing light with the recoil-induced resonance approach may be a great thing for nonlinear-optics research. Normally, nonlinear effects come into play only when the light intensities are quite high. But in the RIR approach, nonlinear effects arise more from the strong interaction of the two laser beams (pump and probe) and the fact that the slow light spends more time in the nonlinear medium (the trap full of atoms).

All of these effects are enhanced when the atoms are very cold. Moreover, because the slow light remains tightly focused over the length of the waveguide region, intensity remains high; it might be possible to study slowed single-photon light pulses, which could enhance the chances of making an all-optical transistor. The light in this setup has been slowed to speeds as low as 1500 m/sec but much slower speeds are expected when the atoms are chilled further. (Vengalattore and Prentiss, *Phys. Rev. Lett*. 95, 243601, 2005)

QUANTUM SOLVENT



Scientists at the Ruhr-Universität Bochum in Germany have performed high-precision, ultracold chemical studies of nitrogen oxide (NO) molecules by inserting them into droplets of liquid helium.

NO, *Science* magazine's "molecule of the year" for 1992, is important because of its role in atmospheric chemistry and in signal transduction in biology. A radical is a molecular entity (sometimes charged and sometimes neutral) which enters into chemical reactions as a unit. To sharpen our understanding of this important molecule and its reactions, it would be desirable to cool it down, the better to observe its complex spectra of quantum levels corresponding to various vibrational and rotational states.

In the new experiment, liquid helium is shot from a cold nozzle into vacuum. The resultant balls, each containing about 3,000 atoms, are allowed to fall into a pipe where NO molecules are lurking. The NO is totally enveloped and, within its superfluid-helium cocoon at a temperature of about 0.4 Kelvin, it spins freely. The helium acts provides a cold environment but does not interact chemically with the NO molecules. Because of this a high-resolution infrared spectrum of NO in fluids could be recorded for the first time.

NO has been observed before in the gas phase, but never before has such a high resolution spectrum be seen in the helium environment. (Haeften et al., *Phys. Rev. Lett*. 95, 215301, 2005)

MEASURING HIGHER-LEVEL QED

A new experiment at Livermore National Lab has made the best measurement yet of a complicated correction to the simplest quantum description of how atoms behave. Livermore researchers did this by measuring the Lamb shift, a subtle shifting of quantum energy levels, including a first measurement of "two-loop" contributions, in a plasma of highly charged uranium ions.

For hydrogen atoms, containing but a single electron and a proton for a nucleus, the Lamb shift can be measured to an accuracy of a few parts in a million, and theoretical and experimental values agree very well. One would like also to measure the Lamb shift (and hence test basic QED precepts) for other elements. One would like also to measure separately the contribution of higher-order contributions to the Lamb shift.

In hydrogen, two-loop and other higher contributions play a very small role in the Lamb shift. Furthermore, uncertainty in the size of the proton limits any effort to measure two-loop effects. This is not true for a uranium atom in which nearly all the electrons have been stripped away. With a much larger nucleus, the proton-size issue is much reduced, and the electric fields holding electrons inside the atom are a million times stronger (10^{17} volts per meter) than in hydrogen. Thus, QED can be tested under extreme conditions.

The Livermore physicists study uranium atoms that have been stripped of all but three electrons. These lithium-like uranium ions, held in a trap, are then carefully observed to search for the Lamb discrepancy from simple quantum predictions as to the frequencies of light emitted by the excited ions. In hydrogen atoms, the two-loop corrections constitute only a few parts per million, but in uranium atoms they contribute about one third of one percent of the Lamb shift. In this way, the Livermore team has measured this higher-level QED term for the first time, with an accuracy of about 10 percent. (Beiersdorfer et al., *Phys. Rev. Lett*. 95, 233003, 2005)

A TERA-ELECTRONVOLT GAMMA RAY ORIGINATING IN THE MILKY WAY

The most energetic parcels of electromagnetic radiation–Tera-electronvolt gamma rays–ever determined to have originated in the plane of our home galaxy were observed recently by the Milagro detector, located at high mountain elevations in New Mexico. The potent photons are believed to have been part of the debris spawned when even more energetic cosmic rays struck the matter-dense heart of the Milky Way.

Photons in the TeV range arrive at the Earth very rarely, not often enough to permit observation from a space-based gamma telescope. Therefore, terrestrial gamma observations are usually carried out by large-area-arrays attached to the ground.

Milagro, operated by scientists from nine institutions, records the arrival of energetic photons at Earth by observing the air shower of secondary particles generated when the gamma rays hit the atmosphere. These particles betray their presence by the light (Cerenkov radiation) emitted when the particles pass through a 6-million-gallon pond instrumented with photodetectors. This method of observation offers a rough ability to determine the direction of arrival.

For the Milagro experiment so far, 70,000 TeV photon events from within a region of the Milky Way plane were culled from an inventory of about 240 million TeV-level events seen so far seen from the same region. These numbers, says team member Roman Fleysher of New York University, are consistent with theoretical estimates for cosmic ray production.

And where do the cosmic rays get their 100-TeV-and-more energies? Ions in the interstellar medium, perhaps near a collapsed star or an active galactic nucleus (AGN), can get caught up by shock waves and accelerated to high energies. (Atkins et al., *Phys. Rev. Lett*. 95, 251103, 2005)