Physics News in 2007

A Supplement to *APS News*

Edited by Phil Schewe, Ben Stein and Jason Bardi

Introduction

Physics News in 2007, 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, Ben Stein and Jason Bardi. (Ben Stein has since left AIP and is now at NIST. Jason Bardi has replaced Ben Stein at AIP)

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/pnu and APS's *Physical Review Focus* website at http://focus.aps.org/.

Gravitational Wave Background

In the standard model of cosmology, the early universe underwent a period of fantastic growth. This inflationary phase, after only a trillionth of a second, concluded with a violent conversion of energy into hot matter and radiation. This "reheating" process also resulted in a flood of gravitational waves.

The gravitational wave background (GWB) dates from the trillionth-of-a-second mark, while the cosmic microwave background (CMB) sets in around 380,000 years later when the first atoms formed. What does the GWB represent? It stems from three different production processes at work in the inflationary era: waves stemming from the inflationary expansion of space itself; waves from the collision of bubble-like clumps of new matter at reheating after inflation; and waves from the turbulent fluid mixing of the early pools of matter and radiation, before equilibrium among them (known as thermalization) had been achieved. The gravity waves would never have been in equilibrium with the matter (since gravity is such a weak force there wouldn't be time to mingle adequately); consequently the GWB will not appear to a viewer now to be at a single overall temperature.

A new paper by Juan Garcia-Bellido and Daniel Figueroa (Universidad Autonoma de Madrid) explains how these separate processes could be detected and differentiated in modern detectors set up to see gravity waves, such as LIGO, LISA, or BBO (Big Bang Observer). First, the GWB would be redshifted, like the CMB. But because of the GWB's earlier provenance, the reshifting would be even more dramatic: the energy of the waves would be downshifted by 24 orders of magnitude. Second, the GWB waves would be distinct from gravity waves from point sources (such as the collision of two black holes) since such an encounter would release waves with a sharper spectral signal. By contrast the GWB from reheating after inflation would have a much broader spectrum, centered around 1 hertz to 1 gigahertz depending on the scale of inflation.

Garcia-Bellido suggests that if a detector like the proposed BBO could disentangle the separate signals of the end-of-inflation GWB, then such a signal could be used as a probe of inflation and could help explore some fundamental issues as matter-antimatter asymmetry, the production of topological defects like cosmic strings, primoridal magnetic fields, and possibly superheavy dark matter.

For comparable results see the paper by Easther and Lim in the *Journal of Astroparticle Physics,* JCAP04(2006)010. (García-Bellido and Figueroa, *Phys. Rev. Lett.* **98**, 061302 (2007))

The Casimir Effect Heats Up

For the first time, a group led by Nobel laureate Eric Cornell at the National Institute of Standards and Technology and the University of Colorado in Boulder has confirmed a 1955 prediction, by physicist Evgeny Lifschitz, that temperature affects the Casimir force, the attraction between two objects when they come to within 5 millionths of a meter of each other or less. These efforts heighten the understanding of the force and enable future experiments to better account for its effects.

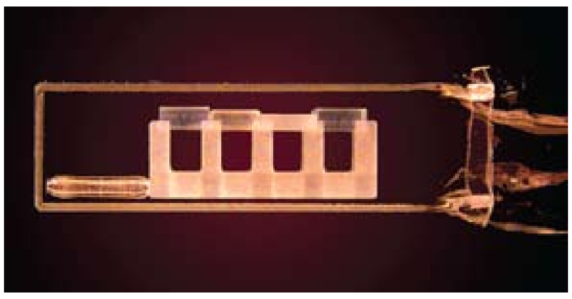


Photo by E. Cornell group/JILA

In their work, the researchers investigated the Casimir-Polder force, the attraction between a neutral atom and a nearby surface. The Colorado group sent ultracold rubidium atoms to within a few microns of a glass surface. Doubling the temperature of the glass to 600 degrees Kelvin while keeping the surroundings near room temperature caused the glass to increase its attractive force threefold, confirming theoretical predictions recently made by the group's co-authors in Trento, Italy.

The Casimir force arises from effects of the vacuum. According to quantum mechanics, the vacuum contains fleeting electromagnetic waves, in turn consisting of electric and magnetic fields. The electric fields can slightly rearrange the charge in atoms. Such "polarized" atoms can then feel a force from an electric field. The vacuum's electric fields are altered by the presence of the glass, creating a region of maximum electric field that attracts the atoms. In addition, heat inside the glass also drives the fleeting electromagnetic waves, some of which leak onto the surface as "evanescent waves." These evanescent waves have a maximum electric field on the surface and further attract the atoms.

Electromagnetic waves from heat in the rest of the environment would usually cancel out the thermal attraction from the glass surface. However, dialing up the temperature on the glass tilts the playing field in favor of glass's thermal force and heightens the attraction between the wall and the atoms. (Obrecht et al., *Phys. Rev. Lett.* **98**, 063201 (2007) Also see the NIST press release: http://www.nist.gov/public_affairs/newsfromnist_casimir-polder.htm)

Radium Atoms Trapped

Physicists at Argonne National Laboratory, near Chicago, have laser-cooled and trapped radium atoms for the first time.

Surprisingly, room temperature blackbody photons–thermal radiation over a wide spectrum emitted by the apparatus itself–were found to play a critical role in the laser-trapping of this rare and unstable element. This represents the heaviest atom ever trapped by laser light.

Using only 20 nanograms of radium-225 (halflife of 15 days) and one microgram of radium-226 (halflife of 1,600 years), the Argonne scientists held tens of radium-225 and hundreds of radium-226 atoms in the laser trap.

Why go through the trouble of trapping radium atoms? Because it might provide a chance to detect a violation of time-reversal symmetry (abbreviated with the letter T), which would manifest itself as an electric dipole moment in the radium atom.

Electric dipole moment searches have been ongoing for over 50 years and continue to yield smaller and smaller limits on the size of these T-violating interactions. These limits place constraints on theories beyond the Standard Model of particle physics and explanations for the matter-antimatter asymmetry in the universe.

Next-generation electric dipole moment searches may take advantage of rare isotopes such as radium-225, which are expected to be extremely sensitive to T-violation owing to their non-spherical "egg"-shaped nucleus. For the rare and unstable radium atoms, a laser trap offers a promising path to such a measurement. (Guest et al., *Phys. Rev. Lett.* **98**, 093001 (2007))

Slowed Light Handed Off

Several years ago, physicists gained the ability to slow a beam of light in a gas of atoms; by manipulating the atoms' spins, the energy and information contained in the light could be transferred to the atoms in a coherent way. By turning on additional laser beams, the original light signal could be reconstituted and sent on its way.

Now, one of the first researchers to slow light, Lene Hau of Harvard, has added an extra layer to this story. She and her colleagues halt and store a light signal in a Bose-Einstein condensate (BEC) of sodium atoms, then transfer the signal, now in the form of a coherent pulse of atom waves rather than light waves, into a second BEC of sodium atoms some 160 microns away, from which, finally, the signal is revived as a conventional light pulse.

This feat, the sharing around of quantum information in light-form and in not just one but two atom-forms, offers great encouragement to those who hope to develop quantum computers. (Ginsberg et al., *Nature* **445**, 623-626 (8 February 2007))

String Theory Explains RHIC Jet Suppression

String theory argues that all matter is composed of string-like shreds in a 10-dimensional hyperspace assembled in various forms. The theory has been put into play in the realm of high-energy ion collisions, the kind carried out at Brookhaven's Relativistic Heavy Ion Collider (RHIC). A few years ago string practitioners attempted to establish a relationship between the 10-dimensional string world and the 4-dimensional (3 spatial dimensions plus time) world in which we observe interactions among quark-filled particles like protons.

This duality between string theory and the theory of the strong nuclear force, quantum chromodynamics (QCD), was recently used to interpret puzzling early results from RHIC, namely the suppression of energetic quark jets that should have emerged from the fireball formed when two heavy nuclei collide head on. The thinking was that perhaps the plasma of quarks and gluons wasn't a gas of weakly interacting particles (as was originally thought) but a gas of strongly interacting particles, so strong that any energetic quarks that might have escaped the fireball (initiating a secondary avalanche, or jet of quarks) would quickly be slowed and stripped of energy on their way through the tumultuous quark-gluon plasma (QGP) environment.

Two new papers by Hong Liu and Krishna Rajagopal (MIT) and Urs Wiedemann (CERN) address this problem. The first paper calculates a specific quark-suppression parameter (namely, how much the quarks, each attached to a string dangling "downward" into a fifth dimension, are pushed around as they traverse the quark-gluon plasma) that agrees closely with the experimentally observed value.

Rajagopal says that in the second paper, the same authors make a specific testable prediction using string theory that bears not just on missing jets of energetic light quarks (up, down, and strange quarks), but on the melting or dissociation temperatures of bound states of heavy quarks (charm-anticharm or bottom-antibottom pairs) moving through the quark-gluon plasma with sufficiently high velocity, as will be produced in future experiments at RHIC and the Large Hadron Collider (LHC) under construction at CERN. (Liu, Rajagopal, and Wiedemann, *Phys. Rev. Lett.* **97**, 182301 (2006) and *Phys. Rev. Lett.* **98**, 182301 (2007))

The Woodstock of Physics

Woodstock press conference, from left to right: Alex Muller (IBM), Paul Chu (University of Houston), Philip Anderson (Princeton), and Brian Maple (UC San Diego)

The famous session at the 1987 March Meeting of the American Physical Society earned its nickname because of the rock-concert fervor inspired by the convergence of dozens of reports all bearing on copper-oxide superconductors. The 20th anniversary of this singular event was celebrated at the APS March Meeting in Denver.

Prior to 1987 the highest temperature at which superconductivity had been observed was around 23 K. And suddenly a whole new set of compounds–not metallic alloys but crystals whose structure put them within a class of minerals known as perovskites–with superconducting transition temperatures above 35 K, and eventually 100K–generated an explosion of interest among physicists. Because of the technological benefits possibly provided by high-temperature superconductivity (HTSC)–things like bulk power storage and magnetically levitated trains–the public was intrigued too.

The commemoration of the Woodstock moment provided an excellent history lesson on how adventurous science is conducted. Georg Bednorz (IBM-Zurich), who with Alex Mueller made the initial HTSC discovery, recounted a story of frustration and exhilaration, including working for years without seeing clear evidence for superconductivity; having to use borrowed equipment after hours; overcoming skepticism from IBM colleagues and others who greatly doubted that the cuprates could support supercurrents, much less at unprecedented temperatures; and finally arriving at the definitive result–superconductivity at 35 K in a La-Ba-Cu-O compound.

In October 1986 Bednorz and Mueller prepared a journal article confirming their initial finding in the form of observing the telltale expulsion of magnetism (the Meissner effect) from the material during the transition to superconductivity. A year later Bednorz and Mueller won the Nobel Prize.

The IBM finding was soon seconded by work in Japan and at the University of Houston, where Paul Chu, testing a Y-Ba-Cu-O compound, was the first to push superconductivity above the temperature of liquid nitrogen, 77 K. Very quickly a gold rush began, with dozens of condensed matter labs around the world dropping what they were doing in order to irradiate, heat, chill, squeeze, and magnetize the new material.

At the March APS Meeting Chu said that he and his colleagues went for months on three hours' sleep per night. Several other speakers at the 2007 session spoke of the excitement of those few months in 1987 when–according to such researchers as Marvin Cohen (UC Berkeley) and Douglas Scalapino (UC Santa Barbara)–the achievement of room-temperature superconductivity did not seem inconceivable.

The Woodstock event, featuring 50 speakers delivering their fresh results at a very crowded room at the New York Hilton Hotel until 3:15 am, was a culmination. In following years, HTSC progress continued on a number of fronts, but expectations gradually became more pragmatic. Paul Chu's Y-Ba-Cu-O compound, under high-pressure conditions, still holds the transition temperature record at 164 K. Making lab samples had been easy compared to making usable power-bearing wires in long spools, partly because of the brittle nature of the ceramic compounds and partly because of the tendency for potentially superconductivity-quenching magnetic vortices to form in the material.

Paul Grant, in 1987 a scientist at IBM-Almaden, pointed out that HTSC applications have largely not materialized. No companies are making a profit from selling HTSC products. Nevertheless, the mood of the 2007 session (Woodstock20) was upbeat. Bednorz said the 1986/87 work showed that a huge leap forward could still take place in a mature research field whose origins dated back some 70 years. Bednorz felt that another wave of innovation could occur. Paul Chu ventured to predict that within ten years, HTSC products would have an impact in the power industry.

Paul Grant referred to the study of superconductivity as the "cosmology of condensed matter physics," meaning that even after decades of scrutiny there was still much more to learn about these materials in which quantum effects, manifested over macroscopic distances, conspire to make electrical resistance vanish, a phenomenon which at some basic level might also be related to the behavior of protons inside an atomic nucleus and to the cores of distant neutron stars.

Hyperactive Antifreeze Proteins

Hyperactive antifreeze proteins naturally secreted by an insect known as the spruce budworm prevent it from freezing to death during winters in North American forests. Ohio University's Ido Braslavsky and his colleagues presented studies of these potent yet nontoxic proteins at the APS March Meeting.

Found in several other species such as snow fleas, the hyperactive proteins bind to ice, modify its crystalline shape, and prevent ice from growing further, effectively reducing the freezing point of ice for an organism that excretes them. These nontoxic substances have more recently been renamed "ice structuring proteins" (ISPs) to distinguish them from the toxic antifreeze products for automobiles.

Extracting ISPs from biological sources has many potential applications, such as preserving organs and blood products, protecting against agricultural frost damage, and even preventing frostbite. These natural proteins are currently used in some "light" ice cream products to improve their texture, but those ISPs, derived from fish, are much less potent.

How the hyperactive versions inhibit ice from growing is a topic of interest to Braslavsky's group and their collaborators, such as Peter Davies from Queen's University. The researchers attached fluorescent molecules, derived from jellyfish, to the protein.

Through a microscope, they watched how the fluorescing ISPs inhibited ice crystals from growing. They observed that the ISPs prevent ice crystals from expanding in their normal disk-shaped form. Instead, they inhibit ice growth in certain directions and cause the crystals to grow in altered shapes.

While a fish ISP promotes the growth of a "bipyramidal" ice-crystal form that looks like two pyramids whose bases are attached to each other, the spruce budworm ISP blocks growth in the preferred direction of the pyramid's apexes. Using the fluorescence microscopy, they watched the proteins attached to the ice blocking growth in this direction. (Meeting Paper J35.8, http://meetings.aps.org/Meeting/MAR07/Event/58982; for more information, see http://www.phy.ohiou.edu/~braslavs/APS2007/)

Quantized Magnetoresistance

The conversion of a tiny magnetic flux into a change in the resistance of an external circuit, a process called magnetoresistance, is at the heart of the $60-billion magnetic hard-disk-drive industry. Digital data, stored on the disk in the form of minuscule domains only 50 by 200 nm in size, representing a 1 or a 0, are read out by a sensor flying only 10 nm overhead.

The first unambiguous observation of a digital version of the magnetoresistance effect–the change in the resistance recorded by the sensor changes in discrete steps as the magnetization orientation relative to the sensor is changed–was reported by physicists from the University of Nebraska and the Institut de Physique et de Chimie des Materiaux de Strasbourg (France).

The quantization of conductance on the sensor side was achieved by having the current flow through a constriction that tapers down to the size of a single atom, a passage which imposes quantum conditions. According to Nebraska scientist Andrei Sokolov, an atom-sized point contact makes the read-write process ever more compact in physical extent, allowing much greater data storage. (Sokolov et al., *Nature Nanotechnology* **2**, 171-175 (2007))

The Ever-Shifting Face of Plutonium

A new theory explains some of the unusual properties of plutonium, the radioactive metal best known for its proclivity to undergo nuclear fission chain reactions, making it a potent fuel for nuclear weapons and power plants. Plutonium is one of the most unusual metals–it's not magnetic and it does not conduct electricity well. The material also changes its size dramatically with even the slightest changes in its temperature and pressure. The atom's unusual set of properties distinguishes it from even its closest neighbors on the periodic table, such as americium.

What makes plutonium unique? In the new theory, developed by condensed-matter theorists at Rutgers University in New Jersey, plutonium's eight outermost or "valence" electrons can circulate among different orbitals, or regions around the atom. In plutonium's 5f orbital, the one with the greatest influence on its atomic properties, the number of valence electrons it contains is most often five (approximately 80% of the time), but can also be six (about 20% of the time) or four (less than 1% of the time), according to the theory. These electrons shuttle in and out of the 5f orbital very quickly–on the order of femtoseconds, or quadrillionths of a second, the researchers say.

Plutonium is an example of a strongly correlated material, in which the valence electrons interact with each other to a great degree, and cannot be treated as independent agents. Taking these interactions into account, the researchers combined two theoretical approaches to solid materials, called the local density approximation and dynamical mean field theory, to come up with their sophisticated analysis.

As their analysis shows, the 5f orbital dictates many of plutonium's key properties, such as its lack of conductivity and magnetism. With their theory, the researchers have also explained the magnetic and electrical properties of americium and curium. They hope their approach will also elucidate the properties of rare-earth elements on the periodic table. (Shim et al., *Nature* **446**, 513-516 (29 March 2007))

Electron Tunneling in Atoms Has Now Been Observed in Real Time

Electron tunneling in atoms has now been observed in real time by a German-Austrian-Dutch team (Ferenc Krausz, Max Planck Institute of Quantum Optics, and Ludwig Maximilians, University of Munich) using light pulses lasting only several hundred attoseconds (billionths of a billionth of a second), providing new glimpses into an important ultrafast process in nature.

The tunneling process is responsible for the operation of certain electronic components, such as scanning tunneling microscopes, Esaki (tunneling) diodes, and quantum-cascade lasers. And in nuclear fission, alpha particles are believed to escape the fracturing nucleus through tunneling. Yet the tunneling process occurs so quickly, on the scale of attoseconds, that it has not been possible to observe directly. With the recent ability to create attosecond-scale light pulses–pioneered by Krausz and others–this is now possible.

In the new experiment, a gas of neon atoms is exposed to two light pulses. One is an intense pulse containing low-energy red photons. The second pulse is an attosecond-length pulse of ultraviolet light. This ultraviolet attosecond pulse delivers photons so energetic that they can rip off an electron and promote a second one to the periphery of the atom, into an excited quantum state.

Then, the intense red pulse, consisting of just a few wave cycles, has a chance to liberate the outlying electron via light-field-induced tunneling. Indeed, the researchers saw this phenomenon, predicted theoretically forty years ago but only verified now for the first time experimentally in a direct time-resolved study. As each wave crest in the few-cycle red pulse coursed through the atoms, the electrons each time upped their probability of escaping through tunneling until it reached about 100%.

The data indicate that, in this particular system, the electrons escape via tunneling in three discrete steps, synchronized with the three most intense wave crests at the center of the few-cycle laser wave. Each step lasts less than 400 attoseconds. (Uiberacker et al, *Nature* **446**, 627-632 (5 April 2007))

Laser Cooling of Coin-sized Objects

Laser cooling of coin-sized objects down to one-kelvin temperatures is now possible. In a set of experiments performed last year, a variation on the laser-cooling technique used in chilling vapors of gases down to sub-kelvin temperatures had been used in macroscopic (but still tiny) samples in the nano-and micro-gram range.

Now, a collaboration of scientists from the LIGO Laboratory at MIT and Caltech and from the Max Planck Institutes in Potsdam and Hanover has used laser beams to cool a coin-sized mirror with a mass of 1 gram down to a temperature of 0.8 K. The goal of chilling such a comparatively large object (with more than 10^{20} atoms) is to investigate the quantum properties of large ensembles of matter.

An important caveat here is the fact that in all these experiments the "cooling" takes place in one dimension only. A temperature of 1 K applies to the motion of atoms along the direction of the laser beams, while the mirror is free to move (although not much) in other directions. Beyond the record low temperature achieved for an object as large as 1 gram, another interesting feature of the experiment pertains to the strength of the force exerted by the laser beams. In the chosen dimension, the beams fix the mirror so steadfastly that it's as if it were being held in place by a spring that's stiffer than a diamond with the same dimensions as the laser beam (long and thin). According to MIT researcher Nergis Mavalvala the sample is held by a rigidity (if the laser beam were solid) characterized by a Young's modulus (the parameter specifying stiffness) of 1.2 tera-pascals, some 20% stiffer than diamond. (Corbitt et al., *Phys. Rev. Lett.* **98**, 150802 (2007))

Newton's Second Law of Motion

Newton's second law of motion has now been tested and found to be valid at the level of 5 x 10^{-14} m/sec^2. This is a thousandfold improvement in precision over the best previous test, one carried out 21 years ago (*Physical Review D*, **34**, 3240, (1986)). The new test was performed by physicists at the University of Washington using a swiveling torsion pendulum.

One implication of Newton's law is that the pendulum's frequency should be independent of the amplitude of its swiveling (as long as the oscillation is small). Looking for a slight departure from this expected independence, the Washington researchers watched the pendulum at very small amplitudes; in fact the observed swivel was kept so small that the Brownian excitation of the pendulum was a considerable factor in interpreting the results.

Newton's second law is expected to break down for subatomic size scales, where quantum uncertainty frustrates any precise definition of velocity. But for this experiment, where the pendulum has a mass of 70 g and consists of 10^{24} atoms, quantum considerations were not important. According to one of the scientists involved, Jens Gundlach, this new affirmation that force is proportional to acceleration (at least for non-relativistic speeds), might influence further discussion of two anomalies:

(1) oddities in the rotation curves for galaxies–characterizing the velocity of stars as a function of their radii from the galactic center–suggest either that extra gravitational pull in the form of the presence of as-yet-undetected dark matter is at work or that some new form of Newton's second law could be operating (referred to as Modified Newtonian Dynamics, or MOND); and (2) the ongoing mystery surrounding the unaccounted-for accelerations apparently characterizing the trajectory of the Pioneer spacecraft (see http://www.aip.org/pnu/1998/split/pnu391-1.htm). (Gundlach et al., *Phys. Rev. Lett.* **98**, 150801 (2007))

Gravity Probe B

Gravity Probe B, the orbiting observatory devoted to testing the general theory of relativity, has measured the geodetic effect–the warping of spacetime in the vicinity of and caused by Earth–with a precision of 1%. The basic approach to studying this subtle effect is to monitor the precession of gyroscopes onboard the craft in a polar orbit around Earth. The observed precession rate, 6.6 arc-seconds per year, is close to that predicted by general relativity. Once certain unanticipated torques on the gyroscopes are better understood, GP-B scientists expect the precision of their geodetic measurement to improve to a level of 0.01%. These first GP-B results were reported at the APS April Meeting by Francis Everitt (Stanford).

A second major goal of GP-B is to measure frame dragging, a phenomenon which arises from the fact that space is, in the context of general relativity, a viscous fluid rather than the rigid scaffolding Isaac Newton took it to be. When Earth rotates, it partly takes spacetime around with it, and this imposes an additional torque on the gyroscopes.

Thus an extra precession, perpendicular to and 170 times weaker than the geodetic effect, should be observed. Everitt said that GP-B saw "glimpses" of frame dragging in this early analysis of the data and expects to report an actual detection with a precision at the 1% level by the time of the final presentation of the data.

Some of the GP-B equipment is unprecedented. The onboard telescope used to orient the gyroscopes (by sighting toward a specific star) provided a star-tracking ability better by a factor of 1000 than previous telescopes. The gyroscopes themselves–four of them for redundancy–are the most nearly spherical things ever made: the ping-pong-ball-sized objects are out of round by no more than 10 nm. They are electrostatically held in a small case and spun up to speeds of 4000 rpm by puffs of gas. The gas is then removed, creating a vacuum of 10^{-12} torr. Covered with niobium and reposing at a temperature of a few kelvin, the balls are rotating superconductors, and as such they develop a tiny magnetic signature which can be read out to fix the sphere's instantaneous orientation. (For more information see einstein.stanford.edu)

One Neutrino Anomaly Has Been Resolved

One neutrino anomaly has been resolved while another has sprung up. A Fermilab experiment called MiniBooNE provides staunch new evidence for the idea that only three low-mass neutrino species exist. These results, reported at a Fermilab lecture and at the APS April Meeting in Jacksonville, Florida, seem to rule out two-way neutrino oscillations involving a hypothetical fourth type of low-mass neutrino.

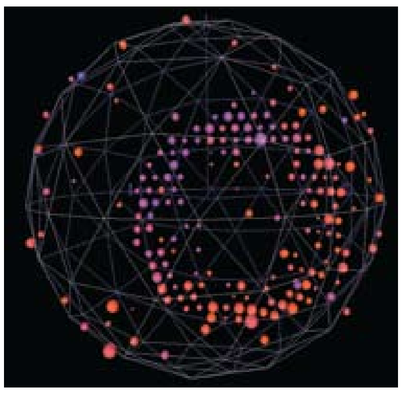


Photo by Fermilab

A neutrino signal observed by the MiniBooNE experiment.

Several experiments have previously shown that neutrinos, very light or even massless particles that only interact via gravity and the weak nuclear force, lead a schizoid life, regularly transforming from one species into another. These neutrino oscillations were presumably taking place among the three known types recognized by the standard model of particle physics: electron neutrinos, muon neutrinos, and tau neutrinos.

However, one experiment, the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos, provided a level of oscillation that implied the existence of a fourth neutrino species, a "sterile neutrino," so-called because it would interact only through gravity, the weakest of physical forces.

From the start, this result stood apart from other investigations, especially since it suggested possible neutrino masses very different from those inferred from the study of solar or atomospheric neutrinos or from other accelerator-based neutrino experiments. MiniBooNE set out to resolve the mystery.

The experiment proceeds as follows: protons from Fermilab's booster accelerator are smashed into a fixed target, creating a swarm of mesons which very quickly decay into secondary particles, among them a lot of muon neutrinos. Five hundred meters away is the MiniBooNE detector. Although muon neutrinos might well oscillate into electron neutrinos, over the short run from the fixed target to the detector one would expect very few oscillations to have occurred.

The Fermilab detector, and the LSND detector before it, looked for electron neutrinos. Seeking to address directly the LSND oscillation effect, Fermilab tried to approximate the same ratio of source-detector distance to neutrino energy. This ratio sets the amount of likely oscillation.

LSND saw a small (but, they argued, statistically significant) number of electron neutrino events. MiniBooNE, after taking into account expected background events, sees none. Thus they see no oscillation and therefore no evidence for a fourth neutrino.

Actually it's not exactly true that they see no electron neutrinos. At low neutrino energy they do see events, and this tiny subset of the data remains a mystery, to be explored in further data-taking now underway using a beam of anti-neutrinos. At the APS meeting, MiniBooNE co-spokesperson Janet Conrad (Columbia) said that the low-energy data are robust (meaning that a shortage of statistical evidence or systematic problems with the apparatus should not be major factors) and that some new physical effect cannot be ruled out.

Tevatron's Higgs Quest Quickens

Physicists from Fermilab's Tevatron collider have reported their most comprehensive summary yet of physics at the highest laboratory energies. At the APS April Meeting in Jacksonville, Florida they delivered dozens of papers on a spectrum of topics, many of which are related in some way to the Higgs boson.

The Higgs is the cornerstone ingredient in the standard model of high energy physics. It is the particle manifestation of the curious mechanism that kicked in at an early moment in the life of the universe: the W and Z bosons (the carriers of the weak force) became endowed with mass while the photon (the carrier of the electromagnetic force) did not. This asymmetry makes the two forces very different in the way they operate in the universe.

Validating this grand hypothesis by actually making Higgs particles in the lab has always been a supreme reason for banging protons and antiprotons together with a combined energy of 2 TeV. However, the search for the Higgs is expected to be shadowed by the production of other rare scattering scenarios, some of them nearly as interesting as the Higgs itself.

According to Jacobo Konigsberg (University of Florida), co-spokesperson for the CDF collaboration (one of the two big detector groups operating at the Tevatron), the search for the Higgs is speeding up owing to a number of factors, including the achievement of more intense beams and increasingly sophisticated algorithms for discriminating between meaningful and mundane events.

Here is a catalog of some of the recent results from the Tevatron. Kevin Lannon (Ohio State) reported a new best figure (170.9 GeV, with an uncertainty of 1%) for the mass of the top quark. Lannon also described the class of event in which a proton-antiproton smashup resulted in the production of a single top quark via a weak-force interaction, a much rarer event topology than the one in which a top-antitop pair is made via the strong force.

Moreover, observing these single-top events allows a first rudimentary measurement of Vtb, a parameter proportional to the likelihood of a top quark decaying into a bottom quark. Gerald Blazey (Northern Illinois), former co-spokesperson of the D0 collaboration, reported on the first observations of equally exotic collision scenarios, those that feature the simultaneous production of an observed W and Z boson, and those in which two Z bosons are observed.

Furthermore, he said that when the new top mass is combined with the new mass for the W boson, 80.4 GeV, one calculates a new likely upper limit on the mass of the Higgs. This value, 144 GeV, is a bit lower than before, making it just that much easier to create energetically. Ulrich Heintz (Boston University) reported on the search for exotic particles not prescribed by the standard model.

Again, no major new particles were found, but further experience in handling myriad background phenomena will help prepare the way for what Tevatron scientists hope will be their main accomplishment: digging evidence for the Higgs out from a rich seam of other particles.

The Efimov Effect: Three's Company, Two's a Crowd

At the APS April Meeting in Jacksonville, physicists discussed the recent observations of the Efimov effect, a purely quantum phenomenon whereby two particles such as neutral atoms which ordinarily do not interact strongly with one another join together with a third atom under the right conditions. The trio can then form an infinite number of configurations, or put another way, an infinite number of "bound states" that hold the atoms together.

The effect was first predicted around 1970 by Vitaly Efimov, then a PhD candidate, but was originally considered "too strange to be true," according to the University of Colorado's Chris Greene, in part because the atoms would abruptly switch from being standoffish to becoming stuck-together Siamese Triplets at remarkably long distances from one another (approximately 500-10,000 times the size of a hydrogen atom in the case of neutral atoms). For decades, experimenters tried in vain to create these three-particle systems (which came to be known as "Efimov trimers").

In 1999, Greene and his collaborators Brett Esry and Jim Burke predicted that gases of ultracold atoms might provide the right conditions for creating the three-particle state. In 2005, a research team led by Rudi Grimm of the University of Innsbruck in Austria finally confirmed the Efimov state in an ultracold gas of cesium cooled to just 10 nanokelvin.

How do the neutral atoms attract one another in the first place? At small distances, ordinary chemical bonding mechanisms apply, but at the vast distances relevant to the Efimov effect, it is mainly through the van der Waals effect, in which rearrangements of electrical charge in one atom (forming an "electric dipole") create electric fields that can induce dipoles in, and thereby attract, neighboring atoms.

The observation of the Efimov effect is a coup in the study of the rich quantum physics between three particles. The effect can conceivably occur in nucleons or molecules (and any object governed by quantum mechanics). However, it will likely be harder to observe in those systems because physicists cannot alter the strengths of interactions between the constituent particles as easily as they can in ultracold atom gases (through their "Feshbach resonances").

But the effect could provide insights on such systems as the triton, a nucleon with one proton and two neutrons, in addition to the BCS-BEC crossover, in which atoms switch from forming weakly bound Cooper pairs to entering a single collective quantum state. (See also article by Charles Day, *Physics Today*, April 2006, Esry *et al.*, *Phys. Rev. Lett.* **83, 1751-1754 (1999)**, and Kraemer et al., *Nature* **440**, 315-318 (16 March 2006).

The Shortest Light Pulse Ever

Researchers in Italy have created the shortest light pulse yet–a single isolated burst of extreme-ultraviolet light that lasts for only 130 attoseconds (billionths of a billionth of a second). Shining this ultrashort light pulse on atoms and molecules can reveal new details of their inner workings–providing benefits to fundamental science as well as potential industrial applications such as better controlling chemical reactions.

Working at Italy's National Laboratory for Ultrafast and Ultraintense Optical Science in Milan (as well as laboratories in Padua and Naples), the researchers believe that their current technique will allow them to create even shorter pulses well below 100 attoseconds. In previous experiments, longer pulses, in the higher hundreds of attoseconds, have been created.

The general process for this experiment is the same. An intense infrared laser strikes a jet of gas (usually argon or neon). The laser's powerful electric fields rock the electrons back and forth, causing them to release a train of attosecond pulses consisting of high-energy photons (extreme ultraviolet in this experiment).

Creating a single isolated attosecond pulse, rather than a train of them, is more complex. To do this, the researchers employ their previously developed technique for delivering intense short (5 femtosecond) laser pulses to an argon gas target. They use additional optical techniques (including the frequency comb that was a subject of the 2005 Nobel Prize in Physics) for creating and shaping a single attosecond pulse.

The results were presented (paper JThA5) at the Conference on Lasers and Electro-Optics and the Quantum Electronics and Laser Science Conference (CLEO/QELS); also see Sansone et al., *Science* **20** October 2006: Vol. 314. no. 5798, pp. 443 - 446.)

Ripping Fluids

A major difference between a solid and liquid is that if you move a knife through a solid, the cleft portions stay cleft, whereas in a liquid the two parts flow back together. Almost always, however, nature provides materials and processes that don't quite fit into such neat categories.

Joseph Gladden (University of Mississippi) and Andrew Belmonte (Penn State) have contrived an experiment in which a cylinder is dragged through a mixture of water, soap, and certain salts. At small drag speeds, the material–a viscoelastic gel-like substance which is a fluid at these temperatures–does indeed close back on itself, as a liquid normally does. At higher speeds, the cylinder creates more of a cleft and the material is slower to "heal" itself. At still higher velocities, the fluid acts like a solid, at least for a while; it is ripped into several parts, with separate surfaces, which take as long as a few hours to close up, and it exhibits various "cracks" emanating from the cylinder's wake.

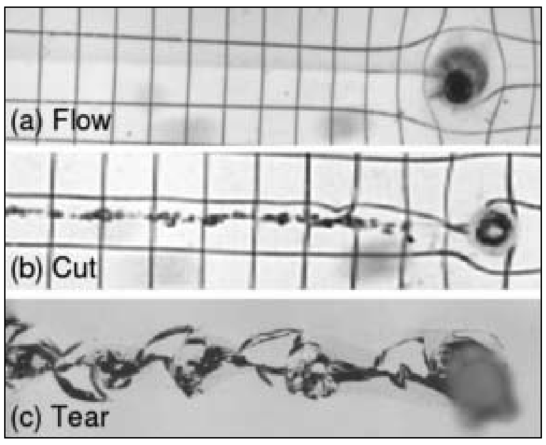


Image courtesy of AIP

Gladden says that the phase diagram (cylinder speed versus cylinder diameter) for the fluid displays three regions: flow, modest tearing, and outright ripping. Mapping out this phase diagram should help in understanding other phenomena involving viscoelastic materials, Gladden says. (*Phys. Rev. Lett.* **98**, 224501 (2007))

Nuclear Magnetic Resonance Imaging with 90-Nm Resolution

Nuclear magnetic resonance imaging with 90-Nm resolution has been achieved by John Mamin and his colleagues at the IBM Almaden lab in San Jose, California. The approach used, magnetic resonance force microscopy (MRFM), maps the location of matter at small scales by observing the resonant vibration of a spindly sliver of silicon (bearing the sample in question) when it is both exposed to radio-frequency waves and scanned over a tiny magnetic tip.

Previously this same group of physicists had used a similar setup to detect the magnetic resonance of a single unpaired electron in a sample. But now they are detecting the magnetic resonance of nuclei in the sample, a much more difficult thing since nuclear magnetism is much weaker than electron magnetism (in the case of hydrogen, some 660 times weaker). The advantage in focusing on nuclear magnetism is that the response of various biologically and technologically important atoms such as H, P, C-13 or F can be differentiated.

Nuclear spin MRFM has been performed before but only with micron-scale resolution. The new imaging, in effect, explores volumes as small as 650 zeptoliters, which is some 60,000 times better than the best conventional MRI can do. Improvements in the imaging process were facilitated by the use of lower temperatures (reducing the thermally driven motion in the cantilever) and the use of very sharp magnetic tips, which enhances the magnetic force due to the spins.

The magnetic field gradient in the vicinity of this tip is greater than a million tesla/meter. The test objects being imaged consisted of tiny islands of calcium fluoride evaporated onto the cantilever tip. Closely spaced islands, roughly 300 nm x 180 nm x 80 nm in size, could be clearly resolved. One of the researchers, Dan Rugar, says that the tiny sample volumes being interrogated hold about 10 million nuclear spins, and that the net nuclear polarization they are detecting adds up to about 3300 spins.

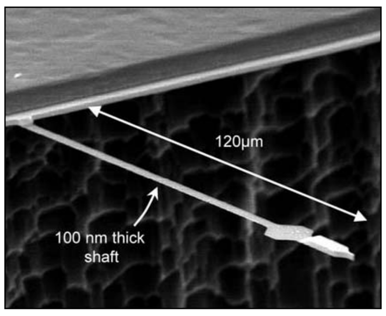


Image courtesy of AIP

He believes, however, that their current apparatus can now detect nuclear magnetism at the level of 200 spins. This would take them much closer to their ultimate goal of imaging molecules at the single nuclear spin level. Mamin et al., *Nature Nanotechnology* **2**, 301-306 (2007))

Warm the World, Shrink the Day

Global warming is expected to raise ocean levels and thereby effectively shift some ocean water from currently deep areas into shallower continental shelves, including a net transfer of water mass from the southern to the northern hemisphere. This in turn will bring just so much water closer to Earth's rotational axis, and this–like a figure skater speeding up as she folds her limbs inward–will shorten the diurnal period.

Not by much, though. According to Felix Landerer, Johann Jungclaus, and Jochem Marotzke, scientists at the Max Planck Institute for Meteorology in Hamburg, the day should shorten by 0.12 milliseconds over the next two centuries. (Landerer, Jungclaus, and Marotzke, *Geophys. Res. Lett.*, **34**, L06307 (2007))

Microfluidic Accelerator

Microfluidics is the science of carrying out fluid chemical processing on a chip whose channels are typically millimeters or microns across. In such a constricted space, viscosity becomes large, and the fluid flow can slow way down, thus limiting the kind of mixing or testing that can be done. Physicists at the University of Twente in the Netherlands, however, use tiny exploding bubbles to speed things up.

The bubbles are produced by shooting laser light into the fluid. (See movie at http://stilton.tnw.utwente.nl/people/ohl/controlled_cavitation.html) The light brings a tiny volume of fluid above its boiling temperature, causing a local bubble explosion, which accelerates the surrounding fluid along the channel, now at speeds of up to 20 m/sec, twenty times higher than would be the case without the bubble, and still another factor of 10 within reach. (The same researchers have produced sonoluminescence in the same way.)

An extra advantage of using flexibly positioned laser light is that for transparent microfluidic chips, fluid pumping can be accomplished without external connections to the chip. Besides being the first to apply such a cavitation technique for speeding up fluids on a chip, the Twente scientists are the first to achieve flow visualization at rates of a million frames per second at a size scale of 100 microns.

The leader of the Twente group, Claus-Dieter Ohl, says that he and his colleagues are currently using the bubble acceleration technique for improving mixing in various enzyme reactions and in producing tiny pores in membranes. (Zwaan et al., *Phys. Rev. Lett.* **98**, 254501 (2007))

Polonium Is the Only Element with Simple Cubic Crystal Structure

Polonium is the only element with a simple cubic crystal structure, and new theoretical work explains why that is. In a solid piece of polonium the atoms sit at the corners of a cubic unit cell and nowhere else.

One reason the study of Po is so difficult is that it is highly radioactive and spews forth decay products; indeed, polonium has more isotopes, 36, than any other element. Physicists at the Academy of Sciences in the Czech Republic have now produced the first detailed theoretical explanation for polonium's unique crystal structure: it is the result of the complicated interplay of relativistic effects which become important in such heavy atoms as polonium (element 84).

Specifically they have identified the so-called mass-velocity term (describing the relativistic increase in mass of electrons traveling with velocities comparable to the velocity of light) as the cause of the simple-cubic structure of polonium.

Another polonium oddity: its elastic anisotropy is greater than for any other solid. That is, it is about 10 times easier to deform a Po crystal along the direction diagonal to the consolidated cubic cells than it is to deform the crystal in a direction perpendicular to any of the cubic faces. According to Dominik Legut, this property results directly from the simple cubic structure of polonium.

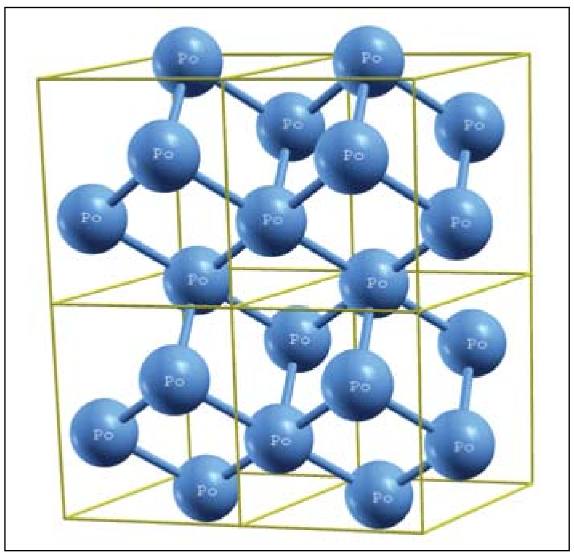


Image courtesy of AIP

Polonium is a hazardous element that appears in the air and soil and in such plants as tobacco, tea, and mushrooms. (Legut et al., *Phys. Rev. Lett*. **99**, 016402 (2007))

First Direct Measurement of DNA Stacking Forces

DNA is one of the most important and studied molecules around, and yet only now has a team of scientists, working at Duke University, succeeded in measuring the force between the nucleotides in a single-stranded DNA (ssDNA) molecule, using an atomic force microscope (AFM).

A double-stranded DNA is characterized by two principal forces–the stacking force between base units along the length of the double helix and the pairing force (Watson-Crick pairing) between the opposing base units forming the rungs of the helix. Measurements of DNA elasticity dating back to the 1990s (see http://www.aip.org/pnu/1997/split/pnu312-1.htm) were done with double-stranded DNA, and it is difficult to separate the effects of the pairing and stacking forces.

That's why Piotr E. Marszalek and his colleagues (Changhong Ke, Michael Humeniuk, and Hanna S-Gracz) turned to ssDNA. They rigged an artificial ssDNA consisting only of adenine base units attached to a gold substrate, and then pulled it with an AFM tip.

With a force resolution of about 1 pico-Newton, the Duke apparatus detected one plateau in elasticity (of the stacking force) at around 23 pN, which was expected, and then a second plateau around 113 pN. (Ke et al., *Phys. Rev. Lett*. **99**, 018302 (2007) a paper measuring forces for a single RNA molecule, finding a single force plateau at 20 pN, appeared in Seol et al., *Phys. Rev. Lett.* **98**, 158103 (2007))

Time and Time Again

The physics world accepts the idea of spacetime, a combined metrical entity which puts time on the same footing as the visible three spatial dimensions. Further spatial dimensions are added in some theories to help assimilate all physical forces into a unified model of reality. But what about adding an extra dimension of time too? Itzak Bars and Yueh-Cheng Kuo of the University of Southern California do exactly that, and add an extra spatial dimension too.

The addition of an extra time and an extra space dimension, together with a requirement that all motion in the enlarged space be symmetric under an interchange of position and momentum at any instant, reproduces all possible dynamics in ordinary spacetime, and brings to light many relationships and hidden symmetries that are actually present in our own universe.

The hidden relationships among dynamical systems are akin to relationships that exist between the multiple shadows of a 3D object projected on a 2D wall. In this case the object is in a spacetime of 4 space and 2 time dimensions while the shadows are in 3 space and 1 time dimensions. The motion in 4+2 dimensions is actually much more symmetric and simpler than the complex motions of the shadows in 3+1 dimensions.

In addition, Bars says that his theory explains CP conservation in the strong interactions described by QCD without the need for a new particle, the axion, which has not been found in experiments.

It also explains the fact that the elliptical orbit of planets remains fixed (not counting well-known tiny precessions). This "Runge-Lenz" symmetry effect has remained somewhat mysterious in the study of celestial mechanics, but now could be understood as being due to the symmetry of rotations into the fourth space dimension.

A similar symmetry observed in the spectrum of hydrogen would also be accounted for in 2-time physics, and again explained as a symmetry of rotations into the extra space and time dimensions. There are many such examples of hidden symmetries in the macroscopic classical world as well as in the microscopic quantum world, Bars argues, which can be addressed for the first time with the new 2T formulation of physics.

There have been previous attempts to formulate theories with a second time axis, but Bars says that most of these efforts have been compromised by problems with unitarity (the need for the sum of all probabilities of occurrences to be no greater than 1) and causality (maintaining the thermodynamic arrow of time).

The USC theorists have reformulated their model to fit into the ongoing supersymmetry version of the standard model and expect their ideas to be tested in computer simulations and in experiments yet to come. (Bars and Kuo, *Phys. Rev. Lett.* **99**, 041801 (2007))

All-Optical Magnetic Recording

All-optical magnetic recording has been demonstrated by scientists at the Radboud University Nijmegen in the Netherlands. Instead of using the customary magnetic read head to flip the magnetic orientation of a tiny domain, they use the fields present in a short burst of circularly polarized light.

Why use light instead of a magnet? Because the magnet is relatively slow and because the magnetic field in the light pulse is intrinsically strong–up to 5 Tesla. The pulses are perpendicularly incident on the storage medium and the helicity of the light pulse establishes whether the orientation set in the domain will be up or down, or digital terms, a 1 or a 0.

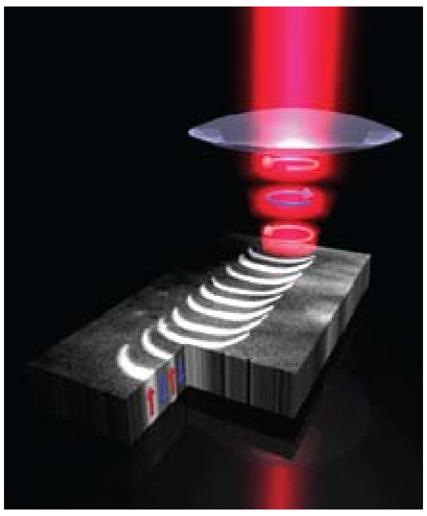


Image courtesy of AIP

Orienting the domain (writing a bit) is accomplished partly through the light's magnetism and partly through the localized heating by the pulse, which enhances the domain's magnetic susceptibility. The bit can be reversed with light of the opposite polarization.

The light pulse is so carefully focused that it addresses only one domain at a time. The speed of the writing process is set by the duration of the laser pulse, 40 fsec, upsetting certain suggestions, made not so many years ago, that the speed of recording in optical medium could not shrink below a picosecond.

True, the size of the domain is 5 microns, which is rather large. However, one of the researchers, Daniel Stanciu, says he expects the domain size to get down to about 100 nm. He believes that the all-optical approach will eventually be the way of achieving the fastest writing of data in a magnetic medium. (Stanciu et al., *Phys. Rev. Lett*. **99**, 047601 (2007))

Hydrogen-Seven

An experiment at the GANIL facility in France is the first to make, observe, identify, and characterize the heaviest isotope yet of hydrogen, H-7, consisting of a lone proton and 6 neutrons. (An earlier experiment saw some inconclusive evidence for this state–see Korsheninnikov et al., *Phys. Rev. Lett*. **90**, 082501 (2003).)

All of the lighter isotopes of hydrogen have previously been seen: H-1 (ordinary hydrogen), H-2 (deuterium), H-3 (tritium), and H-4 up to H-6. Technically speaking, the H-7 state (like H-4, H-5, and H-6) is not a fully bound nucleus. It is considered a resonance since (besides being very short-lived) energy is required to force the extra neutron to adhere to the other nucleons.

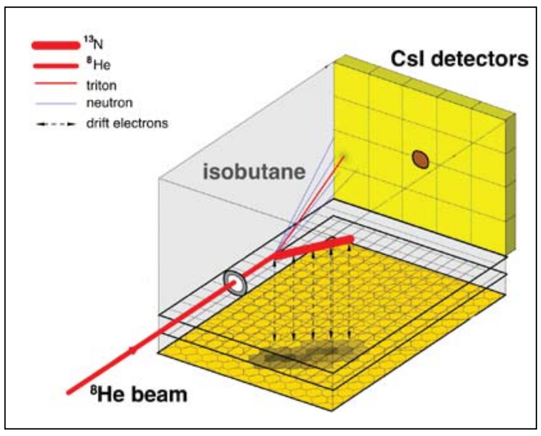


Image courtesy of AIP

In a proper nucleus energy is required to remove a neutron. In the GANIL experiment, a beam of helium-8 ions (themselves quite rare) is smashed into a carbon-12 nucleus residing in a gas of butane. In a few rare occurrences, the He-8 gives one of its protons to the C-12, producing H-7 and N-13, respectively. The H-7 flies apart almost immediately into H-3 and four separate neutrons.

Meanwhile the N-13 is observed in the active-target MAYA detector, a device much like a bubble chamber, allowing its energy and trajectory to be deduced.

By taking the conservation of momentum and energy into account, the fleeting existence of the H-7 is extracted from the N-13 data. A total of seven H-7 events was observed. A rough lifetime for H-7 of less than 10^{-21} seconds can be inferred. The helium-8 nucleus (2 protons plus 6 neutrons) used to make the H-7 is interesting all by itself since it is believed to consist of a nuclear core with two "halo" neutrons orbiting outside.

This radioactive species must carefully be gathered up from carbon-carbon collisions (in a separate step) and then accelerated. One of the GANIL researchers, Manuel Caamaño Fresco says that one of the chief reasons for looking at H-7 is to get a better handle on exotic nuclear matter.

The H-7 nucleus, during its brief existence, might consist of a H-3 core and plus two 2-neutron outriders, or maybe even a single 4-neutron blob outside. Larger still hydrogen isotopes, such as H-8 or H-9, might be observable. (Caamaño et al., *Phys. Rev. Lett.* **99**, 062502 (2007))

Observing Magnetic Polarization in Single Atoms

Physicists from UC Berkeley and the Naval Research Lab have measured the spin properties of individual atoms added to a metal surface. They do this by first forming nm-sized triangular islands of cobalt on top of a copper crystal. The cobalt is ferromagnetic, which means that the spins of the cobalt atoms in the islands all line up together (half of the islands have their collective spins pointing up, while the other half point down).

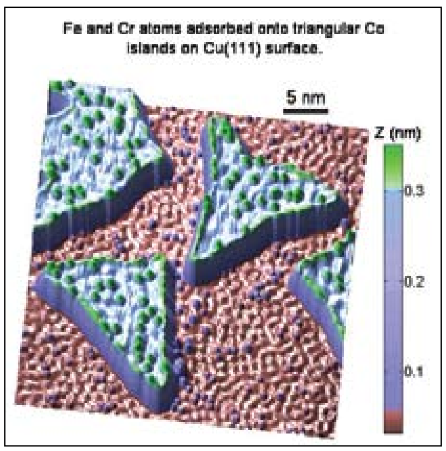


Image courtesy of AIP

Additional magnetic atoms sprinkled on top of the islands (adatoms) have spins that interact magnetically with the underlying cobalt, causing the adatom spins to either align or anti-align with the underlying island spins. Thus when a small number of iron atoms (chromium atoms were also used) are dropped onto the islands they immediately become oriented (polarized) by contact with a cobalt island.

In this way isolated atoms (up to 5 nm apart) were prepared with a definite spin polarization state. Next the quantum energy levels of the magnetic adatoms were studied using the tip of a scanning tunneling microscope (STM) which itself had been magnetized.

The quantum energy levels of the iron and chromium adatoms were sampled by observing currents flowing from the adatoms into the STM tip. Current measured in this way will be larger or smaller depending on whether the spin polarization of the tip is aligned with or against the polarization of the individual magnetic adatoms being probed. The adatom energy states are seen to differ for spin-up and spin-down states, indicating that iron and chromium atoms couple magnetically to cobalt with opposite polarity.

One of the researchers, Michael Crommie of UCB, says that it is still too early to try to store data in the form of individual polarized atoms. Rather they are seeking to understand how the spin of a single atom is influenced by its environment, with an eye toward future spintronics and quantum information applications. (Yayon et al., *Phys. Rev. Lett*. **99**, 067202 (2007))

Light-Driven Femtosecond Electricity

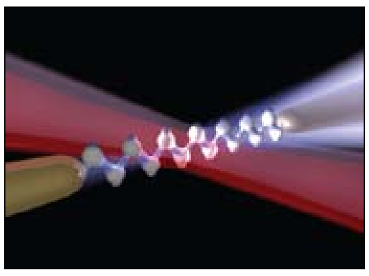


Image courtesy of AIP

Scientists in Canada foresee the use of electromagnetic fields of laser light for inducing and reversing tiny electrical currents along molecular wires without the use of a voltage applied across leads. They would accomplish this feat by shining special laser pulses containing light waves at two different frequencies onto a polyacetylene molecule which acts like a junction between two metallic leads on either side.

Depending on the exact frequencies used, the time duration of the pulse, and the relative phase relation between the two components of light, the induced pulse of electric flow could consist of either a single electron or many.

For the case of one electron set in motion by the 400-femtosecond pulse of laser light, the resulting electrical "current" would be about 0.4 microamps. Why use light rather than voltage to drive electricity? Because the whole thing can be done on a femtosecond scale with lasers.

Ignacio Franco says that a potential use of laser-driven electricity would be in future optoelectronic devices such as ultrafast nanoswitches. (Franco, Shapiro and Brumer, *Phys. Rev. Lett.* **99**, 126802 (2007))

Acoustic Quantum Dots

A new experiment at the Cavendish Lab at the University of Cambridge is the first to controllably shuttle electrons around a chip and observe their quantum properties. A quantum dot restricts electrons to a region of space in a semiconductor so tiny as to be essentially zero-dimensional. This in turn enforces a quantum regime; the electron may only have certain discrete energies, which can be useful, depending on the circumstances, for producing laser light or for use in detectors and maybe even future computers.

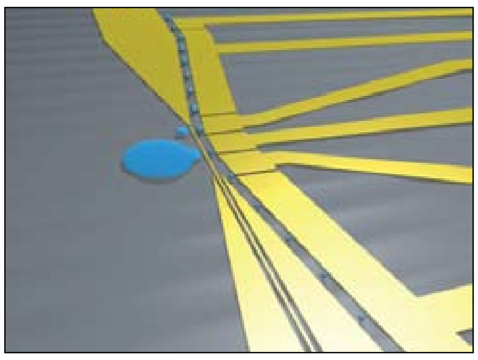


Image courtesy of AIP

A quantum dot is usually made not by carving the semiconductor into a tiny grain but rather by imposing restrictions on the electron's possible motions by the application of voltages to nearby electrodes. This would be a static quantum dot. It is also possible to make dynamic quantum dots–that is, moving dots that are created by the passage of surface acoustic waves (SAWs) moving through a narrow channel across the plane of a specially designed circuit chip. The acoustic wave itself is generated by applying microwaves to interleaved fingered electrodes atop a piezoelectric material like GaAs. The applied electric fields between finger-electrodes induce a sound wave to propagate along the surface of the material.

These acoustic waves have the ability to scoop electrons and chauffeur them along the surface.

The tiny region confining the electron even as it moves is in effect a quantum dot. Such acoustic-based dynamic quantum dots have made before, but according to Cambridge researcher Michael Astley, this is the first time the tunneling of the electrons (even single electrons) into and out of the quantum dots has been observed. This is an important part of the whole electron-shuttling process since one wants control over the electron motions and spins. If, moreover, electrons in two very close acoustic wave channels could be entangled, then this would present the chance to make a sort of flying qubit, which could be at the heart of a quantum computer. (Astley et al., *Phys. Rev. Lett*. **99**, 156802 (2007))

Thermal Logic Gates

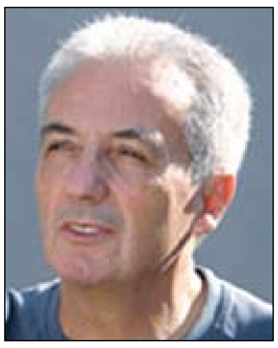
Information processing in the world's computers is mostly carried out in compact electronic devices, which use the flow of electrons both to carry and control information. There are, however, other potential information carriers, such as photons. Indeed a major industry, photonics, has developed around the sending of messages encoded in pulsed light.

Heat pulses, or phonons, rippling through a crystal might also become a major carrier, says Baowen Li of the National University of Singapore. Li, with his colleague Lei Wang, have now shown how circuitry could use heat–energy already present in abundance in electronic devices–to carry and process information.

They suggest that thermal transistors (also proposed by Li's group in Applied Physics Letters, 3 April 2006) could be combined into all the types of logic gates–such as OR, AND, NOT, etc.–used in conventional processors and that therefore a thermal computer, one that manipulates heat on the microscopic level, should be possible.

Given the fact that a solid state thermal rectifier has been demonstrated experimentally in nanotubes by a group at UC Berkeley (Chang et al., *Science*, 17 November 2006) only a few years after the theoretical proposal of "thermal diode," the heat analog of an electrical diode which would oblige heat to flow preferentially in one direction (Li et al, *Phys. Rev. Lett*. **93**, 184301 (2004)). Li is confident that thermal devices can be successfully realized in the foreseeable future. (Wang and Li, *Phys. Rev. Lett*. **99**, 177208 (2007))

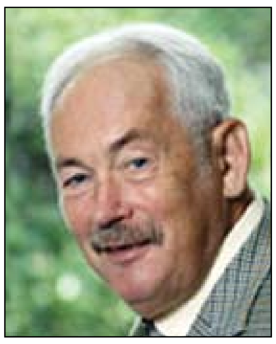
2007 Nobel Prize in Physics



Albert Fert

The 2007 Nobel Prize in Physics was awarded to Albert Fert (Université Paris-Sud, Orsay, France) and Peter Grünberg (Forschungszentrum Jülich, Germany) for the discovery of giant magnetoresistance, or GMR for short. GMR is the process whereby a magnetic field, such as that of an oriented domain on the surface of a computer hard drive can trigger a large change in electrical resistance, thus "reading" the data vested in the magnetic orientation.

This is the heart of modern hard drive technology and makes possible the immense hard-drive data storage industry. Fert and Grünberg pioneered the making of stacks consisting of alternating thin layers of magnetic and non-magnetic atoms needed to produce the GMR effect. GMR is a prominent example of how quantum effects (a large electrical response to a magnetic input) come about through confinement (the atomic layers being so thin); that is, atoms interact differently with each other when they are confined to a tiny volume or a thin plane.



Peter Grünberg

All these magnetic interactions involve the spin of an electron. Still more innovative technology can be expected through quantum effects depending on electrons' spin. Most of the electronics industry is based on manipulating the charges of electrons moving through circuits. But the electrons' spins might also be exploited to gain new control over data storage and processing. Spintronics is the general name for this budding branch of electronics. (Nobel Prize website: http://nobelprize.org/nobel_prizes/physics/laureates/2007/info.html)

Relativistic Thermodynamics

Einstein's special theory of relativity has formulas, called Lorentz transformations, that convert time or distance intervals from a resting frame of reference to a frame zooming by at nearly the speed of light. But how about temperature? That is, if a speeding observer, carrying her thermometer with her, tries to measure the temperature of a gas in a stationary bottle, what temperature will she measure? A new look at this contentious subject suggests that the temperature will be the same as that measured in the rest frame. In other words, moving bodies will not appear hotter or colder.

You'd think that such an issue would have been settled decades ago, but this is not the case. One problem is how to define or measure a gas temperature in the first place. James Clerk Maxwell in 1866 enunciated his famous formula predicting that the distribution of gas particle velocities would look like a Gaussian-shaped curve. But how would this curve appear to be for someone flying past? What would the equivalent average gas temperature be to this other observer? Jorn Dunkel and his colleagues at the Universitat Augsburg (Germany) and the Universidad de Sevilla (Spain) could not exactly make direct measurements (no one has figured out how to maintain a contained gas at relativistic speeds in a terrestrial lab), but they performed extensive simulations of the measurement.

Dunkel says that some astrophysical systems might eventually offer a chance to experimentally judge the issue. In general the effort to marry thermodynamics with special relativity is still at an early stage. It is not exactly known how several thermodynamic parameters change at high speeds. Absolute zero, Dunkel says, will always be absolute zero, even for quickly-moving observers. But producing proper Lorentz transformations for other quantities such as entropy will be trickier to do. (Cubero et al., *Phys. Rev. Lett*. **99**, 170601 (2007))

Nuclear Dripline Droops

Several new heavy isotopes have been discovered, at least one of which pushes beyond the neutron dripline. Driplines are the outer edges defining the zone of observed or expected bound nuclei on a map whose horizontal axis is the number of neutrons in a nucleus (denoted by the letter N) and whose vertical axis corresponds to the number of protons (Z). The nuclear force holding neutrons and protons together (even as the like-charged protons repel each other electrostatically) is so strong that no theory (not even the so called nuclear shell model, fashioned in analogy to the atomic model) can confidently predict whether a particular combination of neutrons and protons will form a bound nucleus. Instead experimenters must help theorists by going out and finding or making each nuclide in the lab.

In an experiment conducted recently at the National Superconducting Cyclotron Lab (NSCL) at Michigan State University, a beam of calcium ions was smashed into a tungsten target. A myriad of different nuclides emerged and streamed into a sensitive detector for identification. Two newly found nuclides–Mg-40 and Al-43–came as no surprise. But another, Al-42, was more unusual since it violated the provisional prohibition against nuclei of this size having an odd number of protons and neutrons.

The new nuclides are not stable, since they decay within a few milliseconds. But this is pretty long by nuclear standards. Why study such fleeting nuclei? Even though they might not exist naturally, the new nuclides still might play a role inside stars or novas where heavy elements, including those that make up our planet and our bodies, are created. Thomas Baumann suggests that even heavier aluminum-isotopes might exist, and that it is worth exploring any possible islands of stability, not just those at the very edge of the periodic table. (Baumann et al., *Nature* **449**, 1022-1024 (25 October 2007))

The Highest-Energy Cosmic Rays

The highest-energy cosmic rays probably come from the cores of active galactic nuclei (AGN), where supermassive black holes are thought to supply vast energy for flinging the rays across the cosmos. This is the conclusion reached by scientists who operate the Pierre Auger Observatory in Argentina. This gigantic array of detectors spread across 3000 sq. km of terrain, looks for one thing: cosmic ray showers.

These arise when extremely energetic particles strike our atmosphere, spawning a gush of secondary particles. Many of the rays come from inside our own Milky Way, especially from our sun, but many others come from far away. Of most interest are the highest-energy showers, with energies above 10^{19} electron volts, far higher than any particle energy that can be produced in terrestrial accelerators. The origin of such potent physical artifacts offers physicists a tool for studying the most violent events in the universe.

To arrive at Earth, most cosmic rays will have crossed a great deal of intergalactic space, where magnetic fields can deflect them from their starting trajectories. But for the highest-energy rays, the magnetic fields can't exert as much influence, and consequently the starting point for the cosmic rays can be traced with some confidence.

This allowed the Auger scientists to assert that the highest-energy cosmic rays were not coming uniformly from all directions but rather preferentially from galaxies with active cores, where the engine for particle acceleration was probably black holes of enormous size. The very largest of cosmic ray showers, those with an energy higher than 57 EeV (1EeV equals 10^{18} eV), correlated pretty well with known AGN's. (Auger collaboration, *Science* **9** November 2007: Vol. 318. no. 5852, pp. 938-943)

Cooper Pairs in Insulators

Cooper pairs are the extraordinary link-up of like-charged electrons through the subtle flexings of a crystal. They act as the backbone of the superconducting phenomenon, but have also now been observed in a material that is not only non-superconducting but actually an insulator. An experiment at Brown University measures electrical resistance in a Swiss-cheese-like plank of bismuth atoms made by spritzing a cloud of atoms onto a substrate with 27-nm-wide holes spaced 100 nm apart. Bismuth films made this way are superconducting if the sample is many atom-layers thick but is insulating if the film is only a few atoms thick, owing to subtle effects which arise from the restrictive geometry.

Cooper pairs are certainly present in the superconducting sample; they team up to form a non-resistive supercurrent. But how do the researchers know that pairs are present in the insulator too? By seeing what happens to resistance as an external magnetic field is increased.

The resistance should vary periodically, with a period proportional to the charge of the electrical objects in question. From the periodicity, proportional in this case to two times the charge of the electron, the Brown physicists could deduce that they were seeing doubly-charged objects moving through the sample. In other words, Cooper pairs are present in the insulator. This is true only at the lowest temperatures. One of the researchers, James Valles, says that there have been previous hints of Cooper pairs in some films related to superconductors, but that in those cases the evidence for pairs in the insulating state was ambiguous. He asserts that the realization of a boson insulator (in which the charge carriers are electron pairs) will help to further explore the odd kinship between insulators and superconductors. (Stewart et al., *Science* **23** November 2007: Vol. 318. no. 5854, pp. 1273-1275)

Persistent Flow or Bose-Condensed Atoms in a Toroidal Trap

A persistent flow of Bose-condensed atoms has been achieved for the first time, offering physicists a better chance to study the kinship between Bose-Einstein condensates (BEC) and superfluids. Both involve the establishment of an ensemble in which many atoms join together in a single quantum entity. But they're not quite the same thing. In a bath of liquid helium at low temperatures, for example, nearly 100% of the atoms are in a superfluid state but only about 10% are in a BEC state (in a BEC millions of atoms have become, in a sense, a single atom). But physicists generally believe that most or all of a BEC is superfluid. Scientists have been able to stir up quantized vortices in BEC samples, one indication that BECs are superfluid. But until now researchers had not been able to get BECs to move around a track in a persistent flow, another sign of superfluidity.

The new experiment, performed by Nobel laureate William Phillips and his colleagues at NIST-Gaithersburg, the Joint Quantum Institute of NIST and the University of Maryland, chilled sodium atoms in a toroidal trap, set them into motion with laser light, and observed a flow for as long as 10 seconds.

One of the scientists on the project, Kristian Helmerson, says that neutral atoms flowing in a toroidal vessel could be fashioned into the atom analog of a superconducting quantum interference device (SQUID), which is used as a sensitive detector of magnetism. This BEC device, sensing not magnetism but slight changes in direction, could serve as a sensitive gyroscope, possibly for navigation purposes. (Ryu et al., *Phys. Rev. Lett*. **99**, 260401 (2007))