Physics News in 2006

A Supplement to *APS News*

Edited by Phil Schewe, Ben Stein and Ernie Tretkoff

Introduction

Physics News in 2006, 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/.

Plumbing the Electron's Depths

Careful observation of a single electron in an atom trap over a period of several months has resulted in the best measurement yet of the electron's magnetic moment and an improved value for alpha, the fine structure constant, the parameter which sets the overall strength of the electromagnetic force.

The theory of quantum electrodynamics (QED) predicts that an electron is perpetually grappling with virtual particles emerging briefly from the surrounding vacuum.

In the absence of these interactions, the magnetic moment of the electron (referred to by the letter *g*), which relates the size of the electron's magnetism to its intrinsic spin, would have a value of 2. But direct measurements of *g* show that it is slightly different from 2. The finer these measurements become, the better one can probe the quantum nature of electrons and QED itself. Furthermore, if the electron had structure this too would show up in measurements of *g*.

To gain the greatest possible control over the electron and its environment, Gerald Gabrielse and his students Brian Odom and David Hanneke at Harvard University create a macroscopic artificial atom consisting of a single electron executing an endless looping trajectory within a trap made of charged electrodes–a central, positively-charged electrode and two negatively-charged electrodes above and below–supplemented by coils producing a magnetic field. The combined electric and magnetic forces keep the electron in its circular "cyclotron" orbit. In addition to this planar motion, the electron wobbles up and down in the vertical direction, the direction of the magnetic field. The heart of the Harvard experiment is to explore these two motions–the circular motion, which conforms to quantum rules, and the vertical motion, which conforms to classical physics–in a new way.

It is this masterful control over the electron's motions and the ability to measure the energy levels of the electron's artificial quantum environment that allows the Harvard group to improve the measurement of *g* by a factor of 6 over previous work. The new uncertainty in the value, set forth in an article in *Physical Review Letters*, is now at the level of 0.76 parts per trillion.

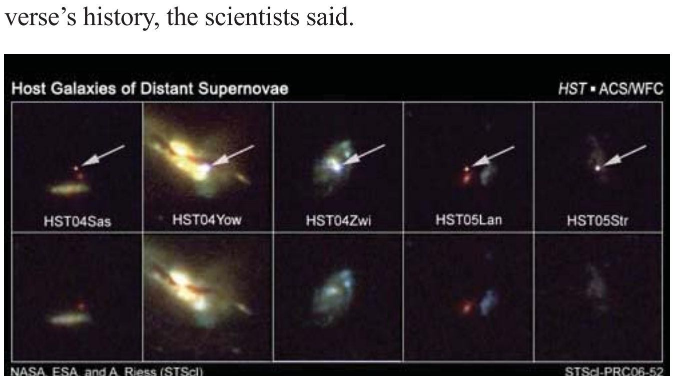
No less important than *g* is alpha. By inserting the new value of *g* into QED equations, and thanks to improved QED calculations of very high accuracy, the experimenters and theorists together determined a new value for alpha, one with an accuracy ten times better than available from any other method. This is the first time a more precise value of alpha has been reported since 1987. The new alpha, published in a companion article in *Physical Review Letters*, has an uncertainty of 0.7 parts per billion.

The measured value of *g* can also be used to address the issue of hypothetical electron constituents. Such subcomponents, the new g measurement shows, could be no lighter than 130 gigaelectronvolt.

According to Gabrielse, an improved value for alpha should, among other things, contribute to the pending adjustment of fundamental constants aimed at redefining the kilogram in a way that avoids the use of an actual weight kept under glass in Paris. (Odom et al., *Phys. Rev. Lett.* 97, 030801, 2006) and Gabrielse et al., *Phys. Rev. Lett.* 97, 030802, 2006)

Dark Energy at Redshift Z=1

Dark energy, the unidentified force that's pushing the universe to expand at ever faster rates, was already at work as early as nine billion years ago, scientists reported in November. New Hubble Space Telescope sightings of distant supernova explosions support the explanation of dark energy as energy of the vacuum whose density has stayed constant throughout the universe's history, the scientists said.



Credit: NASA, ESA, and A. Reiss (STScI)

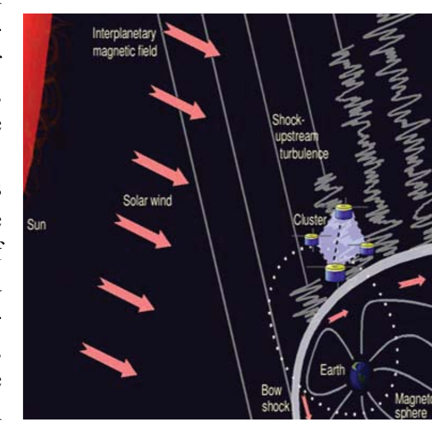
Using the Hubble, a team led by Adam Riess, an astrophysicist at the Space Telescope Science Institute and at Johns Hopkins University has now observed 23 new supernovae dating back to 8 to 10 billion years ago. Until now, astronomers had only seen seven supernovae from that period, Riess said, too few to measure the properties of dark energy. The data show that the repulsive action of dark energy was already active at that time, and are consistent with a constant energy density–in other words, with an energy of the vacuum that does not dilute itself as the universe expands, eventually fueling an exponential growth of the universe.

More complicated models with non-constant energy density–including a class known as quintessence models–are not completely ruled out, Riess said during the press conference: the new data still allows for variations of up to 45 percent from constant density. For more recent ages, dark energy is known to have been constant up to a 10 percent variation.

The new data also confirm the reliability of supernovae as signposts of the universe's expansion, Riess said.

First Direct Evidence of Turbulence in Space

Turbulence can be studied on Earth easily by mapping such things as the density or velocity of fluids in a tank. In space, however, where we expect turbulence to occur in such settings as solar wind, interstellar space, and the accretion disks around black holes, it's not so easy to measure fluids in time and space. Now, a suite of four plasma-watching satellites, referred to as Cluster, has provided the first definitive study of turbulence in space.



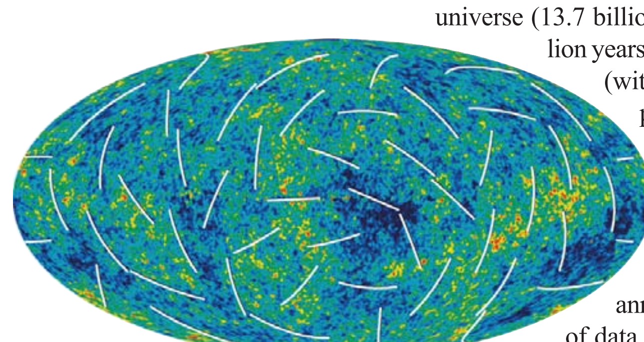
The fluid in question is the wind of particles streaming toward Earth from the sun, while the location in question is the region just upstream of Earth's bow shock, the place where the solar wind gets disturbed and passes by Earth's magnetosphere The waves in the shock-upstream plasma, pushed around by complex magnetic fields, are observed to behave a lot like fluid turbulence on Earth.

One of the Cluster researchers, Yasuhito Narita of the Institute of Geophysics and Extraterrestrial Physics in Braunschweig, Germany, says that the data is primarily in accord with the leading theory of fluid turbulence, the so-called Kolmogorov's model. (Narita et al., *Phys. Rev. Lett.* 97, 191101, 2006)

A New Triumph for Inflation

The inflationary big bang model has passed a crucial test as scientists working on the Wilkinson Microwave Anisotropy Probe released a long-awaited second set of data at a press conference held March 17.

The earlier release of WMAP data 3 years ago nailed down several grand features of the universe that had previously been known only very roughly, including: the time of recombination (380,000 years after the big bang, when the first atoms were formed); the age of the universe (13.7 billion years, plus or minus 200 million years); and the makeup of the universe (with dark energy accounting for 73 percent of all energy).



Credit: NASA/WMAP Science Team

Since that 2003 announcement, WMAP researchers have painstakingly worked to reduce the uncertainties in their results. The new result in the March 17 announcement, based on three years of data, was the release of a map of the sky containing information about the microwaves' polarization.

The microwaves are partly polarized from the time of their origin (emerging from the so-called sphere of last scattering) and partly polarized by scattering, on their journey to Earth, from the pervasive plasma of mostly ionized hydrogen created when ultraviolet radiation from the first generation of stars struck surrounding interstellar gas.

WMAP now estimates that this reionization, effectively denoting the era of the first stars, occurred 400 million years after the big bang, instead of 200 million years as had been previously thought. The main step forward is that smaller error bars, courtesy of the polarization map and the much better temperature map across the sky–with an uncertainty of only 200 billionth of a Kelvin–provide a new estimate for the inhomogeneities in the CMB's temperature.

The simplest model, called Harrison-Zeldovich, posits that the spectrum of inhomogeneities should be flat; that is, the inhomogeneities should have the same variation at all scales. Inflation, on the other hand, predicts a slight deviation from this flatness.

The new WMAP data for the first time measures the spectrum with enough precision to show a preference for inflation rather than the Harrison-Zeldovic spectrum–a test that was long-awaited as inflation's smoking gun. (Papers available on the NASA webpage: http://map.gsfc.nasa.gov/m_mm/pub_papers/threeyear.html)

Two-Dimensional Light

Two-dimensional light, or plasmons, can be triggered when light strikes a patterned metallic surface. Plasmons may well serve as a proxy for bridging the divide between photonics (high throughput of data but also at the relatively large circuit dimensions of one micron) and electronics (relatively low throughput but tiny dimensions of tens of nanometers, or millionths of a millimeter).

One might be able to establish a hybrid discipline, plasmonics, in which light is first converted into plasmons, which then propagate in a metallic surface but with a wavelength smaller than the original light; the plasmons could then be processed with their own two-dimensional optical components (mirrors, waveguides, lenses, etc.), and later plasmons could be turned back into light or into electric signals.

To show how this field is shaping up, here are a few plasmon results from the APS March Meeting.

1. *Plasmons in biosensors and cancer therapy:* Naomi Halas described how plasmons excited in the surface of tiny gold-coated, rice-grain-shaped particles can act as powerful, localized sources of light for doing spectroscopy on nearby bio-molecules. The plasmons' electric fields at the curved ends of the rice are much more intense than those of the laser light used to excite the plasmons, and this greatly improves the speed and accuracy of the spectroscopy. Tuned a different way, plasmons on nanoparticles can be used not just for identification but also for the eradication of cancer cells in rats.

2. *Plasmon microscope:* Igor Smolyaninov reported that he and his colleagues were able to image tiny objects lying in a plane with spatial resolution much better than diffraction would normally allow; furthermore, this is far-field microscopy–the light source doesn't have to be located less than a light-wavelength away from the object. They use 2D plasmon mirrors and lenses to help in the imaging and then conduct plasmons away by a waveguide.

3. *Photon-polariton superlensing and giant transmission:* Gennady Shvets reported on his use of surface phonons excited by light to achieve super-lens (lensing with flat-panel materials) microscope resolutions as good as one-twentieth of a wavelength in the mid-infrared range of light. He and his colleagues could image subsurface features in a sample, and they observed what they call "giant transmission," in which light falls on a surface covered with holes much smaller than the wavelength of the light. Even though the total area of the holes is only 6 percent of the total surface area, 30 percent of the light got through, courtesy of plasmon activity at the holes.

4. *Future plasmon circuits at optical frequencies:* Nader Engheta argued that nano-particles, some supporting plasmon excitations, could be configured to act as nm-sized capacitors, resistors, and inductors–the basic elements of any electrical circuit.

The circuit in this case would be able to operate at optical (10^{15} Hz) frequencies. This would make possible the miniaturization and direct processing of optical signals with nano-antennas, nano-circuit-filters, nano-waveguides, nano-resonators, and may lead to possible applications in nano-computing, nano-storage, molecular signaling, and molecular-optical interfacing.

Nanotubes Unfolded

Two-dimensional carbon, or graphene, has many of the interesting properties possessed by one-dimensional carbon (in the form of nanotubes): electrons can move at high speed and suffer little energy loss. According to Walt deHeer (Georgia Tech), who spoke at the APS March Meeting in Baltimore, graphene will provide a more controllable platform for integrated electronics than is possible with nanotubes, since graphene structures can be fabricated lithographically as large wafers.

Single sheets of graphene were isolated in 2004 by Andre Geim (University of Manchester). In graphene, electron velocity is independent of energy. That is, electrons move as if they were light waves. This extraordinary property was elucidated in November 2005 through experiments using the quantum Hall effect (QHE), in which electrons, confined to a plane and subjected to high magnetic fields, execute only prescribed quantum trajectories. These tests were conducted by groups represented at the APS meeting by Geim and Philip Kim (Columbia University).

The QHE studies also revealed that when an electron completes a full circular trajectory in the imposed magnetic field, its wavefunction is shifted by 180 degrees. This modification, called "Berry's phase," acts to reduce the propensity for electrons to scatter in the backwards direction; this in turn helps reduce electron energy loss.

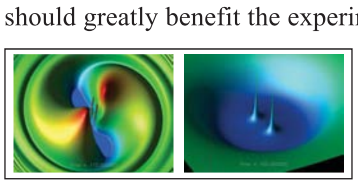
Geim reported a new twist to this story. Studying QHE in graphene bilayers he observed a new version of QHE, featuring a doubled Berry's phase of 360 degrees.

The goal now is to learn more graphene physics. For example, Walt DeHeer reported that a plot of resistance versus applied magnetic field had a fractal shape. DeHeer said that so far there is no explanation for this. As for applications, he said that on an all-graphene chip, linking components with the usual metallic interconnects, which tends to disrupt quantum relations, would not be necessary.

DeHeer's group so far has been attempting to build circuitry in this way; they have made graphene structures (including a graphene transistor) as small as 80 nanometers and expect to get down to the 10-nanometer size.

Black Hole Merger Movie

Accurate calculations of the gravitational waveforms emitted during the collision of black holes can now be made. A new computer study of how a pair of black holes, circling each other, disturbs the surrounding space and sends huge gusts of gravitational waves outwards, should greatly benefit the experimental search for those waves with detectors such as the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the planned Laser Interferometer Space Antenna (LISA).



Black holes encapsulate the ultimate in gravitational forces, and this presents difficulties for computations attempting to model behavior nearby. Nevertheless, some physicists at the University of Texas at Brownsville have now derived an algorithm that not only produces accurate estimates of the gravity waves of the inspiraling black holes, even over the short time intervals leading up to the final merger, but also is easily implemented on computers.

"The importance of this work," says Carlos Lousto, one of the authors of the new study, "is that it gives an accurate prediction to the gravitational wave observatories, such as LIGO, of what they are going to observe." The new results are part of a larger study of numerical relativity carried out at the University of Texas, work referred to as the Lazarus Project (Campanelli, Lousto, Marronetti, and Zlochower, *Phys. Rev. Lett.* 96, 111101, 2006)

In Protons, Virtual Strange Quarks Less Prevalent than Thought

The sea of virtual quarks shimmering inside every proton inside every atom has now been studied with exquisite precision in a new experiment conducted at the Thomas Jefferson National Accelerator Facility in Newport News, VA. The surprising result is that the quark-antiquark pairs bubbling irrepressibly into and out of existence, especially those with a strange flavor, contribute so little to the life of the proton, prompting theorists to puzzle even more intently over the basic question: what is a proton? The simple answer has been that the proton consists of three regular (valence) quarks always present plus the effervescent "sea quarks" emerging from the vacuum plus a fleet of force-carrying gluons. But if ever the whole did not equal the sum of its parts, this is true for the proton. Sum the charge of the valence quarks and you get the charge of the proton. So far, so good.

But sum the mass of the valence quarks and you account for less than 1 percent of the proton's mass. The Hall A Proton Parity Experiment (HAPPEx) at Jefferson Lab scatters a 3-gigaelectronvolt beam of electrons from a slender thermos bottle of liquid hydrogen, providing in effect a target full of protons, and from a helium target, which provides both protons and neutrons. Only those events in which the electron scatters elastically are chosen for analysis.

By controlling the polarization of the electrons, and by comparing the proton and helium scattering data, one can determine separately the contributions from electric, magnetic, and weak-force scattering. And from these, the degree to which sea quarks are present in the proton can be deduced.

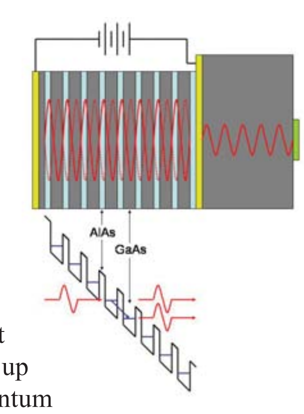
Previous theories, supported by some rough experimental evidence, supported the idea that strange quarks could account for as much as 10 percent of the proton's magnetic moment.

One of the HAPPEx scientists, Paul Souder of Syracuse University in Syracuse, N.Y., reported at the April Meeting in Dallas that, with much greater precision, strange quarks can account for about 1 percent of the proton's charge and no more than 4 percent of its magnetic moment, and that owing to experimental uncertainties both of these measured values might be consistent with zero. In other words, the proton is a lot less strange than thought.

A New Kind of Acoustic Laser

Sound amplification by stimulated emission of radiation, or SASER, is the acoustic analog of a laser. Instead of a feedback-built potent wave of electromagnetic radiation, a saser would deliver a potent ultrasound wave.

The concept has been around for years and several labs have implemented models with differing features. In a new version, undertaken by scientists from the University of Nottingham in the U.K. and the Lashkarev Institute of Semiconductor Physics in Ukraine, the gain medium–that is, the medium where the amplification takes place–consists of stacks (or a superlattice) of thin layers of semiconductors which together form "quantum wells."



In these wells, really just carefully confined planar regions, electrons can be excited by parcels of ultrasound, which typically possess millielectronvolts of energy, equivalent to a frequency of 0.1-1 terahertz. Just as coherent light can build up in a laser by the concerted, stimulated emission of light from a lot of atoms, so in a saser coherent sound can build up by the concerted emission of phonons from a lot of quantum wells in the superlattice.

In lasers the light buildup is maintained by a reflective optical cavity. In the U.K.-Ukraine saser, the acoustic buildup is maintained by an artful spacing of the lattice layer thicknesses in such a way that the layers act as an acoustic mirror.

Eventually the sound wave emerges from the device at a narrow angular range, as do laser pulses. The monoenergetic nature of the acoustic emission, however, has not yet been fully probed. The researchers believe their saser is the first to reach the terahertz frequency range while using also modest electrical power input. Terahertz acoustical devices might be used in modulating light waves in optoelectronic devices. (Kent et al., *Phys. Rev. Lett.* 96, 215504, 2006)

A Hint of Negative Electrical Resistance

A hint of negative electrical resistance emerges from a new experiment in which microwaves of two different frequencies are directed at a 2-dimensional electron gas. The electrons, moving at the interface between two semiconductor crystals, are subjected to an electric field in the forward (longitudinal) direction and a faint magnetic field in the direction perpendicular to the plane. In such conditions the electrons execute closed-loop trajectories which will, in addition, drift forward depending on the strength of the applied voltage.

A few years ago, two experimental groups observed that when, furthermore, the electrons were exposed to microwaves, the overall longitudinal resistance could vary widely–for example, increasing by an order of magnitude or extending down to zero, forming a zero-resistance state, depending on the relation between microwave frequency and the strength of the applied magnetic field.

Some theorists proposed that in such zero-resistance states, the resistance would actually have been less than zero: the swirling electrons would have drifted backwards against the applied voltage. However, this rearwards motion would be difficult to observe because of an instability in the current flow.

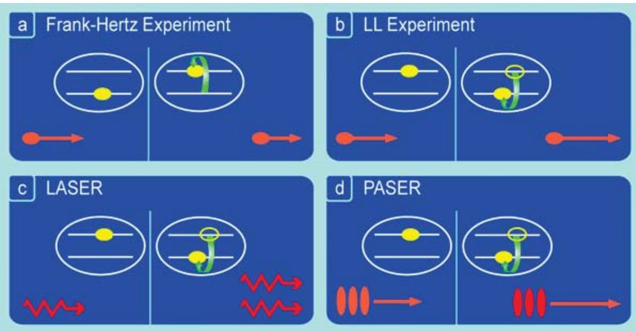
A Utah/Minnesota/Rice/Bell Labs group has now tested this hypothesis in a clever bichromatic experiment using microwaves at the two frequencies. Michael Zudov and Rui-Rui Du sent microwaves of two different frequencies at the electrons, observing that for nonzero-resistance states the resultant resistance was the average of the values corresponding to the two frequencies separately. On the other hand, when the measurements included frequencies that had yielded a zero resistance, the researchers observed a dramatic reduction of the signal.

Judging from the average resistance observed for non-zero measurements, they deduce that whenever zero resistance was detected, the true microscopic resistance had actually been less than zero. (Zudov et al., *Phys. Rev. Lett*. 96, 236804, 2006)

Particle Acceleration by Stimulated Emission of Radiation–PASER for Short

Particle Acceleration by Stimulated Emission of Radiation (PASER for short), a sort of particle analog of the laser process, has been demonstrated, for the first time, by a team of physicists from the Technion-Israel Institute of Technology using the accelerator facilities at the Brookhaven National Lab.

In a regular laser, photons traveling through an active medium (a body of excited atoms) will stimulate the atoms, through collisions, to surrender their energy in the form of additional emitted photons; this coherent process builds on itself until a large pulse of intense light exits the cavity in which the amplification takes place. In the new proof-of-principle PASER experiment, the active medium consists of a CO_2 vapor, and instead of surrendering their energy in the form of stimulated photons, the atoms transfer their energy to a beam of electrons.



The electrons stimulate the atoms into giving up their surplus energy through collisions. The electrons' energy is amplified in a coherent way. Although millions of collisions are involved for each electron, no heat is generated. The transferred energy goes into an enhanced electron motion. One could say that here was a laser which produced no laser light, only a laser-like transfer of energy resulting in electron acceleration. It should be said that the electrons began with an energy of 45 million electron volts (MeV) and absorbed only a modest energy of about 200 thousand electron volts (keV).

Being able to accelerate electrons with energy stored in individual atoms/molecules, a concept now demonstrated with the PASER, provides new opportunities since the accelerated electrons may prove to be significantly "cooler" (they are more collimated in velocity) than in some other prospective acceleration schemes, enabling in turn the secondary generation of high-quality X-rays, which are an essential tool in nano-science. (Banna, Berezovsky, Schachter, *Phys. Rev. Lett*. 97, 134801, 2006)

Hypersound

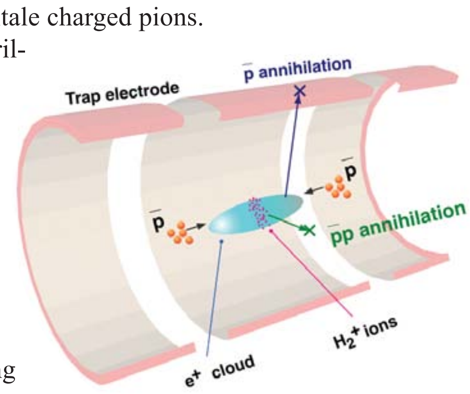
Hypersound, acoustic pulsation at 200 gigahertz frequencies, has been produced in the same kind of resonant multilayered semiconductor cavity as used in photonics. Physicists at the Institute des Nanosciences de Paris (France) and the Centro Atomico Bariloche and Instituto Balseiro (Argentina) generate the high frequency sound pulses in a solid material made of thin gallium arsenide and aluminum arsenide layers. One can picture the sound, excited by a femtosecond laser, as being a short pulse of waves or equivalently as particle-like phonons, excitations pulsing through the stack of layers. These phonons are reflected at either end of the device, called a nanocavity, by further layers with a much different acoustic impedance acting as mirrors. Acoustic impedance is the acoustic analog of the refractive index for light.

Bernard Jusserand says that he and his colleagues hope to reach the terahertz acoustic range. The wavelength for such "sound" is only nanometers in length. They believe that a new field, nanophononics, has been inaugurated, and that the acoustical properties of semiconductor nanodevices will become more prominent. THz phonons, and more specifically the reported nanocavities could, for example, be used to modulate the flow of charges or light at high frequency and in small spaces. THz sound might also participate in the development of powerful "acoustic lasers" or in novel forms of tomography for imaging the interior of opaque solids. (Huynh et al., *Phys. Rev. Lett*. 97, 115502, 2006)

First Antimatter Chemistry

The Athena collaboration, an experimental group working at the CERN laboratory in Geneva, has measured chemical reactions involving antiprotonic hydrogen, a bound object consisting of a antiproton paired with a proton.

This composite object, which can also be called protonium, eventually annihilates itself, creating an even number of telltale charged pions.



Normally the annihilation comes about in a trillionth of a second, but in the Athena apparatus the duration is a whopping millionth of a second.

The protonium comes about in the following way. First, antiprotons are created in CERN's proton synchrotron by smashing protons into a thin target. The resultant antiprotons then undergo the deceleration, from 97 percent down to 10 percent of the speed of light. Several more stages of cooling bring the antiprotons to a point where they can be caught in Athena's electrostatic trap. This allows the researchers to study then, for the first time, a chemical reaction between the simplest antimatter ion–the antiproton–and the simplest matter molecular ion, namely H_2^+ (two hydrogen atoms with one electron missing). Joining these two ions results in the protonium plus a neutral hydrogen atom.

This represents the first antimatter-matter chemistry, if you don't count the interaction of positrons with ordinary matter. According to Nicola Zurlo of the Università di Brescia and his colleagues, the experimental output from the eventual protonium annihilation allowed the Athena scientists to deduce that the principal quantum number of the protonium had an average value of 70 rather than the expected value of 30. Furthermore, the angular momentum of the protonium was typically much lower than expected–perhaps because of the low relative velocity at which the matter and antimatter ions approached each other before reaction.

The Athena scientists hope to perform more detailed spectroscopy on their proton-antiproton "atom" in addition to the already scheduled spectroscopy of trapped anti-hydrogen atoms, which consist of antiprotons wedded to positrons. (Zurlo et al., *Phys. Rev. Lett.* 97, 153401, 2006)

Elements 116 and 118 Are Discovered

At the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, physicists (including collaborators from Lawrence Livermore National Lab in the United States) have sent a beam of calcium-48 ions into a target of californium-249 atoms to create temporarily a handful of atoms representing element 118. The nuclei for these atoms have an atomic mass of 294 units.

In fact, only three of these atoms, the heaviest ever produced in a controlled experiment, were observed. After sending 2 x 10^{19} calcium projectiles into the target, one atom of element 118 was discovered in the year 2002 and two more atoms in 2005. The researchers held up publication after seeing their first specimen in order to find more events. According to Livermore physicist Ken Moody, the three events have been well studied and the odds of a statistical fluke at work here are less than a part in 100 thousand.

Caution would naturally be on the minds of anyone announcing a new element. Evidence for element 118 was offered once before, by a team at the Lawrence Berkeley National Laboratory, but this claim was later retracted when it was discovered that some of the data had been falsified.

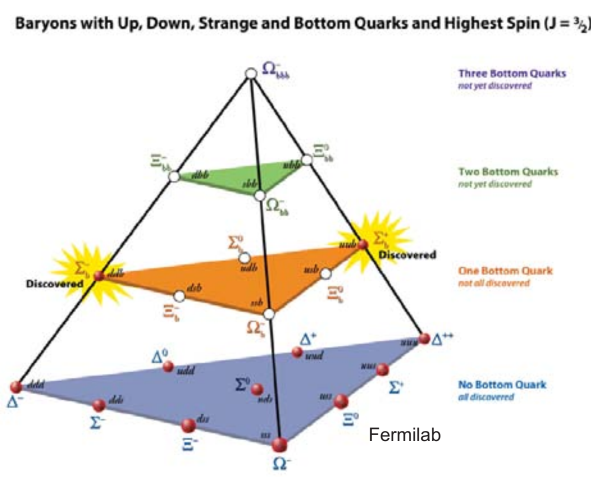
In searching through 10^{19} collision events, how do you know you have found a new element? Because of the clear and unique decay sequence involving the offloading of alpha particles. In this case, nuclei of element 118 decay to become element 116 (hereby itself discovered for the first time), and then element 114, and then element 112 by emitting detectable alphas. The 112 nucleus subsequently fissions into roughly equal-sized daughter particles.

The average lifetime observed for the three examples of element 118 was about one millisecond, not long enough to perform any kind of chemical tests. Element 118 lies just beneath radon in the periodic table and is therefore a kind of noble gas.

The Dubna-Livermore team previously announced the discovery of elements 113 and 115 and next hope to produce element 120 by crashing a beam of iron atoms into a plutonium target. (Oganessian et al., *Phys. Rev.* C 74, 044602, 2006)

New Baryons Discovered

The periodic table of baryons has now been supplemented with several heavyweight members. The new members of the baryonic periodic table are unstable and ephemeral, but their observed existence serves to expand our understanding of matter in the universe. The new baryons, the heaviest yet with masses around 5.8 gigaelectron-volt, were sifted from trillions of proton-antiproton collisions conducted at an energy of 2 tera-electronvolts at the Fermilab.



Up to now there was only one well established bottom-quark-bearing baryon, the so called Lambdab. The first evidence for its existence was reported by CERN and Fermilab in late 1990s based on a handful of events. Now the CDF collaboration at Fermilab is claiming discovery of two baryon types, each on the basis of about 100 events. Actually there are four new so-called $Sigma_b$ baryons: two positively charged baryons with a u-u-b combination (one with spin 1/2, one with spin 3/2), the first of which constitutes a sort of bottom-proton; and two negatively charged baryons with a d-d-b combination (one each with a spin of 1/2 or 3/2). In all cases, the Sigma decays almost immediately into a $Lambda_b$ particle (with a u-d-b set of quarks) plus a pion. In the detector the Lambda typically flies about 100 microns before decaying into $Lambda_c$ (a Lambda baryon with a c quark instead of a b), which quickly decays into an ordinary proton.

The new results were announced at a talk at Fermilab by Petar Maksimovic, of Johns Hopkins University. Jacobo Konigsberg, of the University of Florida, the co-spokesperson for the CDF group says that the statistical odds against the Sigmab particles being real are at the level of a few parts in 10^{19}. (for more information see Fermilab press release: http://www.fnal.gov/pub/presspass/press_releases/sigma-b-baryon.html)

Have Particle Masses Changed since the Early Universe?

Indications of a change in the proton-to-electron mass ratio have shown up in comparisons of the spectra of hydrogen gas as recorded in a lab with spectra of light coming from hydrogen clouds at the distance of quasars. This is another of those tests of so-called physical constants that might not be absolutely constant.

The proton-to-electron mass ratio (denoted by the letter mu) figures in setting the scale of the strong nuclear force.

There is at present no explanation why the proton's mass should be 1,836 times that of the electron. The new search for a varying mu was carried out by Wim Ubachs of the Vrije Universiteit Amsterdam. He and his colleagues studied hydrogen gas in the lab, performing ultra-high-resolution spectroscopy in the difficult-to-access extreme-ultraviolet range. This data is compared to accurate observations of absorption spectra of distant hydrogen (which absorbs light from even more distant quasars) as recorded with the European Southern Observatory (ESO) in Chile.

The astronomical hydrogen is essentially hydrogen as it was 12 billion years ago, so one can seek hints of a changing value for mu. The position of a particular spectral line depends on the value of mu; locate the spectral line accurately and you can infer a value for mu. In this way, the researchers report that they see evidence that mu has decreased by 0.002 percent over those 12 billion years. According to Ubachs, the statistical confidence of his spectroscopic comparison is at the level of 3.5 standard deviations. (Reinhold et al., *Phys. Rev. Lett*. 96, 151101, 2006)

A Baby Picture That's Worth a Nobel Prize

The 2006 Nobel Prize for Physics was awarded to John Mather of NASA/Goddard Space Flight Center and George Smoot of the University of California, Berkeley and Lawrence Berkeley National Laboratory. They are cited for the study of the early universe. They were instrumental in developing the Cosmic Background Explorer (COBE) experiment. This orbiting spacecraft was the first to detect faint temperature variations in the cosmic microwave background (CMB), the bath of radiation representing the first light able to move freely through the universe after the big bang. COBE's map of these temperature variations across the whole sky has been called the earliest "baby picture" we have of our universe.

The CMB was initially observed in the 1960s by Arno Penzias and Robert Wilson at Bell Labs, in New Jersey, for which they would later receive the Nobel Prize. It was thought at the time that the CMB would be least somewhat inhomogeneous since the subsequent galaxies we now see would have to form from slight imbalances of matter in the pervasive hot plasma that constituted the substance of the universe (as far as we know) just before the first atoms formed. But how big those clumps of matter were, showing up as slight temperature variations in the map of the CMB across the sky, was unknown.

At a press conference at the American Physical Society April meeting in 1992, COBE speakers, including Smoot and Mather, announced the discovery of variations at the level of parts per hundred thousand against an overall average temperature of 2.7 degrees Kelvin.

The microwave background is in effect the biggest thing we can see (indeed it spreads out across the whole sky), the farthest-out thing we can map, and the furthest-back in time. COBE was the first to measure the variations and the first to provide a really precise average temperature for the universe, 2.726 degrees Kelvin. The COBE work represented a feat of great experimental science since the faint variations in the temperature of the distant CMB had to be measured against a foreground cloud of microwave radiation coming from our solar system, our galaxy, and other celestial objects.

Later CMB detectors, including the balloon-borne Boomerang and the land-based Degree Angular Scale Interferometer (DASI), added more and more detail to the microwave background.

The most recent and best microwave measurements have been presented by the WMAP detector, which provides the clearest multipole curve yet as well as supplying the best values for important cosmological parameters such as the age of the universe, the overall curvature of spacetime, and the time when the first atoms formed and the first stars.

Attack of the Teleclones

Should quantum cryptographers begin to worry? In contrast with everyday matter, quantum systems such as photons cannot be copied, at least not perfectly, according to the "no-cloning theorem." Nonetheless, imperfect cloning is permitted, so long as Heisenberg's Uncertainty Principle remains inviolate.

Now, quantum cloning has been combined with quantum teleportation in the first full experimental demonstration of "telecloning" by scientists at the University of Tokyo, the Japan Science and Technology Agency, and the University of York. In ideal teleportation, the original is destroyed and its exact properties are transmitted to a second, remote particle; the Heisenberg principle does not apply because no definitive measurements are made on the original particle. In telecloning, the original is destroyed, and its properties are sent to not one but two remote particles, with the original's properties reconstructed to a maximum accuracy (fidelity) of less than 100 percent.

In their experiment, the researchers didn't just teleclone a single particle, but rather an entire beam of laser light. They transmitted the beam's electric field, specifically its amplitude and phase–but not its polarization–to two nearly identical beams at a remote location with 58 percent accuracy or fidelity, out of a theoretical limit of 66 percent.

Telecloning stands apart from local cloning and from teleportation in requiring "multipartite" entanglement, a form of entanglement in which stricter correlations are required between the quantum particles or systems, in this case three beams of light.

In addition to representing a new quantum-information tool, telecloning may have an exotic application: tapping quantum cryptographic channels. Quantum cryptographic protocols are so secure that they may discover tapping. Nonetheless, with telecloning, the identity and location of the eavesdropper could be guaranteed uncompromised. (Koike et al., *Phys. Rev. Lett.* 96, 060504, 2006)

Slow-Motion Boiling

A new study, carried out at a chilly temperature of 33 degrees Kelvin, explains why certain industrial heat exchangers (including those used at power plants) melt catastrophically when steam formation undergoes a process referred to as a "boiling crisis."

Boiling, a sort of accelerated evaporation, is usually a very efficient form of energy transfer because of the transport of latent heat (the heat required for a substance to change its phase); energy moves from a heater to a liquid by the formation of vapor bubbles. There can be an important hitch in this process, however, and that is the poorly understood boiling crisis.

This potentially dangerous situation comes about as follows: at high enough temperatures the formation of bubbles becomes so great that the entire surface of the heating element (the part of the heater in contact with the liquid) can be covered with a vapor film, which insulates the liquid above from absorbing heat. (Just as a water droplet, hitting a frying pan, evaporates only very slowly.) The result is a buildup of heat in the heater and possible meltdown.

What Vadim Nikolayev and his colleagues at the École Supérieure de Physique et de Chimie Industrielles in Paris, Commission of Atomic Energy in Grenoble, and the University of Bordeaux have done is to provide the first detailed look at the boiling crisis by performing simulations and laboratory tests of a theory which suggests that the overheating comes about because of vapor recoil. That is, at high enough heat flux, the growing bubble will forcefully push aside liquid near the heating element, expanding the potentially dangerous insulating vapor layer.

This theory was upheld by experimental work performed not at the blazing temperature of high-pressure steam but near the chilly critical temperature of liquid hydrogen, where boiling would occur very slowly, in a way that could be glimpsed more completely. Thanks to the universality of fluid dynamics, however, lessons learned at 33 degrees Kelvin should be applicable to fluids at 100 degrees Celsius.

Nikolayev believes that better understanding of the boiling crisis will facilitate certain counter-measures. This is important since possible boiling problems occur not just at major industrial sites but also for such consumer electronic products as laptop computers, where soon the rate of heat dissipation will be much higher than for today's models owing to further miniaturization. (Nikolayev et al., *Phys. Rev. Lett.* 97, 184503, 2006)

GeV Acceleration in Only 3 Centimeters

Much of particle physics over the past century was made possible by machines that could accelerate particles up to energies of thousands of electronvolts (keV), then millions of electronvolts (MeV), and then billions (GeV). Possessing such high energies, beam particles can, when they smash into something, recreate for a short time a small piece of the early hot universe. Now the effort to impart more acceleration to particles over a short haul has taken a notable step forward. Physicists at the Lawrence Berkeley National Laboratory and the University of Oxford have accelerated electrons up to an energy of 1 GeV in a space of only 3 centimeters. The device used is called a laser wakefield accelerator since it boosts the electrons using potent electric fields set up at the trailing edge of a burst of laser light traveling through a plasma-filled cavity. Previously, gradients as high as 100 GeV per meter had been attained, but the acceleration process could not be sustained to energies much above 200 MeV. (Leemans et al., *Nature Physics*, October 2006)

Ellipsoidal Universe

A new theoretical assessment of data taken by the Wilkinson Microwave Anisotropy Probe (WMAP) suggests that the universe–at least that part of it that can be observed–is not spherically symmetric, but more like an ellipsoid.

The WMAP data has served to nail down some of the most important parameters in all of science. One remaining oddity about the WMAP results, however, concerns the way in which portions of the sky contribute to the overall map of cosmic microwaves; samples of the sky smaller than one degree across, or at the degree level, or tens of degrees seem to be contributing radiation at expected levels. Only the largest possible scale, that on the order of the whole sky itself (the technical term is quadrupole moment), seems to be under-represented.

Now Leonardo Campanelli of the University of Ferrara and his colleagues Paolo Cea and Luigi Tedesco at the University of Bari (all in Italy) have studied what happens to the quadrupole anomaly if one supposes that the shell from which the cosmic microwaves come toward earth is an ellipsoid and not a sphere. This shell is called surface of last scattering since it corresponds to that moment in history when photons largely stopped scattering from charged particles when it became cool enough for many of the particles to bundle themselves into neutral atoms. If the microwave shell is an ellipsoid with an eccentricity of about 1 percent, then the WMAP quadrupole is exactly what it should be.

This is not the first time a non-spherical universe has been suggested, but it is the first time the idea has been applied to the state-of-the-art WMAP data. What could have caused the universe as a whole to be ellipsoidal? Campanelli, Cea and Tedesco say that a uniform magnetic field pervading the cosmos, or a defect in the fabric of spacetime, could bring about a non-zero eccentricity. (Campanelli, Cea, and Tedesco, *Phys. Rev. Lett.* 97, 131302, 2006)

Atoms in a Trap Measure Gravity at the Micron Level

Nowadays many of the most sensitive measurements in science depend on some quantum phenomenon which very subtly can often be exploited to gain maximum precision. In an experiment conducted at the Università di Firenze (University of Florence), the quantum phenomenon in question is called Bloch oscillation. This weird effect occurs when particles subject to a periodic potential–such as electrons feeling the regular gridlike electric force of a crystalline lattice of atoms–are exposed to an additional static force, say, an electric force in a single direction; what happens is that the electrons do not all move in the direction of the force, but instead oscillate back and forth in place.

In a new experiment conducted by Guglielmo Tino and his Florence colleagues, the particles are supercold strontium atoms held in a vertically oriented optical trap formed by criss-crossing laser beams, while the static force is merely the force of gravity pulling down on the atoms.

Although Bloch oscillations have been observed before, they have never been sustained for as long as 10 seconds, which is the case here.

Close observation of the Bloch oscillations allows you to measure the strength of the static force, with high precision–in this case to measure gravity with an uncertainty of a part in a million.

With planned improvements to the apparatus, the researchers will be able to bring the atoms to within a few microns of a test mass and will measure g with an uncertainty of 0.1 parts per million. With these conditions, one can probe theories which say that gravity should depart from the Newtonian norm, perhaps signifying the existence of unknown spatial dimensions.

According to Tino, unlike gravity-measuring experiments which use torsional balances or cantilevers, the Florence approach measures gravity directly and over shorter distances. The atom-trap setup should also prove useful for future inertial guidance systems and optical clocks. (Ferrari et al., *Phys. Rev. Lett.* 97, 060402, 2006)

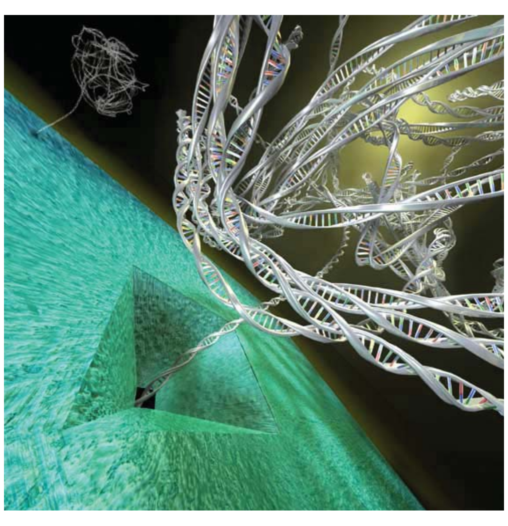
Nanopores and Single-Molecule Biophysics

Some proteins naturally form nanometer-scale pores that serve as channels for useful biochemical ions. Through this ionic communication, nanopores enable many functions in cells, such as allowing nerve cells to communicate.

Nanopores can be destructive, too. When the proteins of bacteria and viruses attach to a cell, their nanopores can facilitate infection, for example by shooting viral DNA through them into the cell.

At the APS March Meeting in Baltimore, John J. Kasianowicz (National Institute of Standards and Technology) showed how single biological nanopores can be used to detect and characterize individual molecules of RNA and DNA. He also demonstrated constructive uses for anthrax-related nanopores in diagnosing anthrax infections and testing anti-anthrax drugs.

Anthrax bacteria secrete a protein called "protective antigen" that attaches to an organic membrane such as a cell wall. The protein forms a nanopore that penetrates the membrane. When another anthrax protein, called "lethal factor," attaches to the protective antigen nanopore, it prevents ionic current from flowing through the pore and out of the organic membrane.



By monitoring animal blood samples for changes in ion current, Kasianowicz and his colleagues at the National Cancer Institute and the United States Army Medical Research Institute for Infectious Diseases electronically detected a complex of two anthrax proteins in less than an hour, as opposed to the existing methods which can take up to several days. Also, they demonstrated a method for screening potential therapeutic agents against anthrax toxins using the anthrax nanopore.

A Brown University group led by Sean Ling was among those reporting progress in developing a nanopore-based method for sequencing DNA faster and more cheaply than traditional biochemical techniques. In one scenario, the change in ion current as DNA moves through the nanopore could yield the sequence of bases in the DNA. However, the letters in DNA are so close to each other (about .4 nm), and the DNA moves so quickly through the nanopore, that researchers have had to come up with creative solutions for reading the individual letters. For example, the Brown group attaches complementary blocks of DNA, about six letters long, to the DNA sequence of interest, so that the researchers would read blocks of multiple letters at a time, while slowing down the passage of the DNA by attaching a magnetic bead to it.

Other researchers are finding value in developing nanopores for fundamental biology studies. Discussing his group's latest work with artificial, silicon-based nanopores, Cees Dekker of the Delft University of Technology in Delft, Holland showed how lasers and other manipulations with the artificial pores are enabling new single-molecule biophysics studies on the properties of DNA, RNA, and proteins by studying how they pass through the pores.

Dune Tunes

For centuries, world travelers have known of sand dunes that issue loud sounds, sometimes of great tonal quality. Now, a team of scientists has disproved the long held belief that the sound comes from vibrations of the dune as a whole and proven, through field studies and through controlled experiments in a lab, that the sounds come from the synchronized motions of the grains in avalanches of a certain size.

Small avalanches don't produce any detectable sound, while large avalanches produce sound at lots of frequencies (leading to cacophonous noise). But sand slides of just the right size and velocity result in sounds of a pure frequency, with just enough overtones to give the sound "color," as if the dunes were musical instruments. In this case, however, the tuning isn't produced by any outside influence but by critically self-organizing tendencies of the dune itself. The researchers thus rule out various "musical" explanations.

For example, the dune sound does not come from the stick-slip motion of blocks of sand across the body of the dune (much as violin sounds are made by the somewhat-periodic stick-slip motion of a bow across a string attached to the body of the violin). Nor does the dune song arise from a resonance effect (much as resonating air inside a flute produces a pure tone) since it is observed that the dune sound level can be recorded at many locations around the dune.

Instead, the sand sound comes from the synchronized, free sliding motion of dry larger-grained sand producing lower frequency sound. (Douady et al., *Phys. Rev. Lett.* 97, 018002, 2006)

Can String Theory Explain Dark Energy?

A new paper by Cambridge physicist Stephen Hawking and Thomas Hertog of CERN suggests that it can. The leading explanation for the observed acceleration of the expansion of the universe is that a substance, dark energy, fills the vacuum and produces a uniform repulsive force between any two points in space. Quantum field theory allows for the existence of such a universal tendency. Unfortunately, its prediction for the value the cosmological constant is some 120 orders of magnitude larger than the observed value.

In 2003, cosmologist Andrei Linde of Stanford University and his collaborators showed that string theory allows for the existence of dark energy, but without specifying the value of the cosmological constant. String theory, they found, produces a mathematical graph shaped like a mountainous landscape, where altitude represents the value of the cosmological constant. After the big bang, the value would settle on a low point somewhere between the peaks and valleys of the landscape. But there could be on the order of 10^{500} possible low points and no obvious reason for the universe to pick the one we observe in nature.

Some experts hailed this multiplicity of values as a virtue of the theory. But critics see the landscape as exemplifying the theory's inability to make useful predictions.

The Hawking/Hertog paper is meant to address this concern. It looks at the universe as a quantum system in the framework of string theory. In Richard Feynman's formulation of quantum theory, the probability that a photon ends up at a particular spot is calculated by summing up over all possible trajectories for the photon. Hawking and Hertog argue that the universe itself must also follow different trajectories at once, evolving through many simultaneous, parallel histories, or "branches."

But applying quantum theory to the entire universe is tricky. Here you have no control over the initial conditions, nor can your repeat the experiment again and again for statistical significance. Instead, the Hawking-Hertog approach starts with the present and uses what we know about our branch of the universe to trace its history backwards. Again, there will be multiple possible branches in our past, but most can be ignored in the Feynman summation because they are just too different from the universe we know.

For example, Hertog says, knowledge that our universe is very close to being flat could allow one to concentrate on a very small portion of the string theory landscape whose values for the cosmological constant are compatible with that flatness. That could in turn lead to predictions that are experimentally testable. For example, one could calculate whether our universe is likely to produce the microwave background spectrum we actually observe. (S. W. Hawking and Thomas Hertog *Phys. Rev*. D 73, 123527, 2006)

Testing Special Relativity and Newtonian Gravity

Lorentz invariance says that the laws of physics are the same for an observer at rest on Earth or one who is rotated through some angle or traveling at a constant speed relative to the observer at rest. Some researchers are looking for a crack in the universe in the form of a very faint field pervading the Cosmos, one that exerts a force on electron spin, which would mean the end of Lorentz invariance. A new experiment conducted at the University of Washington, in Seattle, has sought such an anomalous field and not found it even at an energy scale of 10^{-21} electronvolts. This is the most stringent search yet–by a factor of 100 –for Lorentz-invariance-violating effects involving electrons.

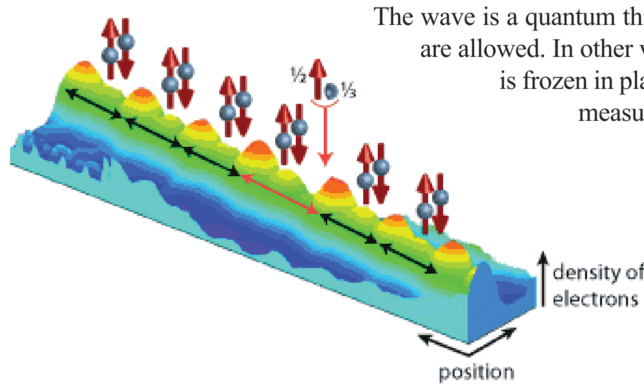
The Washington work, described at the APS April Meeting in Dallas by Claire Cramer, is part of an ongoing battery of tests carried out with a flexible and sophisticated torsion-balance apparatus. In this case, a pendulum is made of blocks whose magnetism arises from both the orbital motion of an electron around its nucleus and from the intrinsic spin of the electron itself. Carefully choosing and arranging the blocks, one can create an assembly that has zero magnetization and yet still have an overall nonzero electron spin. The existence of a preferred-direction, Lorentz-violating spin-related force would have shown up as a subtle mode in the rotation of the pendulum. The conclusion: any such quasi-magnetic field would have to be weaker than about a femtogauss, or 10^{-15} gauss.

Atom Wires

Physicists have built the world's thinnest gold necklaces, at just one atom wide.

Paul Snijders and Sven Rogge from the Kavli Institute of Nanoscience at the Delft University of Technology, in Delft, Holland, and Hanno Weitering from the University of Tennessee build the single-atom wires by evaporating a puff of gold atoms onto a silicon substrate which has first been cleared of impurities by baking it at 1200 degrees Kelvin. The crystalline surface was cut to form staircase corrugations. Left to themselves, the atoms then self-assemble into wires (aligned along the corrugations) of up to 150 atoms.

Then the researchers lower the probe of a scanning tunneling microscope (STM) over the tiny causeway of gold atoms to study the nano-electricity moving in the chain; the STM both images the atoms and measures the energy states of the atoms' outermost electrons. What they see is the onset of charge density waves– normally variations in the density of electrons along the wire moving in pulselike fashion. But in this case, owing to the curtailed length of the wire, a standing wave pattern is what results as the temperature is lowered.



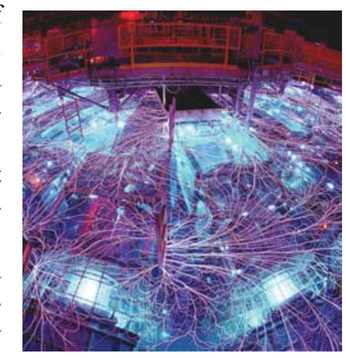
The wave is a quantum thing; hence certain wavelengths are allowed. In other words, the charge density wave is frozen in place, allowing the STM probe to measure the wave–the electron density–at many points along the wire.

Surprisingly, two or more density waves could co-exist along the wire. The charge density disturbance can also be considered as a particle-like thing, including excitations which at times possess a fractional charge. (Snijders et al., *Phys. Rev. Lett*. 96, 076801, 2006)

America's Hottest Lab

A temperature of 2 to 3 billion degrees Kelvin–hotter than the interior of any known star–has been achieved in a lab in New Mexico.

The temperature record was set recently in a test shot at the Z Pinch device at Sandia National Laboratory, where an immense amount of electrical charge is stored in a device called a Marx generator. Many capacitors in parallel are charged up and then suddenly switched into a series configuration, generating a voltage of 8 million volts.



Sandia National Laboratory

This colossal electrical discharge constitutes a current of 20 million amps passing through a cylindrical array of wires, which implodes. The imploding material reaches the record high temperature and also emits a large amount of X-ray energy.

Why the implosion process should be so hot, and why it generates X-rays so efficiently (10 to15 percent of all electrical energy is turned into soft X-rays), has been a mystery.

Now Malcolm Haines of Imperial College, in London, and his colleagues, think they have an explanation. In the hot fireball formed after the jolt of electricity passes through, they believe, the powerful magnetic field sets in motion a myriad of tiny vortices (through instabilities in the plasma), which in turn are damped out by the viscosity of the plasma, which is made of ionized atoms.

In the space of only a few nanoseconds, a great deal of magnetic energy is converted into the thermal energy of the plasma. Last but not least, the hot ions transfer much energy to the relatively cool electrons, energy which is radiated away in the form of X-rays. (Haines et al., *Phys. Rev. Lett*. 96, 075003, 2006)

Rare e-/e+/e- State

The best study of the rare "atom" consisting of two electrons and one positron has been reported.

Positronium (abbreviated Ps) is a very "clean" two-body object: it consists of an electron and a positron which after about 150 nanoseconds annihilate each other. For studying the theory of quantum electrodynamics (QED), Ps is in some ways better even than the hydrogen atom: with pointlike constituents and with no complicating nuclear forces, Ps is a simpler, albeit fragile, quantum system.

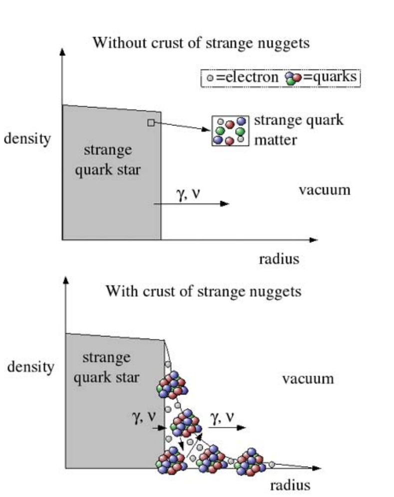
An even more fragile "atom" is the tripartite object consisting of two electrons and one positron. Ps^-, as it is known, is less suitable for QED studies than Ps, but has the great virtue of being the simplest three-body system in physics. Again, it is simpler than H^-, H_2^+, and helium because of its pointlike constituents and the absence of nuclear forces.

Ps^- is, like Ps, a bound state with discrete quantum energy states, although only the ground state is calculated to be stable against dissociation into Ps and a free electron. Very little is known about Ps^- beyond its lifetime.

Now, a new experiment carried out at the Max Planck Institute for Nuclear Physics in Heidelberg has measured the lifetime of Ps^- with a sixfold increase in precision (the new value is half a nanosecond). Ps^- is formed by shooting a positron beam into a thin carbon foil, and its size is actually a bit bigger than a hydrogen atom. (Fleischer et al., *Phys. Rev. Lett*. 96, 063401, 2006)

How Does Matter Terminate?

How does matter terminate? That is, at the microscopic level, how does nature make the transition from a densely packed material surface (the skin of an apple, say) to the nothingness that lies above? This issue is especially dramatic for collapsed stars, where the matter density gradient marking the star-to-vacuum transition can be as great as 10^{26} g/cm^4 (grams per cubic centimeter per centimeter of displacement).



A new model, proposed by physicists at Los Alamos and Argonne National Labs, claims that the prevailing theory of what happens at quark-star surfaces is wrong. These quark stars are characterized by interiors which consist of quark matter from the center all the way to the surface. For quark matter to exist in the low-pressure environment near the surface, matter containing nearly equal numbers of up, down and strange quarks must be preferred over neutrons and protons.

Theorists have speculated about this possibility (often called the Strange Quark Matter Hypothesis) since the early 1980's. A star made in this way, a quark star, is thought to be the densest possible type of matter. Any denser than this, and the star must become a black hole. In the ordinary kind of matter prevailing in our solar system, matter consists of up (u) and down (d) quarks. Converting u or d quarks to strange (s) quarks in neutrons or protons is typically unstable. In the high-density environment of quark stars, however, matter containing up, down, and strange quarks might be stable.

This process really comes into play in collapsed stars, where strange quarks could roughen the surface of the stars. Such a surface, says Los Alamos scientist Andrew Steiner, can be compared to a liquid surface. On Earth, liquid surfaces are generally flat. Because of surface tension, too much energy would be required to overcome the tension and form additional facets above the surface. At a quark star, by contrast, surface tension may not be large and the crust of the star could form extra surfaces, nugget-like objects without any undue energy cost. The positively charged quark lumps would be surrounded by a sea of electrons, as required to make the crust electrically neutral.

What would be the test of the hypothesis of an inhomogeneous termination at a quark-star surface? Again, the Los Alamos group is at odds with the prevailing model, which says that quark stars should be more luminous than neutron stars; this group predicts the quark bumps on an otherwise smooth surface at a quark star would enhance this scattering of photons and neutrinos, lowering the quark star's luminosity. (Jaikumar et al., *Phys. Rev. Lett.* 96, 041101, 2006)

Shock-Produced Coherent Light

Physicists at MIT and Livermore National Lab have discovered a new source of coherent radiation distinct from traditional lasers and free-electron lasers; they propose to build a device in which coherent photons are produced by sending shock waves through a crystal. The result would be coherent light resembling the radiation issuing from a laser; but the mechanism of light production would not be stimulated emission, as it is in a laser, but rather the concerted motion of row after row of atoms in the target crystal.

The passing shock front, set in motion by a projectile or laser blast, successively excites a huge density wave in the crystal; the atoms, returning to their original places in the matrix, emit light coherently, mostly in the Terahertz wavelength band. Although sources of coherent light in this part of the electromagnetic spectrum have developed in recent years, it is still a difficult task.

The next step will be to carry out an experimental test of the shock-wave light production. According to Evan Reed, the first likely application of coherent radiation will be as a diagnostic for understanding shock waves. The radiation should provide information about shock speed and the degree of crystallinity. (Reed et al., *Phys. Rev. Lett.* 96, 013904, 2006)

Nuclear Molecule: Nature's Smallest Dumbbell

An oxygen molecule is a small dumbbell less than a nanometer across: two oxygen atoms with two electrons flying between acting as the bonding agent. Now, an international consortium has succeeded in making a dumbbell far smaller: a beryllium-10 nucleus consisting of two alpha particles with two neutrons flying between acting as a sort of nuclear bonding agency.

This nuclear dumbbell is only a few fermis (10^{-15} m) across. These tiny oblong nuclei are made by colliding a beam of helium-6 nuclei into a gas of helium-4 atoms. (The helium-6 nuclei, which are themselves a novelty, were made by shooting protons at lithium.)

The berillium-10 nuclei created in this way don't live very long. With a lifetime of about 10^{-21} seconds, they fly apart, usually back into helium-4 and helium-6 fragments.

Martin Freer says that the beryllium results support the idea that nuclei sometimes behave like atomic systems in that they can be thought of as a core of particles with extra "valence" particles (electrons/neutrons) exchanged between cores. Several exotic shapes are thought to be possible among the light nuclei. Carbon-12, for instance, can exist as a triangular arrangement of three alpha particles and oxygen-16 as a tetrahedron of alphas. These nuclei are tightly bound, so their exotic geometry cannot be discerned. But berillium-10's prolate shape can be seen clearly through the rotational behavior of the decaying system. (Freer et al., *Phys. Rev. Lett.* 96, 042501, 2006)

Relativistic Electron Cooling

Relativistic electron cooling of an antiproton beam has been demonstrated at Fermilab.

Increasing the density of antiprotons by reducing the spread in longitudinal speeds leads to a larger collision rate in particle colliders, producing more sought-after scattering events that contain rare particles and decays.

Antiprotons, made artificially by smashing protons into a metal target, must be collected on the fly and focused before they can be accelerated and collided with opposite-moving batches of protons; such proton-antiproton smashups are the premier activity at Fermilab's Tevatron facility.

The more compact and tightly focused the two beams are, the more desirable high-energy collisions there will be. The degree of focus and beam density is expressed in a parameter called luminosity. To achieve interesting results it is desirable to have both high collision energy and high luminosity. Taming swarming antiprotons, however, is difficult. One would like all the antiprotons to be co-moving at the same velocity, but because of the way they're made in the first place, they will be flying at high speeds through a beam pipe with a variety of motions, both longitudinal and lateral. The lateral motions can be largely suppressed by a process called stochastic cooling.

Reducing the spread in longitudinal speeds has been harder to accomplish, until now. In the new Fermilab process a continuous beam of electrons at an energy of 4.8 MeV is made to overlap with a beam of 8.9 GeV antiprotons which, because of their higher mass, move at the same speed as the electrons. The electron beam removes some of the unwanted longitudinal velocity spread, increasing thereby the luminosity by a factor of 30 percent. Electron cooling of this kind has been used before but only with much lower-energy particle beams. (Nagaitsev et al., *Phys. Rev. Lett.* 96, 044801, 2006)

Unwired Energy

Recharging your laptop computer or your cell phone might one day be done the same convenient way many people now surf the Web–wirelessly. At the November AIP Industrial Physics Forum, in San Francisco, Marin Soljacic (MIT) spoke about how energy could be transferred wirelessly by the phenomenon of induction, just as coils inside power transformers transmit electric currents to each other without touching. The idea of wireless energy transfer is not new. Nikola Tesla was working on the idea more than a century ago but failed to develop a practical method.

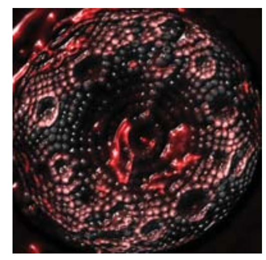
In the new MIT scheme, a power transmitter would fill the space around itself with a non-radiative electromagnetic field–meaning that its energy would not ripple away as electromagnetic waves. Energy would only be picked up by appliances specially designed to resonate with the field; most of the energy not picked up by a receiver would be reabsorbed by the emitter.

Contrary to more traditional, radiative means of energy transmission such as microwaves, it would not require a direct line of sight. It would be innocuous to people exposed to it. With designs proposed by Soljacic in a paper with Aristeidis Karalis and John Joannopoulos, an object the size of a laptop could be recharged within a few meters of the power source. Soljacic and his MIT colleagues are now working on demonstrating the technology in practice.

The Sharpest Object Yet

The sharpest object yet made is a tungsten needle tapering down to about the thickness of single atom.

The needle, made by postdoc Moh'd Rezeq in the group of Robert Wolkow at the University of Alberta and the National Institute for Nanotechnology, starts out much blunter. Exposed to a pure nitrogen atmosphere, however, a rapid slimming begins. To start with the tungsten is chemically very reactive and the nitrogen roughens the tungsten surface. But at the tip, where the electric field created by applying a voltage to the tungsten is at its maximum, N_2 molecules are driven away. This process reaches an equilibrium condition in which the point is very sharp.



Furthermore, what N_2 is present near the tip helps to stabilize the tungsten against further chemical degradation. Indeed, the resultant needle is stable up to temperatures of 900 degrees Celsius even after 24 hours of exposure to air.

The probe tips used in scanning tunneling microscopes (STMs), even though they produce atomic-resolution pictures of atoms sitting on the top layer of a solid material, are not themselves atomically thin. Rather their radius of curvature at the bottom is typically 10 nm or more.

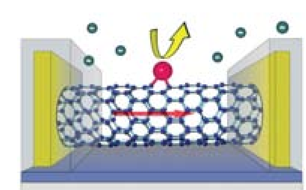
Wolkow says that although a narrower tip will be useful in the construction of STM arrays (you can pack more tips into a small area; and a wide array might even permit movies of atomic motions) the spatial resolution won't improve thereby. The real benefit of the sharp tungsten tips, he believes, will be as superb electron emitters. Being so slender, they would emit electrons in a bright, narrow, stable stream. (Rezeq, Pitters, and Wolkow, J. *Chem. Phys*. 124, 204716, 2006)

Chemical Transistor

A new device, the chemical equivalent of a transistor, might make possible ultrasensitive bio-medical single-antigen detection.

The things we associate with transistors, the closing or opening of a switch or the amplification of a signal, are normally carried out by injecting a tiny electric signal into a gate electrode which then changes the environment of a nearby channel region. This allows a current to be shut off or to be amplified. In an experiment carried out by physicists at the University of California at Irvine, the same things are done through chemical reactions.

Philip Collins and his colleagues use carbon nanotubes as the central working substance of their device. The nanotubes, immersed in a liquid, can be switched from a conducting state to an insulating state by oxidizing them. The chemical reactions are triggered by an electrical potential applied across the interaction area.



The Irvine researchers showed that this process can be performed reversibly and over short periods of time, as fast as 10 microseconds. This is quite slow by today's transistor standards; the more important promise for prospective chemical field effect transistors (or ChemFETs) is the potentially large amplifications. It looks as if only a few electrons' worth of oxidation can be used to switch currents as large as microamps.

In a future bio-detector the switching would be provided not by an applied electrochemical signal but by the trace presence of antigens docking with antibodies attached to the nanotubes. In previous detectors, chemical actuation has required the presence of tens of antigens; here, a single antigen might be enough to change the state of the nanotube. (Mannik et al., *Phys. Rev. Lett.* 97, 016601, 2006)

Liquid Flowing Uphill; Might Be Used to Cool Chips

In a phenomenon known as the "Leidenfrost effect," water droplets can perform a dance in which they glide in random directions on a cushion of vapor that forms between the droplets and a hot surface. Now, a U.S.-Australia collaboration shows that these droplets can be steered in a selected direction by placing them on a sawtooth-shaped surface.

Heating the surface to temperatures above the boiling point of water creates a cushion of vapor on which the droplet floats. The researchers think that the jagged sawtooth surface, acting as a sort of ratchet, redirects the flow of vapor, creating a force that moves the droplet in a preferred direction. The droplets travel rapidly over distances of up to a meter and can even be made to move up inclines.

This striking method for pumping a liquid occurs for many different liquids (including nitrogen, acetone, methanol, ethanol, and water) over a wide temperature range (from -196 to +151 degrees Celsius). A practical application of this phenomenon might be to cool off hot computer processors. In a concept the researchers plan to test, waste heat in a computer would activate a pump moving a stream of liquid past the processor to cool it off. Such a pump for coolants would need no additional power, have no moving parts, and would spring into action only when needed, when the processor gets warm. (Linke et al., *Phys. Rev. Lett.* 96, 154502, 2006)

Stock Market Criticality

In the months before and after a major stock market crash, price fluctuations follow patterns similar to those seen in natural phenomena such as heartbeats and earthquakes, physicists write in the 17 February *Physical Review Letters.*

A University of Tokyo team studied the Standard & Poor's S&P 500 index, focusing on small deviations from long-term index trends. Such up-and-down blips in stock prices are usually "Gaussian," at least when measured over sufficiently long time scales–for example, for more than one day. That means that fluctuations are likely to be small, while larger fluctuations are less likely, their probabilities following a bell curve.

But when the team looked at 2-month periods surrounding major crashes such as the Black Monday event of October 19, 1987, they saw a different story: Fluctuations of all magnitudes were equally probable. As a consequence, the graph of index fluctuations looked statistically similar if plotted over different time scales, anywhere between time scales of 4 minutes and two weeks.

Such behavior is called critical in analogy with a ferromagnetic metal at the "critical temperature," when regions form where the metal's atoms arrange their spins in the same direction, and these regions look similar at different levels of magnification. This self-similarity is also seen in the time intervals between heartbeats, or between earthquakes. Mathematically, however, the stock market case differs in that the probabilities do not change with the size of the event, while in other cases of non-critical self-similarity, the probabilities usually follow a power law.

It is unclear what individual trading decisions lead to criticality in the stock market, co-author Zbigniew Struzik says, although he and the team at the University of Tokyo are working on finding explanations. Also unclear is whether the findings could one day lead to an early-warning system to predict crashes, and if such a system would precipitate a crash– or create one artificially–by inducing panic. (Kiyono et al., *Phys. Rev. Lett.* 96, 068701, 2006)