Physics News in 2004

A Supplement to *APS News*

Edited by Phillip F. Schewe, Ben Stein and Ernie Tretkoff
Media & Government Relations Division, American Institute of Physics (AIP)

INTRODUCTION

Physics News in 2004, 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 complied 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 past 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/.

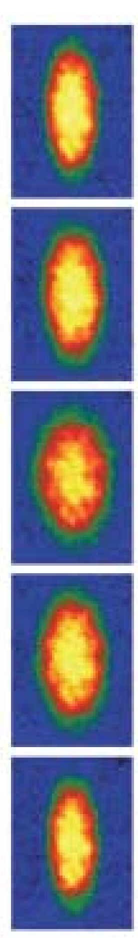
Single-Spin MRFM Sensitivity At IBM. The presence of a single electron's spin has been detected by a magnetic resonance force microscope (MRFM), a device that brings together two exquisite sensing technologies—magnetic resonance imaging (MRI) and atomic force microscopy (AFM).

The ultimate goal of MRFM is to map the interior of a material sample, such as a complicated semiconductor structure or a bio-molecule, at atomic-scale resolution. To do this the MRFM uses a very frail cantilever, 85 microns long and 150 nm thick, with a tiny magnetic tip, plus a nearby radio-frequency coil to create a bowl-shaped resonance zone. Any magnetic particle—such as a single electron or the nucleus of a hydrogen atom—that comes into the zone can interact magnetically with the cantilever, whose oscillation frequency is altered in a detectable way by the presence of the spin.

Since MRFM made its debut more than a decade ago the sensitivity of the device has improved by a factor of ten million, but it can't yet detect single nuclei because the magnetic moment of a single nucleus is too weak, about 650 times weaker than an electron's magnetic moment.

In July, for the first time, an MRFM mustered sufficient sensitivity to detect the spin of a single electron amid a sample where most of the electrons in the atoms are paired up. Dan Rugar and his colleagues at IBM Almaden (San Jose) reported on an MRFM device which uses a slender cantilever operating at a temperature of 1.6 K. The precision of the setup and the chilly conditions permit single electrons in a silicon dioxide sample to be located. The associated spatial resolution, at least in one of the three dimensions, is a mere 25 nm. In terms of imaging sharpness the new IBM device is about 40 times better than the best conventional MRI available. MRFM may also play a part in future quantum information devices owing to its ability to manipulate and read the quantum state of individual spins. (D. Rugar, *et al., Nature* **430**, 329, 2004)

First Evidence For Superfluidity In An Atom-Based Fermi Gas. In April, researchers at Duke University reported evidence for superfluidity in an atom-based Fermi gas. In essence, the researchers observed an ultracold gas of lithium-6 atoms acting as one big vibrating "jelly," and found evidence that their gas was a superfluid, a "perfect" jelly that vibrates for a long time after being shaken.



To produce the observed behavior, the researchers believe that the interaction mechanism among their lithium-6 atoms is in a "cross-over regime," a condition in which the atom pairs are neither molecules nor the type of weakly bound Cooper pairs found in conventional superconductors. In their experiment, the researchers cooled and trapped lithium-6 atoms with a focused laser beam, whose electric field confined the atoms. To start vibrations in the gas, they turned off the trapping laser for a short time, allowing the gas to expand, and then turned the laser back on again. At this point the gas cloud was quivering, and the researchers took a series of pictures to show these vibrations (*See figure*). They measured the cloud's frequency of vibration, as well as how long the vibrations persist. In one case, they adjusted the magnetic field so that the atoms were strongly interacting. In this instance, they measured a frequency of vibration of 2837 Hz, in very close agreement with a theoretical prediction of 2830 Hz for a hydrodynamic Fermi gas. Lowering the temperature of the gas caused the vibrations to last for a longer time, in contrast to an ordinary hydrodynamic gas, in which a lower temperature would cause the oscillations to damp out more quickly.

The Duke physicists ruled out two non-superfluid scenarios for the behavior. Still, the researchers do not have an ironclad case for superfluidity yet, in large part because the theory for strongly interacting superfluid Fermi gases is incomplete. In summary, the experiments constitute the first evidence for what could plausibly be superfluid behavior based on pairs of fermion atoms in a gas. (Kinast *et al., Phys. Rev. Lett*. **92**, 150402, 2004)

Large, Mature Galaxies Formed Surprisingly Early. One would expect that a census of the farthest galaxies that formed earliest in the universe's history would feature numerous small, hot, young, blue galaxies, perhaps smashing into and coalescing with each other. But the Gemini Deep Deep Survey (GDDS) shows something very different. The GDDS explored the so-called Redshift Desert, the poorly patrolled region of cosmic history roughly 3-6 billion years after the Big Bang. Galaxies there are redshifted into a spectral region that corresponds to a natural, obscuring glow in Earth's nighttime atmosphere. Astronomers used a sophisticated technique at the 8-m Gemini North telescope in Hawaii to reveal the feeble spectra of more than 300 galaxies. Survey team member Roberto Abraham (University of Toronto) now speaks of a "Redshift Dessert" with plenty of massive old galaxies where one would expect few. He and his colleagues reported the results at the January meeting of the American Astronomical Society in Atlanta, Georgia. They found that, in a 4-billion-year-old universe, elliptical galaxies up to 3 billion years old already existed. Furthermore, the galaxies in the survey have many heavy atoms that need to be cooked up in repeated cycles of star birth and supernovae. Abraham says that all of their observations should make theorists sweat. (R. G. Abraham et al., *Astron. J.*, **127**, 2455, 2004; S. Savaglio *et al., Astrophys. J.*, **602**, 51, 2004)

Evidence For A Superfluid Solid. In January 2004, two physicists at Penn State reported the results of an experiment in which a solid made of helium-4 atoms appears to behave like a superfluid. Moses Chan and Eun-Seong Kim looked for signs of bizarre quantum behavior in a tiny disk hung from a slender rod. They filled the disk with a porous glassy material (Vycor), into which they inserted helium-4 atoms. Then they chilled the sample to 2 K and subjected it to a pressure of 63 atmospheres, turning the helium into a solid. They oscillated the disk and recorded its resonant frequency. Next the researchers cooled the helium-filled disk further. Below a temperature of about 175 mK a phase change seemed to occur: Without losing its status as a solid, the helium acted like a superfluid. Evidence for this consists in the lowering of the resonant frequency. (*Nature* **427**, 225, 2004)

In September, Chan and Kim reported that they had modified their approach to demonstrate the superfluid-like behavior of a solid in a new way. This time, the solidified helium was not ensconced in any glass matrix. The He atoms were admitted to an open ring-shaped channel in a simple chamber which is free to swivel. Next the He atoms were chilled and submitted to high pressure, causing solidification. One can tell that the helium at this point is solid because of the characteristic oscillation properties. At an even lower temperature, 230 mK, the swiveling changes again, suggesting to Chan and Kim that a portion of the solid (about 1.5% of the sample) has metamorphosed into a freely flowing—but still solid—state of matter, or a frictionless "supersolid." (*Science* **305**, 1941, 2004)

Color Glass Condensate (CGC), an extreme form of nuclear matter, may have been created in experiments at Brookhaven's Relativistic Heavy Ion Collider (RHIC). At the Quark Matter 2004 conference in January in Oakland, California, experimentalists presented possible preliminary evidence for this novel state of matter. While nuclear physicists are debating the evidence for a CGC, the concept itself is an accepted, if evolving, theoretical idea that may describe a universal form of matter at high energies.

During the first quarter of 2003, RHIC researchers studied the collision of gold ions with deuterons. They used a deuteron beam precisely to avoid making the coveted quark-gluon plasma (QGP), the hypothetical soup of individual quarks and gluons that the RHIC researchers hope to recreate in their future experiments. They did this in order to better observe the CGC state, which many believe would be a precursor to QGP.

So what is a color glass condensate? According to Einstein's special theory of relativity, when a nucleus travels at near-light speed, it flattens in its direction of motion. Also, the high energy of an accelerated nucleus may cause it to spawn a large number of gluons, the particles that hold together its quarks. These factors may transform a spherelike nucleus into a flattened "wall" made mostly of gluons. This wall, 50-1000 times more dense than ordinary nuclei, is the CGC.

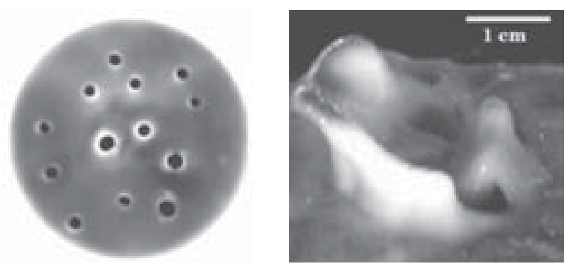
Reporting their gold-deuteron data at the Quark Matter conference, researchers in the BRAHMS collaboration observed fewer-than-usual high-momentum particles emitted transverse to the direction of the collision. According to BRAHMS spokesperson Jens Jørgen Gaardhoje, the data provided evidence that the deuteron nucleus formed a CGC. Gaardhoje pointed out there are conflicting theoretical views, but considers the suppressed production of high-momentum particles to be "a necessary feature" of a CGC. Whether it is sufficient evidence is another story, he says, and the next RHIC runs should provide further insights.

According to Brookhaven theorist Larry McLerran, the CGC has the potential to explain many things in high-energy nuclear physics such as the mechanisms by which particles are produced in nuclear collisions as well as the distribution of gluons inside nuclei. (For more information, see *Brookhaven News Release*, http://www.bnl.gov/bnlweb/pubaf/pr/2003/bnlpr122203.htm)

Halfway Across The BEC-BCS Prairie. In January researchers in Colorado reported the discovery of a new form of atomic matter, a fermionic condensate unlike anything seen before.

Fermions, if you pair them, can become bosons and enter pairwise into a quantum condensate. There is, however, a whole spectrum of pairing mechanisms. At one extreme is the case where the atoms pair strongly, after which they can (as molecules) collapse into a Bose Einstein condensate (BEC). At the other end of the spectrum the atoms can pair weakly, or more to the point, combine in an unbound but correlated state analogous to the Cooper pairs of electrons that form the essence of quantum currents in superconductors or the pairs of helium-3 atoms that constitute a superfluid. A number of labs have reported forming condensations of strongly-bound molecules. In January Deborah Jin and her colleagues at NIST and the University of Colorado reported making great progress in moving across the plain between the BEC and BCS pairing alternatives. The type of pairing can be adjusted by altering the strength of an external magnetic field. The NIST researchers, who cool potassium-40 atoms to microkelvin temperatures, are at the crossover region: they are not at the BEC regime because the applied magnetic field would not permit the kind of pairing one needs for a BEC condensate. Also they can affirm that they are not in the BCS regime either because the strength of the interaction among atoms is too strong for the kind of weak Cooper pairing that occurs in superconductivity or helium-3 superfluids. This new condensed form of atomic matter should not be thought of merely as a way station between the BEC and (weak) BCS pairing alternatives, but as a unique state in its own right. (Regal *et al.*, *Phys. Rev. Lett*. **92**, 040403, 2004; additional background in *Physics Today*, Oct. 1999 and Oct. 2003.)

Persistent Holes have been observed in a shaken non-Newtonian fluid. Normally, a fluid takes the shape of its container and any puncture of the surface quickly fills. However, in an experiment performed at the University of Texas at Austin, stable holes appeared in a cornstarch-water mixture that was vertically vibrated at frequencies above 120 Hz, with accelerations between 12 and about 20 times the gravitational acceleration. Holes did not form spontaneously; but if a puff of air poked a hole in the fluid, the hole could persist indefinitely. As seen from above in the left photograph, the holes had diameters comparable to the 5-mm depth of the fluid and extended to the bottom of the container, which was 9.4 cm across. The researchers attribute the holes' stability to shear thickening—an increase of viscosity with shear rate. At higher accelerations, as shown in the side view (right) of a single hole, the rim grew fingerlike protrusions that rose 2 cm above the surface and undulated erratically. (F. S. Merkt *et al.*, *Phys. Rev. Lett.* **92**, 184501, 2004.)



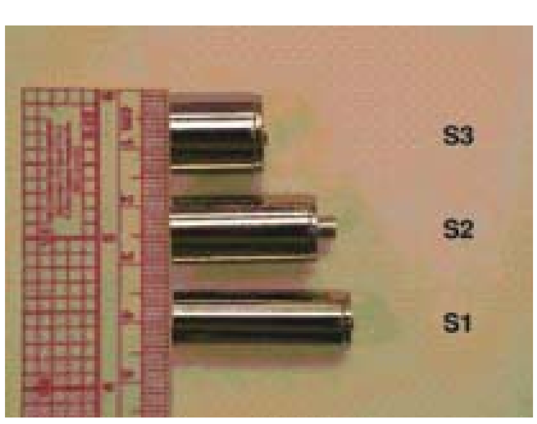
Element 115 Has Been Discovered at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia. JINR physicists and their collaborators from Lawrence Livermore National Lab in the US produced 4 atoms of the new superheavy element by striking a target of americium—243 atoms with a beam of calcium—48 ions. The beam energy used, 248 MeV, was chosen to produce just the right energy conditions for making the amalgamated nucleus but not causing it to break up right away.

The nuclei of these precious atoms apparently lived for 90 msec. They expired by decaying first to element 113 by the emission of an alpha particle; then to element 111 by alpha emission again; and then by three more alpha decay steps to element 105 ("Dubnium") which, after the delay of a whole day, from the time of the original interaction, finally fissioned.

The long lifetime observed for element 115 suggests that physicists might be getting closer to the "island of stability," the presumed region on the chart of possible nuclear isotopes for which certain combinations of protons and neutrons are much more stable than some of the other heavy nuclei made artificially at accelerators. This experiment also marks the discovery of a second element, 113, which had not been seen before either. (Oganessian *et al.*, *Phys. Rev. C* **69**, 021601(R), 2004)

The Accelerating Expansion of the universe, the notion that the big bang enlargement of spacetime is not slowing down but actually gathering speed, received new experimental support in the form of supernova observations made by the Hubble Space Telescope (HST). Previous evidence for such a cosmic acceleration consisted of studies of the dimness of remote supernovas, and represented a major revision for some scientists who had long thought that the mutual gravity among galaxies would slow or even reverse the cosmological expansion. The new HST observations consist of reexaminations of 170 previously studied supernovas and the announcement of 16 new objects, including 6 of the 7 most distant type Ia supernovas yet recorded. The new data are in line with the accelerating-expansion hypothesis employing the mysterious mechanism usually referred to as "dark energy." The energy of the universe would be divided up as follows: 29% in the form of matter (dark plus luminous) and 71% as dark energy. (Riess *et al.*, *Astrophys. J*, **607**, 665, 2004)

Amorphous Steel with large cross-sections, long a goal of metallurgists, has been fabricated by scientists at Oak Ridge National Lab. The amorphous steel produced has a hardness and strength more than twice that of the best ultra-high-stength conventional steel. Some amorphous (glassy) iron-based alloys have been employed in making transformer cores, and have reduced energy losses thereby by two-thirds. But not until now has glassy steel of the kind used in building structures been made.



Steel, an alloy of mostly iron atoms with varying amounts of carbon and other elements, is ordinarily a crystal. If produced quickly from a liquid phase, however, a disordered solid can result. The addition of a small amount of yttrium frustrates the onset of crystallization as the liquid metal solidifies.

The researchers have produced centimeter-sized pieces of the amorphous steel, and they believe that structural steel in bulk metallic glass form can be produced economically with traditional drop-casting methods, in which metallic glasses are made by pouring the hot liquid into a cold copper mold. In addition, the steel is ferromagnetic at cryogenic temperatures but paramagnetic at room temperature, a property the researchers say could open up new industrial applications. (Z. P. Lu et al., *Phys. Rev. Lett.* **92**, 245503. See also related work reported by a University of Virginia group: Ponnarnbalam *et al.*, *J. Mat. Res*, **19**, 1320, and by a Caltech group: Xu *et al.*, *Phys. Rev. Lett*. **92**, 245504, 2004).

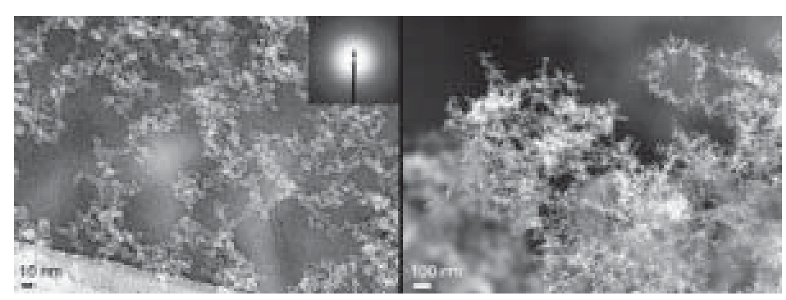
Sub-Wavelength Lensing in flat panels of left-hand materials (LHM) has been seen in two experiments. This means that a planar sheet—and not something that has to be machined into a traditional lens shape—can be used to focus light into a tight spot. The size of this spot, furthermore, is less than half the wavelength of the light being used. Getting around the diffraction limit would be a boon to optics and is normally achieved only by parking the object very close to the source of the illumination.

Left-handed materials possess a negative index of refraction. This means that a light ray approaching from air into the LHM will be deflected not toward but back and away from a line drawn perpendicular to the surface of the material. This bizarre deflection leads to novel optical effects. When the idea of the LHM phenomenon was first propounded, many felt that such materials could not exist. Even after the first experiments were reported skepticism lingered. Later more evidence arrived showing preliminary lensing effects with flat panels, the hallmark of LHM optical abilities.

Now, two groups have reported more direct evidence for flat-panel lensing and for better-than-wavelength focusing. George Eleftheriades and his colleagues at the University of Toronto, using a material devised from printed metallic strips mounted on a plane and sandwiched between two patterned sheets, show that a source of microwaves can be lensed better than the diffraction-limit would allow, but not into a "perfect focus" called for in some LHM theories. The energy losses in the material, which some commentators had predicted would hamper prospective LHM lenses, were actually quite minimal. Meanwhile, Vladimir Kissel and his associates at the Institute for Theoretical and Applied Electromagnetics in Moscow have also observed "superresolution" in their lensing of microwaves with a flat panel, achieving a spatial resolution as good as one-tenth the wavelength. (Grbic and Eleftheriades, *Phys. Rev. Lett*. **92**, 117403, 2004, and Lagarkov and Kissel, *Phys. Rev. Lett*. **92**, 077401, 2004)

Sedna, A Planet-Like Object, is the most distant body in our solar system discovered so far, and is probably the largest thing found in the solar system since the discovery of Pluto in 1930. First spotted using a modest 48-inch telescope by Caltech astronomers, and then scrutinized by much larger scopes, Sedna is believed to have a 10,500-year orbit around the Sun, and is presently about 13 billion kilometers away, but should swing as far away as 130 billion kilometers in its elongated trajectory before returning toward the sun. Astronomers who have studied the object believe it is smaller than Pluto and might represent the first object from the Oort Cloud to be glimpsed. Long held to be the outermost preserve of matter in the solar system, the Oort Cloud (or at least its inner edge) might be a bit nearer than previously thought, if Sedna is indeed an Oort object. (NASA press conference, 15 March 2004.)

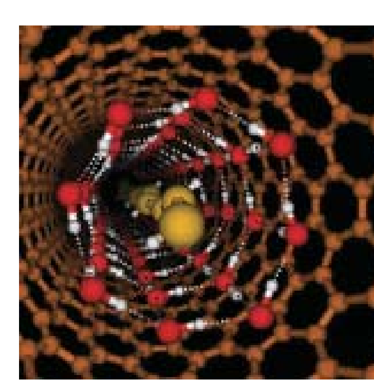
Carbon Nanofoam Is The First Pure-Carbon Magnet. Discovered a few years ago, carbon nanofoam is the fifth known allotrope of carbon—the others being graphite, diamond, fullerene, and carbon nanotubes. The foam is one of the lightest known solid substances (with a density of ~2 mg/cm^3). It is also a semiconductor. At the 2004 APS March Meeting, physicists announced an even more interesting property: though made entirely from carbon atoms that are normally considered nonmagnetic, the foam nevertheless can act like a ferromagnet.



Blasting a high-power laser at disordered solid carbon, a Greece-Australia-Russia research collaboration created a gossamer web made of carbon clusters (with an average diameter of 6-9 nanometers) randomly interconnected. Unlike other forms of carbon, freshly produced carbon nanofoam is ferromagnetic; that is, it is strongly attracted to a permanent magnet at room temperature. Although the room-temperature ferromagnetic behavior disappears after a few hours, it persists at lower temperatures.

Researchers have concluded that the observed novel magnetic behavior is an intrinsic property of the carbon nanofoam and can be traced to its complex microstructure. Namely, carbon atoms in the foam form heptagon structures that have an unpaired electron, one that does not form a chemical bond and has a magnetic moment which may lead to the magnetism. The researchers also have preliminary indications that the novel magnetic behavior also occurs in another nano-compound made of boron and nitrogen, two other elements that are ordinarily non-magnetic. One possible application of the carbon nanofoam is in biomedicine, where tiny ferromagnetic clusters injected into blood vessels could increase the quality of magnetic resonance imaging pictures. (J. Giapintzakis *et al.*, APS March Meeting paper: Paper A17.005, and A.V. Rode *et al.*, *Phys. Rev. B* **70**, 054407, 2004)

Nanotube Water, a one-dimensional form of water consisting of a string of water molecules confined in a carbon nanotube, has been studied with neutron scattering by physicists at Argonne National Lab. Neutron scattering measurements, along with computer simulations of the molecular interactions between the water and the surrounding single-walled carbon nanotube, confirmed that water molecules had successfully been taken up into the nanotubes in the form of a "wire." Surrounding the water wire was another water structure, a sheath of water (*See figure*).



The result of this novel architecture was that fluid-like behavior was observed at temperatures far below the freezing point of normal water. The hydrogen bonds along the water chain seem to be softened, allowing, for example, a freer movement of protons along the chain. The Argonne researchers believe that this anomalous behavior might help to explain other phenomena featuring nm-scale confined water, such as water migration from soil to plants via xylem vessels and the proton translocation in transmembrane proteins. (A. I. Kolesnikov *et al.*, *Phys. Rev. Lett.* **93**, 035503, 2004)

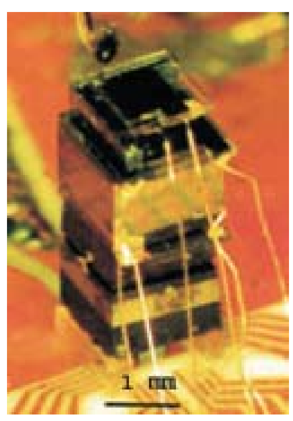
Entanglement Between A Photon And A Trapped Atom has been directly observed for the first time, offering a method for establishing links between quantum memories over appreciable distances. Entanglement has usually been directly measured between species of the same kind, such as all photons or all atoms. In recent experiments, however, University of Michigan researchers achieve inter-species entanglement by trapping a cadmium ion with electric fields. They put the trapped cadmium's outer electron into an excited state. The atom immediately decays to one of two ground states while emitting a photon. The photon's polarization correlates with the resulting ground state of the atom.

This cross-species entanglement technique has shortcomings—researchers cannot actively create an entangled state but must wait for it to occur by detecting the photon, so the entanglement is immediately destroyed and efficiency is not high. However, if two remotely located trapped atoms simultaneously decay in the same way as reported in this experiment, and the two emitted photons are jointly detected after interfering on a beamsplitter, then the two atoms become entangled and available for subsequent use for long-distance quantum computing and quantum communication. (Blinov *et al., Nature* **428**, 153, 2004).

Parity Violation In Electron-Electron Scattering has been seen for the first time, adding to physicists' understanding of the weak force. According to parity conservation, physics is the same in both ordinary and mirror worlds. The weak force does not conserve parity, a fact established in the 1950s by watching the decays of cobalt nuclei. Since then parity violation has also been observed in other reactions, such as transitions between energy levels within atoms and electron-positron annihilations, but never before in low-angle, relatively low-energy electron-electron scattering.

Electrons participate not only in electromagnetic interactions, but also in weak nuclear interactions via beta decay and related processes. Researchers at SLAC scattered a high-energy beam of polarized electrons off electrons in a liquid hydrogen target and measured the fractional difference in scattering rates when the intrinsic spin of the beam electrons was lined up with or against the direction of the beam. The observed asymmetry not only demonstrated that a bit of parity-violating force was present (in keeping with theoretical ideas about the weak force) but also provided the first direct measurement of the electrons' "weak charge." The value was in excellent agreement with predictions of the standard model of particle physics. (P. L. Anthony *et al.*, *Phys. Rev. Lett.* **92**, 181602, 2004.)

The World's Smallest Atomic Clock has been built at NIST in Boulder, Colorado. About the size of a rice grain (*See photo*), the clock is built around a semiconductor laser, micro-optics, a heater, and a microcell filled with cesium atoms. Using only 73 mW of electrical power, the clock has a precision of 2.5×10^{-10} over 1 second and 2.5×10^{-11} over 250 seconds. Far more precise clocks are available—some are good to about one part in 10^{-15} but they can require a large tabletop's worth of equipment. This new, tiny, low-power, high-precision clock is also likely to be cheap; it uses standard microfabrication techniques whereby the same process sequence can make thousands of the physics packages on silicon wafers. The timekeeper could be used, for example, in a variety of hand-held, battery-operated devices. (S. Knappe *et al., Appl. Phys. Lett.* **85**, 1460, 2004.)



Can Chemical Environment Affect Nuclear Properties? A new experiment shows that the decay lifetime of radioactive beryllium-7 changes by almost 1% when the Be-7 is placed inside a carbon-60 molecule. This is one of the largest shifts yet seen in a chemically induced modification of a nuclear lifetime. The Be-7 is unstable, and one way for it to decay is for the nucleus to capture one of its own electrons, a process in which a proton is turned into a neutron. If the Be atom lies in the cavity within a C_{60} molecule (in which case it is referred to as endohedral Be, or abbreviated further, Be@C_{60}) the surrounding halo of carbon-based electrons apparently modifies the wave-functions of the beryllium-associated electrons and the associated "phase space" so that the rate at which electrons are captured by the Be nucleus is speeded up. The researchers from Tohoku University and Yokohama National University (Japan) doing the present experiment believe that it would be premature to suggest that this approach can be used to mitigate the problems of storing radioactive materials, but, in the near term the use of endohedral fullerenes (cargo-carrying C_{60} molecules) might lead to specialized radio-therapies or tracers for tagging metabolic pathways in the body. (Ohtsuki *et al., Phys. Rev. Lett*. **93**, 112501, 2004)

Five-Photon Entanglement has been achieved by physicists at the University of Science and Technology in China. Previously the greatest degree of full quantum entanglement came in experiments involving four particles. The Chinese researchers entangle two pairs of photons, and then entangle these with yet another single photon. The progress from four to five entangled particles is significant since apparently the handling of quantum information with a built-in error correction process would require the manipulation of five entangled particles engineered to serve as qubits. (Zhao *et al., Nature* **430**, 54, 2004)

The Cassini Spacecraft Arrived At Saturn in June after a 3.5-billion-km, seven year voyage from Earth. For four additional years or longer the craft will loop around the ringed planet and its moons making various measurements. In December 2004 Cassini delivered a detachable probe, called Huygens, at the moon Titan. Titan is of great interest to scientists since it is the only moon in the solar system with an atmosphere of its own. (For more Cassini news, see NASA website: http://www.nasa.gov/mission_pages/cassini/main/index.html)

Optical Hall Effect. Physicists in Japan have shown theoretically that an optical equivalent of the Hall effect exists and that it should be seen in experiments with polarized light. In the classic Hall effect, an electric current pulled along a conductor by an electric field will be deflected sideways if a magnetic field is applied perpendicular to the electric field. The physicists say that something similar should happen when a polarized light ray moves from one medium into another. The angles of the reflected and refracted rays with respect to the incident ray still obey Snell's law, but the rays no longer all lie exactly in the same plane. The amount of the sideways shift at the deflection will depend on the change in the index of refraction between the two media. Masaru Onoda at the National Institute of Advanced Industrial Science and Technology in Tsukuba, Japan, and his colleagues at the University of Tokyo believe that the effect can be explored in upcoming experiments using photonic crystals. (M. Onoda *et al., Phys. Rev. Lett*. **93**, 083901, 2004)

3D Neutron Imaging For Medicine. To take pictures of the body, medical professionals conventionally use x-rays, magnetic fields, ultrasound, or radioactive isotopes. At the July meeting of the American Association of Physicists in Medicine in Pittsburgh, Duke University researchers presented the first 3D pictures—of an inorganic test object—from a new technique that employs neutrons. Neutrons are highly penetrating, and therefore can image deeply buried body structures that cannot be reached by other probes. In addition, neutrons can easily identify almost every naturally occurring chemical element in the body. Called Neutron Stimulated Emission Computed Tomography (NSECT), the technique involves illuminating the body with fast neutrons with energies between 1 and 10 MeV. The neutrons cause the nuclei of atoms and molecules in the body to emit gamma-ray photons with distinctive energies.

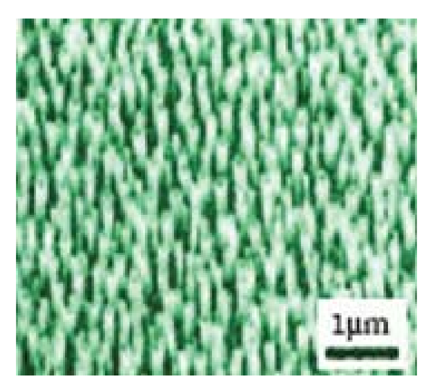
At the AAPM meeting, Carey Floyd presented the first 3D images ever reconstructed from the emission of characteristic gamma rays stimulated by fast neutrons. The images, of an iron-copper sample, demonstrate the technique's ability to completely distinguish between the iron and copper that made up the object. With further development, NSECT could potentially diagnose breast cancer early by looking for differences in the concentration of trace elements that are known to exist between benign and malignant tissue. While an individual neutron is more damaging to the body than a single x-ray of equal energy, the researchers' preliminary calculations indicate that an accurate test for breast cancer could be performed at a dose similar to that of a current mammography examination. As a next step, the group plans to develop a prototype system that can image the distribution of iron in the liver in order to diagnose hemochromatosis without the need for a biopsy. (AAPM Meeting Paper WE-D-315-6)

Acoustically Powered Deep-Space Electric Generator. Space is a new frontier for an acoustical version of a 19th century mechanical device. For future deep space missions to the outer planets and beyond, space agencies would like their probes to have a lighter, smaller, and more efficient source of electricity. With this need in mind, a Los Alamos-Northrop Grumman team has built a device that uses sound waves to produce 60 watts of electricity.

The core of this device is called TASHE, short for "thermoacoustic-Stirling heat engine." The TASHE is a looped contraption made from pipes and heat-exchanging devices. In the TASHE system, intense, spontaneously generated sound waves (in the place of mechanical pistons in the 19th century design) shuttle parcels of helium gas between a cold end and hot end. The hot and cold end temperatures are generated by connecting the engine to a high-temperature heat source and an ambient-temperature heat sink through the heat exchangers. Thermally driven expansion and contraction of the gas, in concert with pressure oscillations (induced by the temperature difference), intensify the power of the initial sound waves which become strong enough to drive a piston connected to the device. The motion of the piston vibrates a coil of copper wire that produces electricity as it moves relative to a permanent magnet.

The acoustic device has 18% efficiency, compared with 7% for thermoelectrics, the current electrical-generation technology in spacecrafts in which a temperature difference across a material is converted into electric power. The new device can produce a projected 8.1 watts of electricity per kilogram, as opposed to 5.2 watts/kg for thermoelectrics. These properties allow for a potential increase in the size and power of science instruments in future space probes. This is the latest application of the TASHE, which is also being developed to liquefy remote reserves of natural gas for a more economical transport of this fossil fuel resource to market than previously possible. (Backhaus, Tward, and Petach, *Appl. Phys. Lett*., **85**, 1085, 2004)

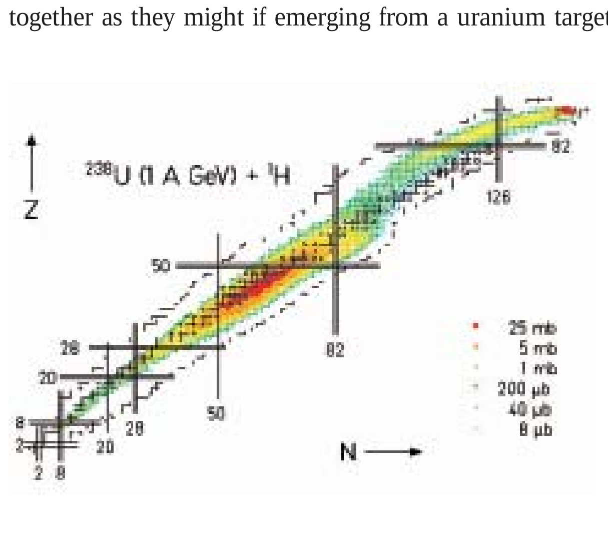
An Antenna For Visible Light, analogous to antennas for radio waves, can be made with carbon nanotubes. In a radio antenna, whose size is about equal to the wavelength of the incoming wave, the wave excites electrons into meaningful currents. Such a response, amplified and tuned, is the backbone of radio and TV broadcasting. At optical wavelengths, this is harder to do. Nevertheless, a rudimentary antenna effect for visible light has now been observed by scientists at Boston College using an array of carbon nanotubes, in which infalling light excites miniature electrical currents.



According to Yang Wang one would like to measure these electrical excitations directly, but this requires nano-diodes capable of processing electrical pulses oscillating at optical frequencies, and these are not yet available. The next best thing is to observe the secondary radiation emitted by the faint excitations. The nanotubes used in the experiment are in effect little metallic antennas about 50 nm wide and hundreds of nm long (*See figure*). Not only can the nanotubes respond in the manner of dipole radio antennas to incoming light, but they also exhibit a polarization effect: when the incoming light is polarized at right angles to the orientation of the nanotubes, the response disappears.

Possible applications for visible-light antennas include efficient solar energy conversion and optical television, in which a TV signal, superimposed on a laser beam sent down an optical fiber, is demodulated at the customer end by an array of nanotubes (each functionalized by a fast diode). (Y. Wang *et al., Appl. Phys. Lett.* **85**, 2607, 2004.)

Map of the Nuclear World. An experiment at the Gesellschaft fur Schwerionenforschung (GSI) in Darmstadt has created and analyzed the largest number of elements (from nitrogen up to uranium) and the largest number of subsidiary isotopes (1400) ever seen in a single nuclear research effort. The only ingredients were uranium and hydrogen. The GSI physicists did not smash a beam of protons into a stationary uranium target, but rather the other way around. The reason for slamming energetic U-238 nuclei into a stationary liquid-hydrogen target is that fragment nuclei of all sizes, flying away from the col-lision point, don't glom together as they might if emerging from a uranium target and, furthermore, can be more accurately identified since they are free of bound electrons whose electrical charge might confuse the task of measuring the number of protons in the detected particle.

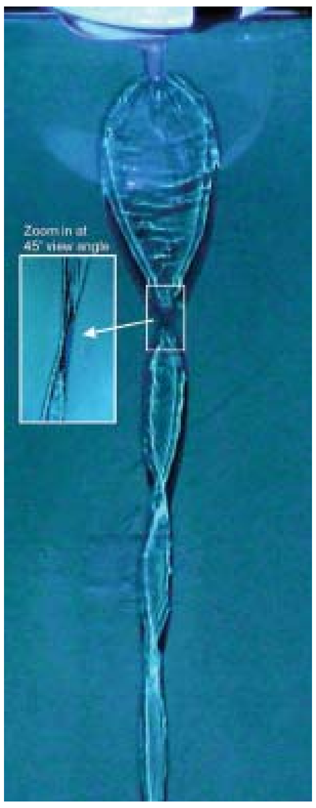


What comes out of this meticulous and comprehensive nuclear experiment is a set of cross sections, each a measure of the likelihood for creating that particular nuclide. The GSI work, in other words, not only enumerates a chart of the nuclides but produces a chart of cross sections for producing those nuclides in a collision (*See figure*). This information is valuable for planning a future accelerator of rare isotopes, for studying how to break down nuclear waste in sub-critical reactors, and for studying fundamental aspects of nuclear fission and nuclear viscosity. (Armbruster *et al.*, *Phys. Rev. Lett*. **93**, 212701, 2004)

CERN Celebrates 50th Anniversary. The European Organization for Nuclear Research, CERN, celebrated its 50th anniversary on 29 September. The Geneva-based CERN has been the site of several notable achievements and discoveries in the area of elementary particle physics. These include the observation (1973) of neutral-current weak interactions; the production (1983) of the Z boson and its charged cousins, the W+ and W- bosons; the creation of the World Wide Web (1990); hints of a novel kind of new nuclear matter (perhaps quark-gluon plasma) amid high-energy, heavy-ion collisions (2000); and creation of slow-moving anti-hydrogen atoms (2002).

The Large Electron Positron collider (LEP), recently retired, was the scene of additional high-precision measurements of the weak nuclear force and other aspects of the standard model. LEP is lending its 27-km-round tunnel for the construction of the Large Hadron Collider (LHC), in which two beams of 7-TeV protons (or heavy ions) will be collided head-on. Out of the violence of these smash-ups, physicists hope to achieve such long-sought goals as producing the Higgs boson and various members of a family of supersymmetric particles, and maybe even discern evidence for the existence of extra dimensions. Completion is expected in the year 2007. (See http://intranet.cern.ch/Chronological/2004/CERN50/)

Braiding Patterns In Flowing Streams have been explained by a University of New Mexico team. Ordinarily, a stream of water meanders when it flows down an inclined plane that is not perfectly water-repelling. Some researchers considered such meandering to be inevitable, even for water flowing down a perfectly smooth plane. But the New Mexico team discovered that meandering can be eliminated if water flows down the plane at a constant rate, a somewhat rare but possible occurrence. Moreover, such non-meandering streams often have visually striking "braids," a fixed pattern of wide and narrow water regions that goes all the way down the plane. Using a simple laboratory setup, the researchers discovered an easy way to duplicate this braiding pattern (*See figure*). They sent a fluid (a mix of water, glycerol and some food coloring) down a narrow cylindrical nozzle. As it exited the nozzle the fluid struck a slanted acrylic plane, where it formed a braiding pattern as it ran downstream into a lower reservoir. Describing the lab fluid's behavior with equations, the researchers found that braiding occurs as a competition between the fluid's inertia and surface tension. The researchers found it easy to tweak the braid's properties; for example, they could decrease the length of the braids by making the plane less steep and they could eliminate the braids altogether by increasing the viscosity of the fluid. It is possible these observations have geophysical implications. (K. Mertens, V. Putkaradze, and P. Vorobieff, *Nature* **430**, 165, 2004)



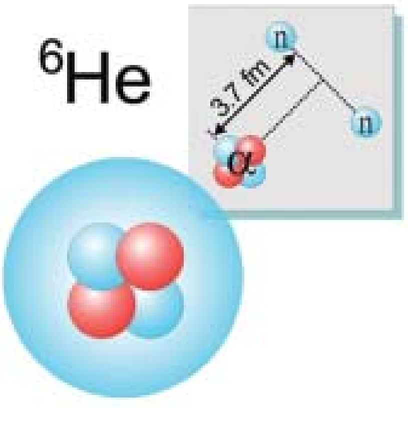
The 2004 Physics Nobel Prize went to David J. Gross (Kavli Institute, University of California, Santa Barbara), H. David Politzer (Caltech), and Frank Wilczek (MIT) for their discovery of asymptotic freedom, according to which the interaction between quarks inside nuclear particles such as protons and neutrons actually gets weaker the closer the quarks are to each other and stronger the farther they are apart. This hypothesis helped lead to the establishment of quantum chromodynamics (QCD) as a firm theory of the strong nuclear force, somewhat, but not exactly, in analogy with quantum electrodynamics (QED), the theory of the electromagnetic force.

The work of Gross, Politzer, and Wilczek explained why individual quarks could never be observed in the lab. In their picture, quarks are connected by lines of force embodied in the form of particles called gluons. The quarks themselves possess a "color charge" analogous to electrical charge. The energy that could be used to free quarks from each other's embrace—energy in the form, say, of a fast-moving incoming beam particle—would indeed force the quarks farther apart for a while, but this energy (imagine a rubber band being stretched) would eventually be converted into the creation of a new quark-antiquark pair. One or the other of these newly made quarks would immediately ally itself with one of the two separating quarks, resulting not in any free quarks but only in two quark pairs. Conversely, quarks very close together are practically free of each other's influence.

QCD has passed every confirmed experimental test so far, but physicists continue to look for oddities that might signify a departure from this theory.

(More information about the prize can be found at the Nobel Prize website: www.nobel.se/physics/laureates/2004; See also *Physics Today*, December 2004)

The Helium-6 Nucleus consists of a He-4 nucleus surrounded by a halo cloud consisting of two more neutrons. The charge radius for He-6 has been measured for the first time. The experimental value, 2.1 fm, is larger than the radius for He-4 (1.7 fm) because the halo neutrons in He-6 cause the core portion of the nucleus to inflate somewhat (*See figure*). The He-6 nuclei are made at Argonne National Lab by smashing a beam of lithium ions into a target. The stray He-6 atoms made in the process (about a million per second) are drawn into and lodged within a trap at a rate of about one a minute. This is sufficient to do laser spectroscopy on the atoms. The charge radius of the nucleus can be deduced from the way in which the frequency of the light corresponding to an internal atomic transition from one quantum state to another in the atoms is shifted in going from He-6 to He-4. Zheng-Tian Lu of Argonne says that He-6 is the lightest known nucleus to have a neutron halo, and that the collaboration's next experimental quarry, He-8, represents the most neutron-rich (highest neutron-to-proton ratio) nuclear matter in the world. (Wang *et al.*, *Phys. Rev. Lett*. **93**, 142501)

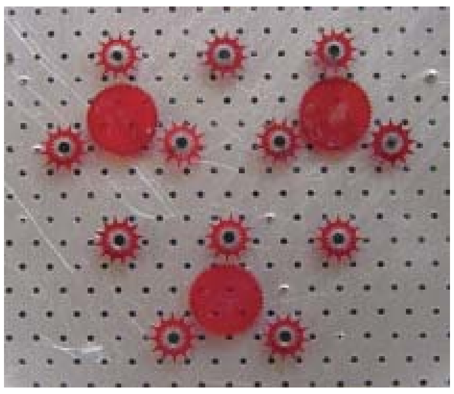


Our Sixth Sense Is As Fine-Tuned As It Can Be, says Todd Squires, a physicist at Caltech. He has investigated why the natural selection process, operating over evolutionary time, settled upon specific dimensions for the vestibular semicircular canals (SCC), the set of three mutually perpendicular, fluid-filled tubes housed in the inner ear of vertebrates that give an organism its sense of balance. The SCC structures are essentially donut-shaped, with a major radius of 3 mm and minor radius of 0.2 mm. The torus is interrupted by a membrane, called a cupula, impregnated with tiny hairs that sense the sloshing of the fluid through the canals. Sensing an acceleration or rotation involves the fluid being momentarily left behind while the head (and the SCCs) rotate in a new direction. The fluid displaces the cupula, deflecting the sensory hairs and triggering a neural signal to the brain and muscles controlling the eye. This is what gives us the sense of motion, and sometimes dizziness.

The SCC is roughly the same size (to within a factor of three) in mice as it is in whales. Why should SCCs be all of this one size, as if evolutionary pressures had "converged" on an optimal solution? In performing studies of optimal design, Squires varied four different key physical parameters—SCC major radius, minor radius, cupula thickness and height—and discovered that the greatest canal sensitivity occurred for those parameter values manifested in actual vertebrates.

Knowing how the canals work is important for understanding various forms of dizziness and for understanding peculiarities of some ordinary visual experiences. (Todd Squires, *Phys. Rev. Lett.* **93,** 198106, 2004)

Microfluidic Machines, self-assembled and yet reconfigurable, have been created by a collaboration of Northwestern, ProChimia Poland and Harvard scientists. The machines consist largely of patterns of rotors that perform a variety of tasks in a liquid environment, including manipulation or sorting of floating particles and mixing of reagents. The rotors are made in tiny molds and then loosed onto a liquid-air interface, where they are guided into place and set spinning by electromagnets positioned beneath the interface. By changing the magnet activity, the overlying rotors can be put into new arrangements for carrying out a new job (*See figure*). The rotors are at the millimeter scale but can be made much smaller. Unlike conventional machines the rotor arrays have no fixed axles and are virtually friction free. (Grzybowski *et al.*, *Appl. Phys. Lett.* **84**, 1798, 2004)



Supernova Debris On Earth, in the form of deposits of iron-60, a radioactive isotope of iron occurring on our planet at much smaller levels, has been studied by German physicists. The same team of scientists reported first signs of the deposits five years ago. Back then they analyzed three layers of South Pacific sediment, each over 2 million years thick in geologic time. The new measurements, acquired at a site some 3000 km away, are much more robust: 28 layers (rather than 3), from deeper depths (4830 m rather than 1300 m), with a better dating method (beryllium-10 dating) and a more accurate estimate of the layers' age (in some cases to within a few 100,000 years). On the basis of their measurement, the researchers deduce that the samples represent the remains of a star that exploded 2.8 million years ago (with an uncertainty of 0.3 million years) at a distance from Earth of some tens of parsecs. Depending on exactly how far away the supernova was, it might have had caused an increase in cosmic ray flux for about 300,000 years. (Knie *et al.*, *Phys. Rev. Lett*. **93**, 171103, 2004)

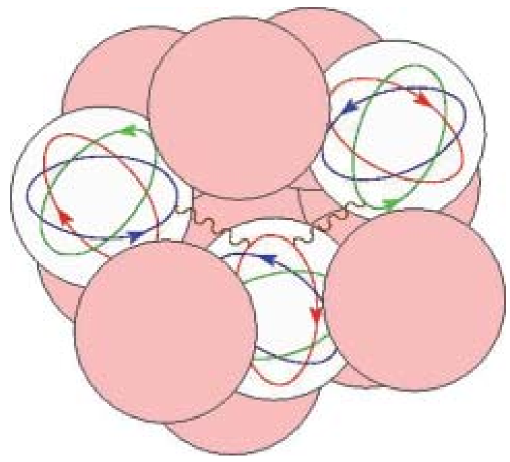
Making Stellar Magnetic Fields In A Jar. An experiment at the University of Maryland reports the first experimental observation of a magnetorotational instability—the creation of an induced magnetic field in a rotating electrically conducting fluid immersed in an external magnetic field.

In the Maryland experiment a baseball-sized copper ball is rotated within a vessel containing liquid sodium. With this setup, the researchers try to simulate the ingredients shared in common by Earth's core, the outer envelopes of stars, and the accretion disk surrounding black holes. In each case a conducting fluid, differential rotation (inner parts of the fluid rotating faster than outer parts), and potent magnetism add up to interesting physics. Until now there had been only theories and simulations of this physical environment.

The Maryland experiment demonstrates that an organized magnetic field can arise even from a hydrodynamic turbulent fluid. According to Daniel Lathrop, one of the scientists involved, the new test allows researchers to study the interplay between moving fluids, the ways in which turbulence can occur, and how the fluid rotation can be braked. (D. R. Sisan *et al.*, *Phys. Rev. Lett.* **93**, 114502, 2004.)

Newly Created Antihydrogen Atoms have been caught speeding for the first time. The only place anti-atoms exist on Earth for more than a microsecond is in a chambered vault at the CERN Antiproton Decelerator lab in Geneva. There, antiprotons created in high-energy proton collisions and positrons from a radioactive source are cooled and brought together in a vessel filled with electrodes at various voltages. The ATRAP collaboration, one of the CERN H-bar groups, has measured the speeds of the anti-atoms by seeing how many of them emerge from a region of oscillating electric fields without being ionized. They have determined that the anti-atoms are moving with an average energy of 200 meV, which corresponds to a velocity only about 20 times that of the thermal speed of an equivalent sample of atoms kept at a temperature of 4.2 K. This is still too warm for the purpose of holding the anti-atoms in a trap, but the researchers suspect that their current crop of anti-atoms contains some with much lower velocities and that there will be a way to cull an ever colder allotment in the future now that there is a speedometer for antihydrogen atoms. (Gabrielse *et al.*, *Phys. Rev. Lett.* **93**, 073401, 2004)

The Quark-Meson Coupling Model (QMC) model, a theory that incorporates self consistent changes in the quark structure of a nucleon when it is bound in matter, has been updated into a theory of quasi-nucleons interacting through many-body forces. Thanks to this, the QMC model can now challenge the time-honored descriptions of the nucleus where nucleon structure was supposed to play no role.



The QMC model describes the interactions between a quark in one nucleon and a quark in another nucleon by meson exchange (*See illustration*). The quarks in that second nucleon are in turn interacting with the quarks in another and so on. The resulting picture of the nucleus is then that of quasi-nucleons interacting through forces that involve 2, 3, or even 4 bodies. The necessity of such many-body forces was empirically known from traditional nuclear physics, and the merit of the QMC model is that it explains their origin and predicts their intensity.

The QMC theory has stood up to experimental tests for some years. For example, it has been helpful in explaining changes in hadron masses in dense matter, and there are even hints from extremely precise measurements of the ratio of electric to magnetic form factors of a proton bound in helium (at Mainz and Jefferson Lab) supporting the subtle changes predicted there.

The authors of the QMC model, Pierre Guichon (Saclay, France) and Tony Thomas (Adelaide, Australia—now at Jefferson Lab), believe the newer version of their model will help in interpreting data coming from heavy-ion collision experiments aiming to create a quark-gluon plasma state. (P.A.M. Guichon and A.W. Thomas, *Phys. Rev. Lett.* **93**, 132502, 2004)

Strontium-76 Is One of the Most Deformed Nuclei in its ground state and is the most deformed of all nuclei in which the number of protons (Z) equals the number of neutrons (N). Earlier evidence suggested that Sr-76 should be about as deformed a nucleus as one can have in its ground state. In a study carried out at the CERN-ISOLDE facility in Geneva, a new method for measuring this deformation has been put into practice. First, the rare Sr-76 nuclei were made by smashing a proton beam into a target of niobium. The newly made Sr nuclei then diffused out of the target, ionized, and were swept away and sent to the heart of a spectrometer. Gamma rays from the disintegration of the Sr-76 nuclei were then observed, and the approximate shape of the nuclei was worked out from the pattern of emergent gammas. Sr-76 was not only shown to be highly deformed, as expected, but its shape is now determined to be highly prolate (its equatorial axis is some 40% shorter than its longer axis) rather than oblate. (E. Nacher *et al., Phys. Rev. Lett.* **92**, 232501, 2004)

Our Universe Has No Topological Scale Smaller Than 24 Gigaparsecs—about 75 billion light years—according to an analysis of data from the Wilkinson Microwave Anisotropy Probe. Because of conceivable "hall of mirrors" effects of spacetime, the universe might be finite in size but give us the illusion of being infinite. For example, the cosmos might be tiled with some repeating shape, around which light rays might continuously wrap themselves, somewhat like a video game in which an object might disappear off the left side of the screen and reappear on the right. In the new study, researchers looked for signs of such "wrapped" light in the form of pairs of circles, in opposite directions in the sky, that exhibit similar patterns of cosmic microwave background temperature fluctuations. If the universe were finite and smaller than the distance to the "surface of last scattering" (the place in deep space where the cosmic microwaves originate and that constitutes the edge of the visible universe), then multiple images should show up in the microwave background. But no such correspondences appeared in the analysis. The researchers turned the lack of recurring patterns into a lower limit of 24 Gpc on the scale of cosmic topology, a factor of 10 larger than previous observational bounds. (N. J. Cornish *et al.*, *Phys. Rev. Lett.* **92,** 201302, 2004.)

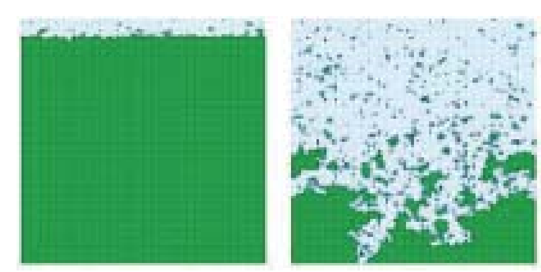
Misbehaving Muons bolster earlier evidence of new physics beyond the standard model, though further experimental and theoretical work may be needed to confirm this possibility. At Brookhaven National Laboratory's "g-2" experiments, an international collaboration has been studying the decay of the muon by measuring the muon's magnetic moment. In 2001, researchers studied positively charged muons and found a discrepancy between the experimental value and the predictions of the standard model, though the discrepancy was later reduced after researchers discovered an error in the theory. In January, researchers reported measurements on negatively charged muons that matched the precision of the previously reported positive muon results. Combining the data on positive and negative muons, the researchers find a disagreement between the experiments and the standard model of as much as 2.8 standard deviations, about the same level of discrepancy that was originally reported in 2001 before the theory error was discovered. What would cause this discrepancy? Perhaps the muon's magnetic moment is being influenced by hypothesized but yet-undiscovered "supersymmetric" particles that are not included in the standard model. However, further work may be needed to check and refine the very difficult theoretical calculations on the muon's magnetic moment. (G. W. Bennett *et al., Phys.Rev.Lett.* **92**, 161802, 2004. More information at Brookhaven web page: http://www.bnl.gov/bnlweb/pubaf/pr/2004/bnlpr010804.htm)

Chemical "Defect" Engineering. At a November symposium of the AVS Science & Technology Society in Anaheim, researchers from the University of Illinois reported on an approach to reliably making small-scale versions of a pn junction, the crucial region of a semiconductor that changes from electron-rich (the "n" zone) to electron-poor (the "p" zone). Today, pn junctions are only 25 nanometers (100 atoms) deep. But to make increasingly smaller (and faster) silicon chips, the International Technology Roadmap for Semiconductors dictates that by 2010 the pn junctions must have depths of 10 nanometers, or just 40 atoms. The conventional method for making the junctions is called "ion implantation," in which charged versions of a foreign atom ("dopant") are accelerated into a silicon wafer to create electrically active regions that are either electron-rich or electron-poor. Unfortunately, current ion-implantation methods cannot make 10-nm-deep pn junctions without inadvertently moving silicon atoms into some of the spots intended for dopants. But the Illinois researchers are using surface chemistry to come to the rescue of this conventional technology. In computer simulations, they showed how removing surface layers such as silicon dioxide frees up dangling bonds. Silicon atoms then preferentially rise to the surface while tending to leave the dopant atoms in place. Verified in subsequent experiments, this idea for "defect engineering" has been shown to be a feasible solution for using traditional ion-implantation technology to make smaller-scale silicon-based electronic devices. (Meeting Paper EM-TuA7)

Synchronized Swimming In Bacteria creates dramatic, previously unknown fluid patterns, researchers have discovered. Bacteria swim through fluids by quickly rotating corkscrew-shaped "flagella," hair-like appendages that can be up to five times greater than the length of their main body (generally a few microns in size). It's not a routine feat for a bacterium to stay above water: a typical organism is about 10% denser than water, so gravity tends to sink the creatures. Nonetheless, aerobic bacteria often swim up to the oxygen-rich surface in order to find and consume the million O_2 molecules per second that they need to survive. Conventional wisdom has been that such swimming does little to stir up the fluid itself.

Studying concentrated populations of the common aerobic bacterium *Bacillus subtilis* in small, half-inch-diameter fluid drops, a group of physicists at the University of Arizona has found that the combination of upward swimming and downward sinking in the suspension can produce striking flows that strongly mix the fluid and concentrate the bacteria. The crowd of swimming bacteria creates arrays of circulating vortices whose size is orders of magnitude larger than an individual bacterium. Jets and surges of fluid that straddle the vortices can move 100 microns per second and be as large as 100 microns. These speeds and lengths greatly exceed the swimming speeds and sizes of the organisms themselves, which move only tens of microns per second.

The new results provide, possibly for the first time, information on the way in which concentrated swimming bacteria order themselves. Such accumulations can have many important consequences. For example, they may greatly aid in the formation of biofilms, and can even be micromixers in tiny quantities of fluid. In addition, the way the fluid currents concentrate bacteria into small spaces may be crucial for triggering the phenomenon of "quorum sensing," whereby congregated bacteria sense sufficiently high amounts of each other's secreted chemicals to turn on specific capabilities, such as the emission of light in bioluminescent bacteria. Quorum sensing is found in many important bacteria, including those that create gum disease. (Dombrowski *et al., Phys. Rev. Lett.* **93**, 098103, 2004)



Why are Seacoasts Fractal? In a famous paper written decades ago, Benoit Mandelbrot asked how long the coastline of Britain really was. The answer depends on what kind of meter stick you use. The closer one looks at any scale of a rocky coast map, the more indented and lengthy the "coastline" becomes. Not only that, but the coast's underlying geometry seems be fractal, meaning that it is extremely fractured and also self-similar: the shape looks, in a statistical sense, the same at all levels of magnification.

Scientists in France have inquired into the physical processes that actually could carve out a fractal coast. Their simulation of a rocky coast evolution depends on an iteration of erosion action. First, waves are allowed to erode the weak points in a smooth shoreline. This makes the shore irregularly indented and longer. This erosion exposes new weak points, but at the same time mitigates the force of the sea by increasing the wave damping. These steps are then repeated over and over. The resultant coast is fractal, with an effective dimension of 4/3. According to Bernard Sapoval and A. Baldassarri of the Ecole Polytechnique (Palaiseau, France) and their colleague A. Gabrielli of the "Enrico Fermi" Center (Rome), this new study provides the first suggestion of how a fractal shoreline comes about. (Sapoval *et al.*, *Phys. Rev. Lett.* **93**, 098501, 2004)

The Cryogenic Dark Matter Search (CDMS) collaboration reported their first results at the 2004 APS April meeting. They did not find any specific evidence for weakly interacting massive particles (or WIMPs), a finding which is at odds with positive results reported a few years ago by the Dark Matter (DAMA) group in Italy. Both teams maintain sensitive detectors far underground, the better to filter out extraneous particles from entering their apparatus which operate, in effect, as underground telescopes. Their mission is to try to record the existence of WIMPs, which may be a component of the much sought dark matter that supposedly lurks unseen in and around and among galaxies. In CDMS, located 2341 feet deep in the Soudan mine in Minnesota, a target of germanium and silicon is maintained at temperatures close to absolute zero. At masses as high as 100 times the mass of a proton, an intruding WIMP, if it interacted inside the target at all, would engender a characteristic pattern of crystalline vibrations and secondary particles in the semiconductor target material. At the April meeting Harry Nelson (UC-Santa Barbara) said that the CDMS null measurement could be cast in the form of a cross section. In this case the CDMS apparatus established a cross section of less than 4×10^{-43} square centimeters for a 60-GeV-mass WIMP particle to show up in their detector. This level of sensitivity is the best yet for dark matter searches. (D. S. Akerib *et al., Phys. Rev. Lett.* **93**, 211301, 2004; CDMS Webpage: http://cdms.berkeley.edu/index.html)

Accelerator For BECs. Two research groups have banged quantum gases together at record high velocities. Both groups begin by cooling clouds of rubidium atoms to ultralow temperatures. Next, through magnetic manipulation the clouds are split into two separate clouds, each containing a native population with a characteristic spin value. Physicists in the Netherlands further cool the clouds to produce Bose-Einstein condensates (BEC) before using the same magnetic control over the atoms to urge the clouds back together again at an increasing speed. Earlier experiments had managed to "collide" separate BEC samples at slow speeds of mm/sec (slow in relation to the velocity of sound in the BEC—several mm/sec) in order to observe characteristic interference stripes, and affirm the intrinsic wavelike nature of BEC as a whole.

The Dutch experiment is able to achieve speeds of 20 cm/sec. The respective clouds are about 10 microns in size; the relative size of the clouds and their initial separation (up to record distances of 4 mm) is analogous to the separation of two tennis balls on opposite sides of a tennis court. When the two "tennis balls" collide, a spherical interference pattern shows up.

The higher speed is important because below sound speed, the superfluid BEC behaves like one giant matter wave, while above sound speed the BEC behaves like a collection of individual atoms. So in this experiment it is more accurate to think of 100,000 atoms (in the one cloud) scattering with 100,000 atoms (in the other cloud) rather then to think of two interacting clouds. Furthermore, because the speeds are still slow, the atom-atom collision can still be thought of as being the collision of two waves.

In the BEC accelerator, matter waves of atom pairs are scattered out of the clouds at an energy of 10^{-7} eV. These matter waves are a superposition of spherical-shaped "s" and dumbbell-shaped "d" waves and hence show quantum mechanical interference. This interference is being directly imaged (Buggle *et al.*, *Phys. Rev. Lett.* **93**, 173202), and yields accurate measurement of the interaction properties between ultracold atoms.

Comparable observations were reported by physicists from the University of Otago in New Zealand, although in this experiment the atoms were at 200-nanokelvin temperatures but did not constitute a BEC. (Thomas *et al.*, *Phys. Rev. Lett.* **93**, 173201, 2004).

A Natural Nuclear Reactor In Gabon. Since uranium-235 undergoes self-sustaining fission in commercial reactors and since uranium lies in the Earth in great quantities, Paul Kuroda predicted that naturally operating reactors are possible under special conditions. Not nowadays, when the ratio of uranium-235 to uranium-238 is only about 0.7%, but in the past, when the ratio was much higher. The conditions necessary for self-sustained fission would be as follows: a uranium deposit where U-235 was present at the 3% level (the level at which modern reactors operate); the presence of material (such as water, carbon, and most organic compounds) that could moderate, or slow down, the neutrons issuing from fission reactions; and the absence of material (such as Fe, K, Be, Gd) that would absorb the neutrons outright.

In 1972, such a natural reactor was found at the Oklo mine in Gabon, in West Africa. There a 2-billion-year-old uranium deposit some 5-10 meters thick and 600-900 meters wide was bathed by an ancient river. This "reactor" is estimated to have released 15 gigawatt-years of energy and operated at an average power of 100 kilowatts.

Physicists at Washington University in St. Louis have now defined a likely mode of operation for this ancient reactor and confirmed one of the proposed mechanisms of its self regulation. According to Alex Meshik, the reactor cycled on (producing heat that boiled the nearby water) typically for 30 minutes and then off (when the now-scarce water failed to moderate the nuclear fission process) typically for 2.5 hours. This cycling saga is deduced from microscopic mass-spectrometric examination of the rock samples from the area. Meshik says that tiny alumophosphate grains found in the material of ancient reactor preserve a signature of the reactor's operational mode. "It is fascinating that xenon isotopic composition measured today provides us with such pristine timing records for a natural reactor operated 2 billion years ago." (A. P. Meshik *et al.*, *Phys. Rev. Lett.* **93**, 182302, 2004).

WYP PARIS *from page 1*

in a highly divided world," Sreenivasan said. "We should mitigate this imbalance not only because it is a moral imperative but also because it is a practical necessity." Science has revolutionized the world, by bringing about developments in energy, electronics, information, and communication. But investment in science is low in developing countries. They need skilled individuals, support for these individuals, and transparent institutions.

Sergio Rezende, President of FINEP in Brazil, also discussed the widening gap between rich and poor countries, and the need for physicists to convince governments to create institutions for improving science in developing countries. He said that politicians and the public, especially in developing countries, are mainly concerned about short-term results, and therefore do not invest enough in science. It is not simple to change that situation, he said. A further problem is the "brain drain" from developing nations—young people who wish to become scientists often must leave their home country to study, and often they don't return.

In a round table discussion on what physics can bring to the socio-economic challenges of the 21st century, Burton Richter of SLAC said that one major challenge would be energy demand. Economic growth, especially in developing nations, will lead to too great a demand for oil. There are many approaches to solving this problem, he said, and the role of physicists is to help develop options. "The sooner one starts to fix the problems the easier it is to solve," he said. For instance, scientists can work on ways to conserve energy and make our energy use more efficient, and develop other energy sources, such as nuclear, hydrogen, and solar power. Richter said that he honestly believes that science can meet the world's energy needs. "But it's not going to be one thing. Solar energy will be a part of it; nuclear energy will be a part of it; wind will be a part of it; conservation will be a part of it; efficiency will be a part of it."

Environmental challenges are another area where physics can contribute, said Sylvie Joussaume, Director of the French National Center for Scientific Research (CNRS). For instance, physics can help in the areas of climate modeling and satellite observations to predict or provide warning of natural disasters.

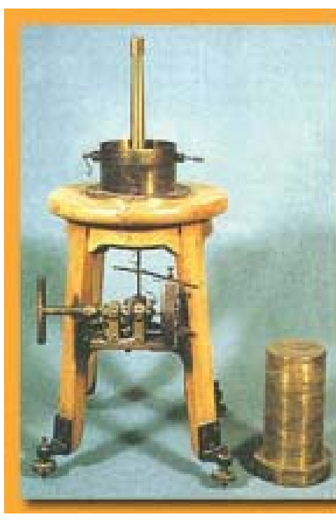
For the students, one of the greatest benefits of the conference was the chance to travel and to meet other students from around the world. The students hailed from over 70 countries, including the United States, France, England, Russia, Czech Republic, Poland, India, Israel, Pakistan, Sudan, Tanzania, Brazil, Mexico, Japan, and Indonesia. The students, selected from recent participants in Physics Olympiads, were some of the best physics students in their countries. Some of them knew each other from the Olympiad and were pleased to see their friends again. Others said they really enjoyed the opportunity to meet new people. During breaks from the lectures they discussed physics problems, science education in their countries, their career plans, as well as issues such as the challenges facing women in physics. They also joked around, played games, and just had fun. A special banquet was held on Friday night for the students. Many of them said they especially liked getting to travel and see Paris, a rare opportunity for some of the students.

One university student from India, Varun Balerao, who planned to become an engineer, said he was enjoying the conference very much. He said he really liked spending the evenings after the conference touring the city. Chintan Hossain, one of the four American students attending the conference, especially appreciated Denis Le Bihan's talk about physics and brain imaging. Hossain is a sophomore at MIT, double majoring in physics and brain and cognitive science, and hopes to work with some of the imaging techniques that Le Bihan described. Abdelfatah, a student from Sudan, said he felt inspired by the talks, but especially liked meeting the other students. He was studying medical physics, and hopes become a doctor in his home country.

The World Year of Physics has now officially begun. Many other events will be held throughout the year.

LETTERS

Example of Pierre Curie's Electrometer Survives



The caption on a photo in "This Month in Physics History" in the December 2004 issue of *APS News* says "Pierre and Jacques Curie's electrometer." [see accompanying photo—Ed.] The Department of Physics of the University of Colorado has an apparatus that is quite similar to the one shown. Our device is a high-impedance voltage source which was used to charge gold leaf electroscopes that measured ion currents in ion chambers. The source of the high voltage is the potential difference that is developed across the two faces of a crystal that is about 20 x 4 x 0.2 cm. At the top of the apparatus in the photo is what appears to be one tall post. There are actually two posts which are lined up one behind the other in the photo. The long crystal is hung from a cross piece that joins the tops of the two posts. A rod attached to the lower end of the crystal passes through the circular wooden table, and masses can be hung on a hook on the lower end of the rod to apply a desired stretching force on the vertical hanging crystal. The two faces of the crystal are covered with what appears to be tin foil, and two flexible brass arms touch the two sides of the crystal to conduct the charge to the two terminals. These can be connected to a gold-leaf electroscope. The cylinder on the table to the right is a brass cover that protects the hanging crystal from dust. On the cover of ours is the following inscription: "Quartz Piezo Electrique; de P. Curie; No. 32; Societé Central de prod. Chemiques; 44 Rue des Ecoles, Paris"

I have tested this apparatus by hanging masses on the bottom of the crystal and observing the resulting deflection of the gold leaf of an electroscope. Then separately, with an electronic power supply I charged the electroscope to the same deflection and found the potential difference generated by the crystal to be approximately 400 volts. I do not know the function of the apparatus mounted midway up on the four wooden legs. It might be a mechanical system for applying known forces to the crystal and measuring the resultant elongation of the crystal. I have seen a number of photos of Marie Curie in her laboratory with this apparatus and a gold leaf electroscope appearing side by side.

Albert Bartlett
Boulder, CO

VIEWPOINT *from page 4*

seemed totally different are in fact the same thing. The most famous equation of physics, $E=mc^2$, came from the September paper and with that energy and mass became one.

This is what Einstein did in 1905, by means of pure reason, at the age of 26. While he never had another year like 1905, he did have a long and fruitful career. His single greatest paper, "*The Foundation of the General Theory of Relativity*, came in 1916. Einstein's papers rank with the greatest in the history of physics; however, the question remains: *Why is Einstein, the physicist, the standard of greatness?*

As *homo sapiens*, we are distinguished by our large brain. Humans are the thinking animal. Since the 18th-century Enlightenment, two ideas have become deeply embedded in the minds of western humans.The first idea, coming out of Isaac Newton's work, is that physical laws determine the behavior of Nature.

Nature is not capricious; it is lawlike. The second idea, coming out of John Locke, is that reason is the means to discover Nature's laws. When Einstein divines the laws of Nature by the power of pure reason, he confirms deep-seated human beliefs about the lawfulness of Nature and about the awesome power of human reason. As the thinking animal, humans are drawn to Einstein because, consciously or unconsciously, we share vicariously in Einstein's accomplishments.

Einstein is also special because he was a physicist. In physics, more than other science, the power of pure reason can be convincingly exhibited. Einstein created theories that required new and uncomfortable ways of thinking.But as a physicist, Einstein did more: he used his novel theories to make detailed, quantitative predictions of never-observed phenomena.

When his prediction put at issue a direct product of "*God's thought*" such as his prediction about the nature of space, the stuff of great import as well as high drama was in the making. In Einstein's *General Theory of Relativity*, a massive object influences neighboring space by imposing a shape upon it. As a result of this, Einstein recognized that as light passed the Sun, its path would deviate very slightly. How slightly? Einstein predicted that light's path would deviate by 1.75 seconds of arc (in one degree there are 3,600 seconds of arc).

When the Great War ended in 1918, people were emotionally exhausted and they longed for a world that made sense. Einstein's prediction was tested by Arthur Eddington when he measured the deviation of starlight as it passed the darkened Sun during a total eclipse. He measured the light's deviation to be 1.98 arc seconds, thereby confirming Einstein's prediction. Einstein predicted, Eddington confirmed, and people all over the world were comforted to know that "all is right with the world." Einstein became a world celebrity.

Einstein gives all people a sense of pride because he is one of us. He is special because, through his physics, he dramatically displays the essence of both his and our natures. That is why Einstein is the standard of greatness.

John Rigden, of Washington University in St. Louis, is the author most recently of Einstein 1905: The Standard of Greatness, *Harvard University Press (2005).*