AN OCEAN OF QUARKS

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

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

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

The outward-streaming particles provided the tomographic evidence for determining the properties of the fireball. The reformation of the frenzied quark era lasts only a few times 10-24 seconds. The size of the fireball is about 5 femtometers, its density about 100 times that of an ordinary nucleus, and its temperature about 2 trillion degrees Kelvin or 175 MeV. But was it the much-anticipated quark-gluon plasma? The latter, with the temperature of 200 trillion degrees Kelvin, has never been created in a laboratory.

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

THE BIGGEST SPLASH OF LIGHT FROM OUTSIDE THE SOLAR SYSTEM

Superfluidity was first seen with gold nuclei at the upper end of the spectrum over a period of minutes and then by more and more telescopes; at radio wavelengths emissions were monitored for months. For an instant the flare was brighter than the full moon.

For the first time since starting nuclear collisions at RHIC in the year 2000 and their causes. The Roukes group reported its findings at the APS March Meeting in Los Angeles.

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THE MOST DISTANT CRAFT LANDING IN THE SOLAR SYSTEM

The Huygens probe, given long passage by the Cassini spacecraft into the middle of Saturn’s minor planetary system, has successfully parachuted onto the surface of Titan, the only moon with a considerable atmosphere. Pictures taken from miles above the surface during the descent and pictures taken on the surface itself suggest the presence of boulders or ice chunks and some kind of shoreline, perhaps of a hydrocarbon lake or sea. The data gained so far include a sort of acoustic sampling of the atmosphere during the descent and some color photographs. The Titan probe is named for Christian Huygens, who first noticed, in 1655, that Titan (TII) was the first to provide the proper interpretation of Saturn’s ring system.

THE SOLAR SYSTEM

Superfluid detection of extrasolar planets

Direct detection of extrasolar planets has been achieved for the first time. In our later, cooler epoch quarks conventionally occur in groups of two or three, held together by gluons. Could a nucleus be made to rupture and spill its innards into a common swarm of unconfined quarks and gluons? What is this RHIC set out to show?

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THE BIGGEST SPLASH OF LIGHT FROM OUTSIDE THE SOLAR SYSTEM

The biggest splash of light from outside the solar system to be recorded here at Earth occurred on December 27, 2004. The light came from an object called SGR 1806-20, about 50,000 light years away in our own galaxy. SGR stands for “soft gamma repeater,” a class of neutron star possessing a gigantic magnetic field. Such “magnets” can erupt violently, sending out immense bolts of energy in the form of gamma rays and light at other wavelength regions of the electromagnetic spectrum.

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The eruption was first seen with telescopes at the upper end of the spectrum over a period of minutes and then by more and more telescopes; at radio wavelengths emissions were monitored for months. For an instant the flare was brighter than the full moon. (NASA press conference, 18 February; www.nasa.gov/press/2005/vgrbusr/; many telescopes participated in the observations, reports appeared in the 28 April 2005 issue of Nature.)
**PYROFUSION: A ROOM-TEMPERATURE, PALM-SIZED NUCLEAR FUSION DEVICE**

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

The key component of the UCLA device is a pyroelectric crystal, a class of materials that includes lithium niobate, an inexpensive solid that can be used to filter signals in cell phones. When heated, a pyroelectric crystal stores electric charge, and as the crystal cools, it releases the stored electric charge.

**Ultraviolet Frequency Comb**

Physicists at JILA, the joint institute of NIST and the University of Colorado, have created a new optical process to extend the production of coherent radiation into the extreme ultraviolet region of the electromagnetic spectrum. This process takes advantage of the fact that ultrashort laser pulses of femtosecond widths, separated by nanoseconds, manifest themselves as discrete frequencies, each separated by a specific interval.

The Fourier transform of these short pulses is a long series of evenly spaced spikes that look like the tines of a comb. The JILA researchers have pushed the coverage of the frequency comb into the ultraviolet, where the electromagnetic spectrum exhibits a series of high harmonics of the original, near-infrared laser frequency comb.

The new approach demonstrated in the JILA work has drastically improved the spectral resolution of these high frequency electromagnetic light sources by many orders of magnitude, which will also be important in making the harmonic generation process more efficient.

**Pyrofusion**

In a vacuum chamber containing deuterium gas, they place a lithium tantalate (LiTaO₃) pyroelectric crystal so that one of its faces touches a copper-cooled tungsten probe. The probe itself is surmounted by a tungsten probe. They cool and then heat the crystal, which creates an electric potential of about 120 kilovolts at its surface.

The electronic field at the end of the tungsten probe tip is so high (25 V/m) that it strips electrons from nearby deuterium atoms. Repelled by the positively charged tip, and crystal, which creates an electric potential of about 120 kilovolts at its surface.

**Superfluidity in an Ultracold Gas of Ferromion Atoms**

Superfluidity in an ultracold gas of fermion atoms has been demonstrated in an experiment at MIT, where an array of vortices has been set in motion. Scientists believe the Earth is kept warm, and tectonic plates in motion, by a reservoir of energy deriving from two principal sources: residual energy from the Earth’s formation and additional energy from radioactive decay. The rudimentary inventory of geoneutrinos observed so far is consistent with the theory. (Araki et al., Nature 436, 499-503 (28 July 2005))

**Geoneutrinos Detect**

Physicists at the University of Lund have demonstrated that atom pairing in Bose-Einstein condensates (BECs) using photoassociation is coherent. Coherent pairing of atoms has been observed before using a tuned magnetic field – a Feshbach resonance – between the atoms. But molecules made that way are only loosely bound.

In the photoassociation experiment, a cloud of two cold ⁴¹K atoms is created by laser cooling. One of the lasers is tuned to a resonant optical transition between two states. Joseph Fortagh and his colleagues believe that the new ultraviolet frequency comb promises to provide an important tool for ultrahigh resolution spectroscopy and precise measurements in that spectral domain. It will open the door to unprecedented spectral resolution, making it possible for scientists to study the fine structure of atoms and molecules with coherent XUV light. (Jones et al., Phys. Rev. Lett. 94, 193012, 2005)

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In the JILA experiment, femtosecond-long pulses, spaced 10 nanoseconds apart, are sent into a coherent storage device – an optical buildup cavity. The cavity length is determined so that each time of the incoming frequency comb is matched to a respective cavity resonance mode. In other words, the pulse train is matched exactly into the cavity such that a pulse running around inside the cavity is reinforced by a steady stream of incoming pulses.

The other end of the cavity contains an infrared laser that is not highly detuned, but is efficiently amplified by the cavity. The output of the cavity is an intense series of spikes, and add a few other elements to it. In a vacuum chamber containing deuterium gas, they place a lithium tantalate (LiTaO₃) pyroelectric crystal so that one of its faces touches a copper-cooled tungsten probe. The probe itself is surmounted by a tungsten probe. They cool and then heat the crystal, which creates an electric potential of about 120 kilovolts at its surface.

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HOW EFFECTIVE WILL FLU VACCINE BE?
A new way of predicting the flu vaccine's efficacy by using the tools of statistical physics was described by Michael Deem of Rice University at the APS March Meeting.

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

In one standard approach, researchers study all the mutations in the entire H protein from one season to the next. In another approach, researchers study the ability of antibodies produced in ferrets to recognize either the vaccine strain or the mutated flu strain, which had been thought to be prophylactic. Both approaches can be time-consuming and less than efficient in humans.

However, these approaches are only modestly reliable indications of the vaccine's efficacy. Deem and his Rice University colleagues point out that each H protein has 5 "epi-topes," antibody-triggering regions mutating at different rates. The Rice team refers to the original mutations as the "correct" epitopes. Deem's team has shown that it is possible to study whole vaccine efficacy in humans.

The protein RecA performs some profoundly complex tasks, in which ultrashort pulses of light create a set of equally spaced frequency peaks resembling a comb. The comb can be used to measure other optical frequencies with unprecedented precision and ease (and with much smaller equipment than previously possible). They enable better atomic clocks which in turn can make the Global Positioning System more precise.

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

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

Meanwhile, Hall and Hänsch developed techniques for measuring the frequency of light to what is currently 15 digits of accuracy. These frequency-measurement techniques helped scientists to devise fundamental definitions of physical units (for example, Hall and others developed a new definition of the meter) to inspect (proofread) the DNA's binding energy and to detach after a certain time (the "kinetic" part) if the DNA has the "wrong" binding energy.

Measurement optical frequency has also helped to test Einstein's theory of special relativity to record-breaking levels of precision. In addition, optical-frequency measurements have made possible tabletop experiments that search for new physics, such as the question of whether the fine structure constant, the quantity that determines the inherent strength of the electromagnetic force, is changing over time.

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

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

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

In tests on a standard copper surface, such as the kind used to manufacture microchips, the molecule has taken 10,000 steps without faltering. According to Bartels, possible uses of walking molecules may include a sequence of molecular movement for molecule-based information storage or even computation.

DTA moves along a straight line as if placed onto railroad tracks without the need to fabricate any nano-tracks, the naturally occurring copper surface is sufficient. The researchers now aim at developing a DTA-based molecule that can convert thermal energy into directed motion like a molecular-sized ratchet. (Kwon et al. Phys. Rev. Lett. 95, 161101, 2005)

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

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

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

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

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

The photon pair can be produced in either of two crystals, and the uncertainty in the production details of the individual photons is what provides the ability to arbitrarily create the sequence of correlated photons that all physicists have dreamed of. They are creating a "cloud of correlated photons."

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

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

Historically, lensing required a lens-shaped optical medium for bringing the diverging rays coming from a point source into focus on the far side of the lens. But in recent years, researchers have found that in "negative permittivity" mate- rials, in which a material’s response to an applied electric field is opposite that of normal material, a "left-handed" material can prevent light from traveling in a direction of wave propagation that is different from the normal one. This is possible because in the negative-permittivity material, light travels not in the usual direction, but in a direction that is left-handed.

The University of Texas at Austin physicists have made super lenses by using a "negative" material that has a negative refractive index. "It’s like having the refractive index in the negative log. It’s a negative lens," said physicist John Pendry, who led the team.

The technique is based on negative refraction, a phenomenon that occurs when light travels through a material that has a negative refractive index. When light travels through such a material, it is deflected in a way that is opposite to the way it is deflected when it travels through a normal material.

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UNCOVERING NEW SECRETS IN A DNA HELPER
The protein RecA performs some profoundly important functions in bacteria. Two independent groups have shed light on how the bacterial protein helps (1) identify and (2) replace damaged DNA while making few mistakes. Error-correction mechanisms keep DNA fidelity during replication to within an average of one error per billion "letters" or base pairs. This researcher's results provide insight on how damage to existing DNA from processes such as UV radiation can be detected and repaired efficiently in living organisms, including humans, who carry an extra copy of a Helicobacter pylori gene.

When the double-helix DNA is seriously damaged, single-stranded DNA is exposed and RecA polyadenylates (polyadenylates) it to a modified, active form that is a biochemical SOS signal. To do this, Tsvi Thury and his colleagues at the Weizmann Institute of Science and Rockefeller University suggest that RecA performs "kinetic proofreading" in which RecA can precisely identify a damaged strand and its length by using ATP (the energy-delivering molecule in cells) to inspect (proofread) the DNA's binding energy and to detach after a certain time delay (the "kinetic" part) if the DNA has the "wrong" binding energy.

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The researchers argue that the RecA performs the precise binding and unbinding actions that are necessary for kinetic proofreading through “assembly fluctuations,” a protein’s structural changes brought about by constant binding and dissociation of RecA from its target. According to the authors, this is the first known process in which kinetic proof-reading and assembly fluctuations are combined (Tlusty et al., Physical Review Letters, 17 December 2004, Phys. Rev. Lett. 93, 238103 (2004)).

Meanwhile, elsewhere in the laboratory (Kevin Dorfman and Jean-Louis Viovy) have studied how RecA exchanges a damaged strand with a similar copy. (Fichtl et al., Phys. Rev. Lett. 93, 268102, 2004)

**ELECTRON CLOUDS CAN FREEZE INTO AN “ORBITAL GLASS”**

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

Now, scientists have found evidence that these and other orbital processes can slow down dramatically— as long as 0.1 seconds, a slowing by 14 orders of magnitude—for electrons in low-temperature FeCr2S4, a spinel (class of mineral) with a relatively simple crystalline structure. (Fichtl et al., Phys. Rev. Lett. 93, 268102, 2004)

**COMPLEX HYBRID STRUCTURES**

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

In the new experiment, two such light pulses are sent into the BEC and stopped. The entry of these pulses into the BEC set in motion the oscillating paddles. The waves are further modulated by solitons, waves which can propagate in the condensate without losing their shape but change the energy profile of the wave packet. The solitons move through the condensate as if they were the neighboring atomic nuclei that surround the electrons. This modulates the slowing of the neighboring atomic nuclei that surround the electrons also distort more slowly in response to the glacially changing orbitals. In contrast to conventional glasses, a complete “freeze” of the electron clouds does not occur at the lowest temperatures. Completely frozen orbitals are prevented by quantum-mechanical tunneling: the clouds keep themselves moving by making transitions between different low-energy cloud configurations even without the energy they normally require. (Fichtl et al., Phys. Rev. Lett. 94, 027001, 2005)

**EVIDENCE FOR QUANTIZED DISPLACEMENT**

Physicists at Boston University have found evidence for quantized displacement in nanomechanical oscillators. They performed an experiment in which tiny silicon pillars, each just 100 nanometers in diameter and 500 nanometers tall, were coated with a layer of nickel and then heated using a heat gun. The resulting heat caused the nickel film to expand and displace the silicon pillars from their rest position. The nickel film was then cooled, and the pillars were observed to be displaced by discrete amounts.

Next, a gold-film electrode is deposited on top of the silicon pillars. Then a voltage is applied, and the nickel film is heated using a heat gun. The resulting heat causes the nickel film to expand and displace the silicon pillars from their rest position. The nickel film is then cooled, and the pillars are observed to be displaced by discrete amounts. The Boston University experiment sees signs of exactly this sort of behavior. (Gaidarzy et al., Phys. Rev. Lett. 94, 030402, 2005)

**LIQUID CARBON CHEMISTRY**

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

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

**240 ELECTRONS SET IN MOTION**

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

Previously a 20-electron-volt “surface plasmon” was observed: the absorption of the UV energy resulted in a systematic oscillation of the ensemble of electrons visualized as a thin sphere of electric charge. Now a new experiment has found evidence of a second resonance at 40 eV of energy. This second type of collective excitation is considered a “warm plasmon” since the shape of the collective electron ensemble is thought to be oscillating with respect to the center of the molecule. The collaboration consists of physicists from the University of Nevada, Reno, Lawrence Berkeley National Lab, Justus-Liebig University (Giessen, Germany), and the Max Planck Institute (Dresden). (Scully et al. Phys. Rev. Lett. 94, 060403, 2005)

**DEGENERATE GAS STUCK IN OPTICAL LATTICE**

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

By adjusting an external magnetic field, the pairs of atoms loaded in their specified sites can be guided to interact with one another (in the case of the “Feshbach resonance”) with a varying strength. According to Tilman Esslinger, it is this ability to put atoms where you want them in a crystal-like scaffolding, and then to make them interact with a strength that you can control, that may make this set up particularly useful for testing various condensed matter theories, such as those that strive to explain high-temperature superconductivity, on a real physical system. (Kohl et al. Phys. Rev. Lett. 94, 080403, 2005)

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

Nickel-78, the most neutron-rich of the doubly-magic nuclei, has had its lifetime measured for the first time, which will help us better understand how heavy elements are made.
Physicists believe gold and other heavy elements (beyond iron) were built from lighter atoms inside star explosions billions of years ago. In the “r-process” (standing for rapid) unfolding inside the explosion, a succession of nucleons build up on the many available neutrons. The method was verified by a novel simulation showing all the species in the chart of the nuclides were being made one after the other. In some models the buildup can slow down at certain strategic bottlenecks. Nickel-78 is one such roadblock. This is because Ni-78 possesses a “doubly magic” nucleus. It has both closed neutron and proton shells; it is “noble” in a nuclear sense in the way that a noble gas atom is noble in the chemical sense owing to its completely filled electron shell.

This crucial nucleus is very rare and hard to make artificially. Nevertheless, scientists at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University have culled 11 specimens of Ni-78 from among billions of high-energy collision events recorded in effect. The NSCL is a factory for reproducing supernova conditions here on Earth. Hendrik Schatz, speaking at the April APS meeting in Tampa, reported that from the data Ni-78 decayed records, a lifetime of 110 milliseconds could be deduced. This is some 4 times shorter than previous theoretical estimates, meaning that the bottleneck nucleus lived shorter than was thought, which in turn means that the bottleneck may not happen at all in the r-process. So far the exact conditions and site for the r-process are still unknown. With the new measurement model conditions have to be readjusted to produce the observed amounts of precious metals in the universe. This will provide a better idea of what to look for when searching for the site of the r-process. (See also Hosmer et al., Phys. Rev. Lett. 94, 112503, 2005)

THE FIRST DIRECT MEASUREMENT OF Recoil MOMENTUM

The first direct measurement of recoil momentum for single atoms struck by light in an absorptive medium has been made by Gretchen Campbell, Dave Pritchard, Wolfgang Ketterle, and their colleagues at MIT. Photons do not possess mass, but a beam of light does carry momentum. In general, when light strikes a mirror, the mirror will recoil ever so slightly, and this recoil has previously been measured. But what about a single photon striking a single atom? In the experiment, a beam of atoms from a thermal reservoir of Rb atoms—where is Planck’s constant and lambda is the wavelength of the light in vacuum. In a dispersive medium, the index of refraction for the medium, n, comes into play: an object absorbing the photon will recoil with a momentum equal to nh/lambda. This is what has been measured for the first time on an atom basis.

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

Nevertheless, the interaction of the light with all the atoms has to be taken into account, even if the specific interaction being measured, in effect, is that of single atoms. The atoms “feel” the collective recoils of all the other atoms. The recoil is damped by the collective refraction, is applicable after all. Ketterle believes that this new insight about what happens when light penetrates a dispersive medium provides an important correction for high-precision measurements using cold atoms. (Campbell et al., Phys. Rev. Lett. 94, 170403, 2005)

LIGHT MAY arise FROM tiny RELATIVITY Violations

Light may arise from tiny relativity violations, according to a new experiment. Speaking of the meeting of the Division of Atomic, Molecular, and Optical Physics in Nebraska in May, Alan Kostelecky of Indiana University described how light might exist as a result of breaking Lorentz symmetry. In Lorentz symmetry, the laws of physics stay the same even when you change the orientation of a physical system (such as a barbell-shaped molecule) in space. Break Lorentz symmetry and you might be able to see space-time a preferred direction. In its simplest form, broken Lorentz symmetry could be visualized as a field of vectors everywhere existing in the universe. In such a picture, objects might behave slightly differently depending upon their orientation with respect to the vectors. In a recent paper, the authors propose that the very existence of light is made possible through a vector field arising from broken Lorentz symmetry. In this vector field, there is a “smirring” of the vector field analogous to a whispering to a flow through a field of grain.

The researchers have shown that this picture would hold in empty space as well as in the presence of gravity, which is often ignored in conventional theories of light. This theory is in contrast to what is generally thought, but is not yet confirmed, that gravity can be seen as a result of and as a result of underlying symmetries in particles and force fields. Kostelecky says that the new theory can be tested by finding minute changes in the way light interacts with matter (and changes its orientation with respect to the putative vector field). (Bluhm and Kostelecky, Physical Review D, 71, 065008, 2005)

A NEW KIND OF NANOPHOTONIC WAVEGUIDE

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

If photonics is to keep up with electronics in the effort to produce smaller, faster, less-power-hungry circuits, then photonics must move towards the nanoscale. These waves, called surface plasmons, can have a propagation wavelength much smaller than the free-space optical wavelength. This achieves one of the desired reductions: with a shorter wavelength the spatial dimension of the device can be smaller. Furthermore, a subwavelength plasmon is also a very slow electromagnetic wave. Such a slower-moving wave spends more time “feeling” the nonlinear properties of the device medium. This can lead to slower loss and the device can carry more data before it “blows out,” allowing for a drastic reduction of the losses by cooling. (Karlalis et al., Phys. Rev. Lett. 95, 063901, 2005)

ROOM-TEMPERATURE ICE in ELECTRIC FIELDS

Room-temperature ice is possible if the water molecules are subjected to a high enough electric field. Some physicists had predicted that water could be cooled into freezing at fields around 109 V/m. The fields are thought to trigger the formation of ordered hydrogen bonding needed for crystallization. Now, for the first time, such freezing has been observed, said physicists John Joannopoulos and Hendrik Schatz at the National Superconducting Cyclotron Laboratory at the University of Michigan. At a much lower field than was expected, only 106 V/m, Exploring a new freezing mechanis- am should lead to additional insights about ice formation in various natural settings, Kang bok Hu, an artist physicist at UC Berkeley, has now, for the first time, produced a BEC in a ring-shaped trap about 1 millimeter across. By using an extra magnetic field, in addition to those used to maintain the atoms in the trap to start with, the whole trap can be “tilted,” so as to accelerate the atoms up to velocities of about 50-150 m/s (or equivalent- ally, to energies of about 100 pico-electron-volts per nucle- on, as compared to the TeV energies sought for particle physics). After this initial “launch” phase, the atoms are allowed to drift around the ring; they do this not in clumps (as you would have with particles in a colliding-beam storage ring) but in a state known as a Bose-Einstein condensate (BEC). In a BEC,point all of the circulating con- densed could be made to interfere with other particles. From such an interferometer one could devise gyroscopes or high-precision rotation sensors. Other possible realms of study include quantized circulation, fluid analogues of general relativity, and fluid analogues of SQUID detectors and other superconducting devices (Gupta et al., Phys. Rev. Lett. 95, 143201, 2005)

MAGNETIC BURNING

A new experiment suggests that the fast flipping of the magnetic orientation of some molecules in a solid sample resembles the propagation of a flame front through a material being burned, and that the “magnetic burning” process is similar to the condensation of some substances without actually having flames present. In a chemical fire–say, the burning of the pages of a book—the flame front marks a dividing point: ahead of the front is intact burned book material, behind is ash, the state of material that has been oxidized in the combustion process. Now, consider the magnetic equivalent as studied by a collaboration of scientists from CUNY-City College, CUNY-Lehman College, the Weizmann Institute, and the University of Florida. A crystal of manganese dioxide (MnO2–mc)–which, with a net spin of 7/2, is quite susceptible to magnetic influence. Turning on a strong...
external magnetic field opposed to the prevailing magnetic orientation of the crystal can cause a sudden reversal of spins of the molecules. The reversal propagates along a front through the crystal (which can be thought of as a stack of nanomagnets) just as a flame moves through a bed of solid fuel in a controlled combustion. In the magnetic case, much heat will be generated as the spins get flipped (the heat energy being equal to the difference in energy of the before and after spins), but there will be no destructive burning. The “lawn” consists of the molten cloud in molecular magnets has several of the qualities of regular burning (a flame front and combustion) but not the destructiveness. Myriam Sarachik says that magnetic burning might offer a more controlled way of learning how to control and channel flame propagation. (Suzuki et al., Phys. Rev. Lett. 95, 147201, 2005)

GUIDED SLOW LIGHT

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

Slow-light pulses in a sample of atoms had been accomplished before by slowing down light in a medium of high dispersive medium —that is, a medium in which the index of refraction varies greatly with frequency. Previously, this dispersive quality had come about by tailoring the internal states of the atoms in the medium. In the present Harvard experiment, by contrast, the dispersive quality came about by tailoring the external qualities of the atoms, namely their motion inside an elongated magnetic trap. In the lab setup, two pump laser beams can be aimed at the atoms in the trap; the beams propagate away from the rest of the magnetic field in its unexcited state, a typical atomic nucleus consists of a number of constituent neutrons and protons bobbing around inside a roughly spherical shape. However, if struck by a projectile from outside, such as a beam particle supplied by an accelerator, the nucleus can be split into a primary or secondary target of lead. The excited states of lead integrate the debris coming out allows the researchers to reconstruct the turbulent nature of the tin nuclei. The dipole resonance was seen, as expected, but also a new resonance: an excess in energy of the before and after spin states), but there will be no destructive burning.

NUCLEAR SEISMOLOGY

Physicists at the GSI lab in Darmstadt, Germany, have discovered a new excited nuclear state, one in which a neutron nucleus swells away from the rest of the magnetic field in its unexcited state, a typical atomic nucleus consists of a number of constituent neutrons and protons bobbing around inside a roughly spherical shape. However, if struck by a projectile from outside, such as a beam particle supplied by an accelerator, the nucleus can be split into a primary or secondary target of lead. The excited states of lead integrate the debris coming out allows the researchers to reconstruct the turbulent nature of the tin nuclei. The dipole resonance was seen, as expected, but also a new resonance: an excess in energy of the before and after spin states), but there will be no destructive burning.

QUANTUM SOLVENT

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

MEASURING HIGHER-LEVEL QED

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

A TERA-ELECTRONVOLT GAMMA RAY ORIGINATING IN THE MILKY WAY

The most energetic paracells of electromagnetic radiation-Tera-electronvolt gamma rays—ever determined to have originated in the plane of our home galaxy were observed recently by the Milagro detector, located at high mountain elevations in New Mexico. The potent photons are believed to have been part of the debris spawned when even more energetic cosmic rays struck the matter-dense heart of the Milky Way. Photons in the TeV range arrive at the Earth very rarely, not often enough to permit observation from a space-based gamma telescope. Therefore, terrestrial gamma observations are usually carried out by large-area-arrays attached to the ground. Milagro, operated by scientists from nine institutions, the record the arrival of energetic photons at Earth by observing the air shower of secondary particles generated when photons of these energies strike the atmosphere. These particles betray their presence by the light (Cerenkov radiation) emitted when the particles pass through a 6-million-gallon pond instrumented with phototodetectors. This method of observation offers a rough ability to determine the direction of arrival. For the Milagro experiment, the event rate, 70,000 TeV photon events from within a region of the Milky Way plane were culled from an inventory of about 240 million TeV-level events seen so far seen from the same region. These numbers, say team member Roman Flesher of New York University, are consistent with the estimate that tens to hundreds of these events could be expected.

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

WHY DO WE RESIDE IN A THREE-DIMENSIONAL UNIVERSE?

Andreas Karch (University of Washington) and Lisa Randall (Harvard) propose to explain why there are three spatial dimensions. Currently, the popular string theory of matter holds that our universe is actually ten-dimensional, including, first of all, the dimension of time, then the three “large” dimensions we perceive as "space," plus six more dimensions that are difficult to see, perhaps because they are hidden in some way. The size of these dimensions is such that the force of gravity. Having several dimensions rolled up in one way to explain why gravity is so weak.

Another view, pioneered by Randall and Raman Sundrum, holds that if gravity is localized on a 3D defect in the larger multi-dimensional universe and if spacetime is sufficient for a new defect to form, then our 3D space may be an effective 3D "brane" that we can observe. The "currated" in the 1D universes that are possible by tailoring the internal states of the atoms in the medium has been demonstrated by Adrich et al., Phys. Rev. Lett. 95, 161501, 2005)

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