Frontiers

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Einstein proved right again (nearly)
An international team of astronomers has used an unusual double pulsar to provide the strongest confirmation yet of general relativity – the theory most believe best explains gravity. The team studied the double pulsar PSR J0737-3039A/B, which consists of two rotating neutron stars, each a mere 20 km across yet weighing more than the Sun and separated by only a million kilometres. Given the tiny size, high mass density and very short orbital period of just 2.4 hours, the double-pulsar system has a gravitational potential 100 000 times that of the Sun – greater than anything else in the universe, apart from black holes. The team carried out four separate tests on tiny deviations in the stars' behaviour, verifying Einstein's theory to an accuracy of 99.5% (*Science* **313** 1556).

Photonic crystals turn magnetic
Physicists in Germany have made a new type of photonic crystal by fine-tuning the magnetic, rather than the electric, properties of a material. Photonic crystals are nanostructured materials in which periodic variations in the electric permittivity produce a "photonic band gap" that prevents photons with certain wavelengths from travelling through the crystal. But until now it has not been possible to make such crystals by modifying the magnetic permeability, which is unity for natural substances at optical wavelengths. The researchers got round this problem by making a "metamaterial" from pairs of thin gold wires. It was placed on a quartz-based slab that served as a 1D waveguide to channel light along certain paths (*Phys. Rev. Lett.* **97** 083902).

Superconducting qubits get entangled
US physicists have taken another step towards the dream of a quantum computer by entangling two superconducting quantum bits (or qubits) for the first time. Circuits made from superconducting elements are promising candidates for such a device because they are compatible with conventional methods for making integrated circuits. The two qubits were each made from a Josephson tunnel junction and the researchers were able to confirm the entanglement using a "quantum state tomography". This involves measuring a series of different parameters for the two particles and using these to reconstruct the quantum state, much as image "slices" are combined into a 3D picture in medical tomographic imaging (*Science* **313** 1423).

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Gravity lens hints at dark matter


NASA

Shot in the dark Researchers have found that the visible matter (pink) in the bullet cluster does not coincide with the cluster's mass distribution, providing evidence for dark matter (blue).

Astronomers in the US claim to have observed dark matter, the elusive substance posited to make up most of the mass in the universe. The alleged discovery, which was made by studying a violent galactic collision called the bullet cluster, gives few clues as to what dark matter actually is. However, it does provide strong support for the standard "cold dark matter" model of cosmology (*Astrophys. J. Lett.* at press).

Dark matter was originally proposed to explain the abnormally high rotation speeds of galaxies, which would be torn apart if they contained only the matter that we can detect using telescopes. By definition, dark matter does not couple to electromagnetic radiation; but astronomers can infer its presence by measuring the gravitational-lensing effect it has on light emitted by normal, luminous matter. This is precisely the method adopted by Doug Clowe of the University of Arizona and his team.

Using several different telescopes, Clowe and co-workers were able to determine the relative positions of luminous and dark matter in the bullet cluster at different wavelengths. The bullet cluster is ideal for such a study because the luminous matter in one of the colliding clusters interacts with that in the other and slows down, while the dark matter in each cluster passes straight through without disruption. This separates each cluster into two components that can be detected by comparing X-ray images of the luminous matter with measurements of the cluster's total mass via gravitational lensing. When the researchers did this, they found two large clumps of dark matter speeding away from the collision with two smaller clumps of luminous matter trailing behind.

Clowe states that the results are "direct proof that dark matter exists". As such, the findings appear to deal a blow to researchers working on modified theories of gravity, which get round the need for dark matter. But HongSheng Zhao from St Andrews University in the UK, who works on a theory called TeVeS, does not see it this way: "If we assume that neutrinos have a mass of 2 eV, which is within experimental limits, then the bullet cluster presents no serious difficulty to modified gravity theories."

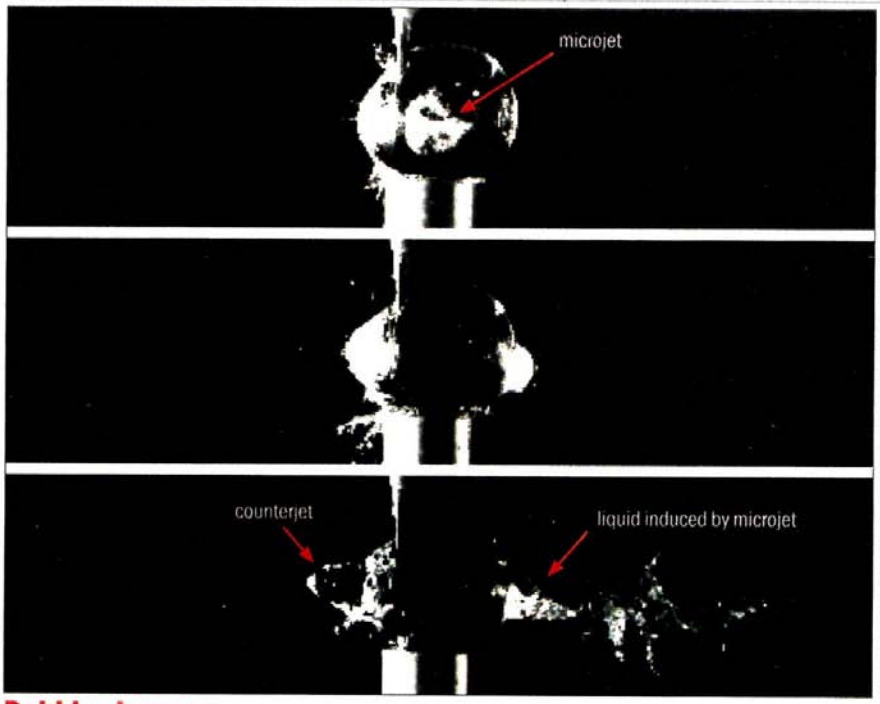
Spin Hall effect hots up

Spintronics, we are often told, is the microelectronics of the 21st century. In addition to exploiting the charge of electrons like any other electronic device, a spintronic circuit would also utilize the spin angular momentum of electrons to perform more complex logical operations at higher speeds and with reduced power consumption. However, while various spintronics devices have been built, one crucial component is still missing: a reliable source of spin-polarized electrons that works at room temperature; in other words, a battery.

Now, David Awschalom and co-workers at the University of California in Santa Barbara have taken an important step towards such a source by exploiting the spin Hall effect (*Phys. Rev. Lett.* **97** 096605 and arXiv.org/abs/cond-mat/0607288). Demonstrated for the first time by the same group in 2004, the spin Hall effect arises due to spin–orbit coupling, which causes an electric field to appear as a magnetic field from the point of view of a fast-moving electron.

As a result, "spin-up" electrons flowing through a conductor will be displaced in the opposite direction to that of "spin-down" electrons, generating a spin current in the transverse direction. And because the spin Hall effect does not require a magnetic field, unlike the conventional Hall effect, it has great potential as a source of spin-polarized electrons for semiconductor-based spintronics. Such devices would be much easier to fabricate than the metallic ones made so far.

Using Kerr-rotation spectroscopy, the team observed the effect in thin surface layers of the semiconductor zinc selenide between 10 and 295 K. Previous experiments, which showed electrical generation of spin-polarization in gallium-arsenide semiconductors, had to be performed at cryogenic temperatures. Unfortunately the spin polarization at 20 K in zinc selenide about 10 times stronger than at room temperature.



Bubbles in space

Cavitation is an unusual process whereby tiny air bubbles grow and collapse inside water droplets. These bubbles can be very useful, and are used, for example, to kill bacteria and destroy kidney stones. But when energy is focused in such a small volume, temperature "hotspots" can form that emit liquid jets and shockwaves. This can be a big problem in industry because cavitation can cause erosion in everything from ship propellers to pipelines. These high-speed CCD camera stills, in which bubbles have been generated inside centimetre-sized drops via a spark discharge, could help researchers understand cavitation in much more detail. Taken in zero-gravity conditions by Philippe Kobel at the Ecole Polytechnique Fédérale de Lausanne in Switzerland and co-workers on board a parabolic flight, they show an isolated, spherical droplet of water that would be impossible to create on Earth (*Phys. Rev. Lett.* **97** 094502). The results reveal that bubbles that are not formed exactly in the centre of the drop, but to one side, collapse with toroidal symmetry and generate two liquid jets that escape from the drop in opposite directions.

Optical take on NMR

Physicists in the US have invented a new form of nuclear magnetic resonance (NMR) that could significantly improve the resolution and sensitivity of the technique. The method, developed by Michael Romalis and co-workers at Princeton University, involves shining a laser on a sample and measuring how the interaction rotates the plane of polarization of the beam. The new technique could lead to real-time 2D imaging of samples, with the resolution limited only by light diffraction.

Most NMR experiments involve placing a sample in a magnetic field, which encourages the spin of the nuclei to point in the same direction as the field. The frequency with which the spins wobble or "precess" about this direction provides useful information about the local molecular environment. But because the magnetic moment is too small to be detected individually, the spins are deliberately driven out of alignment by applying a radio-frequency pulse to a metal coil. As they return to equilibrium, the nuclei create a bulk magnetization that induces an oscillating electric current in the coil.

The new technique that has been developed by Romalis and colleagues is completely different (*Nature* **442** 1021). Rather than measuring the frequency shifts of signals in an NMR spectrum, it involves shining a plane-polarized visible laser beam onto a sample and measuring how the nuclear spins rotate the plane of polarziation of the beam. There could be several advantages to the new technique. In particular, it works with small, tightly focused laser beams, which could allow samples to be studied at micrometre resolution in real time. In contrast, obtaining even 100 μm resolution in magnetic resonance imaging (MRI) is difficult. The technique is also particularly suitable for heavy nuclei, which usually have poor spectra in traditional NMR. It could even be used to create 3D maps of tissues because near-infrared light can penetrate into such material.

Innovation

Astrophysics targets homeland security

You could be forgiven for thinking that the hunt for dark matter and the global fight against terrorism have little to do with one another. However, based on technology developed for astroparticle physics, a spin-out company from the ETH-Zurich in Switzerland is about to launch a radiation detector that could make security screening much more efficient, *writes Matthew Chalmers*.

The market for passive radiation screening devices at airports, seaports and border crossings has increased enormously in recent years, both to prevent radiological materials being smuggled and to safeguard against environmental damage. The problem with existing technology is the large fraction of "false positives", which can be triggered by trace levels of radiation in goods ranging from porcelain to bananas and so disrupt the flow of freight. It is also possible to shield certain radioactive materials from the screening devices.

The new technology developed by Arktis Radiation Detectors can reduce the false-alarm rate by a factor of 10 while increasing the sensitivity to dangerous radioactive materials such as uranium. "We had been working for quite some time doing R&D for direct dark-matter searches," explains team leader Rico Chandra, a particle physicist at the ETH. "Then, while participating in a discussion about 'homeland security', we were challenged to draw on that experience to consider new screening techniques."

As no-one knows for sure what dark matter consists of, physicists need detectors that can discriminate candidate signals from weakly interacting massive particles (WIMPs) against background signals that involve gamma radiation. Furthermore, the technology has to be scalable to large areas to catch very faint signals and must have sufficient resolution to measure the energy spectrum of any WIMPs detected. Exactly the same attributes apply to security applications.

"We have done a lot of work with detectors based on noble gases, which allow us to discriminate between highly penetrating neutrons and gamma rays," says Chandra. "This is vital for screening applications, which have to be able to probe deep containers." Such detectors, he adds, are also cheap and simple enough to scale to large dimensions with useful energy resolution, which makes for faster measurements that could mean the difference between, say, having to stop a truck or allowing it to drive on.

Chandra says that the main challenge is to produce a low-cost detector that can be operated "hassle free". Arktis hopes to launch its first commercial product in 2008.