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1. Proton size

The charge radius r_{E} and the Zemach radius of the proton have been measured in muonic hydrogen atoms $p\mu^-$ at the Paul Scherrer Institute (Switzerland). The nuclear size affects the energy levels of muonic atoms to a higher extent than that of ordinary ones, as the muon is on average 186 times closer to the nucleus than the electron. The $p\mu^-$ atoms in excited states were formed in collisions of the μ^- beam from an accelerator with H_2 gas as a result of the substitution of muons for electrons. The measured quantities were the Lamb shift and the hyperfine splitting of the energy levels. To achieve this, laser pulses were applied to cause 2S–2P resonance transitions and X-ray photons emitted in 2P–1S transitions were recorded. The r_{E} radius was found to be 0.84087(39) fm, while the Zemach radius, defined in terms both of the electric charge distribution and the magnetic moment, was 1.082(37) fm. The new higher-accuracy experiment confirmed the discrepancy discovered in 2010 by the same collaboration in the measurements of r_{E} of ordinary and muonic hydrogen. The deviation from the CODATA (Committee of Data for Science and Technology) proton rms charge radius consolidated over a number of experiments (based on spectroscopic studies of ordinary hydrogen and e^-p-scattering) comes to $\approx 7\sigma$. The cause of the discrepancy remains unclear. Effects beyond the Standard Model are not excluded, provided the interactions between the protons and e^- and μ^- differ in some unknown respect.

Source: *Science* **339** 417 (2013)
http://dx.doi.org/10.1126/science.1230016

2. Analog of the Josephson junction in Bose–Einstein condensate

Researchers at the National Institute of Standards and Technology (NIST) and the University of Maryland have observed the quantum phase slip effect in a ring of Bose–Einstein condensate with a revolving barrier. The Bose–Einstein condensate comprising $\approx 6 \times 10^5$ ^{23}Na atoms was kept in a toroidal optical trap. The condensate was initially at rest, but a barrier — a region with the reduced density of condensate (a spot with a weak coupling) — was rotating along the ring at a frequency of up to 3 Hz. The barrier was created by a laser beam driven by an acousto-optical reflector. The flux of atoms relative to the barrier was an analogue of the electron current in the superconducting ring of the SQUID. The measurements of state of the condensate were conducted at the stage of free fly-apart of the condensate cloud after turning off the trap potential. Up to three consecutive phase slips were observed upon increasing the frequency of barrier rotation — that is, of transitions in the condensate between the quantum states with different angular momenta. Vortices due to the presence of the radial velocity gradient emerged in the condensate after the first such jump. This technique may lead to creating exceptionally sensitive gyroscopes with characteristics outperforming those for gyroscopes with superfluid helium as the base.

Source: *Phys. Rev. Lett.* **110** 025302 (2013)
http://arXiv.org/abs/1208.3608

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Translated by V I Kisin

3. Topological insulator SmB_6

Three groups of researchers have established that cooling samarium hexaboride (SmB_6) to below 4 K converts it into a 3D topological insulator which, in its bulk, is an insulator and, on its surface, is a conductor. The role of topological effects in Kondo insulators (to which SmB_6 belongs) was predicted by V Galitsky and his colleagues in 2010. These effects show themselves in SmB_6 by virtue of interaction between localized (pinned) and free electrons. The conducting properties of a specimen were investigated in the experiment by S Wolgast and his colleagues (University of Michigan, USA) using eight electric contacts attached to it, with four contacts placed on opposite sides of the specimen. This arrangement allowed Wolgast and his colleagues to reliably establish that the specimen conductivity is of a surface nature. The same conclusion was made on the basis of measuring the Hall effect resistivity in an experiment at the University of California, where it was established that resistance is independent of specimen thickness. X Zhang et al. (University of Maryland) applied the microcontact spectroscopy method, and additionally confirmed that SmB_6 constitutes a topological insulator.

Sources: http://arXiv.org/abs/1211.5104,
http://arXiv.org/abs/1211.6769,
http://arXiv.org/abs/1211.5532

4. NMR technique on the nanoscale

Two independent groups of researchers implemented the nuclear magnetic resonance method for studying nanometer-scale specimens. NV-defects in a diamond crystal at room temperature were used as detectors. The NV defect comprises an atomic pair formed of a nitrogen atom which has replaced a carbon atom, and an atomic vacancy, i.e., an empty crystal lattice site. T Staudacher (University of Stuttgart, Germany) and his colleagues placed specimens of different compositions directly onto the surface of diamond, with the NV-defect placed underneath it at a depth of ≈ 7 nm. A specimen placed in a magnetic field was irradiated by microwaves, and the variable magnetic fields generated in it induced transitions between spin states in the NV-defect. The fluorescent photons emitted subsequently were recorded by a photodiode. The NV-defect thereby responded to a spin precession of $\approx 10^4$ protons in a volume of the specimen measuring ≈ 5 nm^3. A similar method was applied in an experiment conducted by H J Mamin (IBM research Center in San Jose, USA) and his colleagues, but the organic specimen was located now at some distance from the diamond surface, and the NV-defect recorded a signal incoming from a larger volume. The researchers hope that in the future this method will be capable of yielding a 3D image of nanoparticles; this would be important for achieving a progress in nanotechnologies. In some ways, the NMR method is simpler than using a force resonance microscope, since the NMR does not require cooling to cryogenic temperatures.

Sources: *Science* **339** 557 (2013), *Science* **339** 561 (2013)
http://dx.doi.org/10.1126/science.1231540,
http://dx.doi.org/10.1126/science.1231675

5. Mass ejection from pre-supernova

The Palomar Transient Factory Wide-Field Survey discovered that, 37 days prior to the supernova SN 2010mc explosion, a pre-supernova star outburst took place, radiating energy of 6×10^{47} erg. The width of the spectral lines pointed to a speed of the emitted gas on the order of 2000 km s^{-1}. A possible explanation for this event is the mass eruption of $\sim 0.01 M_{\odot}$ ($M_{\odot}$ stands for a solar mass). There was probably a causal connection between the mass eruption event and the supernova explosion, as the probability of an accidental coincidence of such events over a period of 37 days is only estimated as 0.1%. Such eruptions preceding a main explosion were predicted by the theory of stellar evolution. The photometric and spectroscopic data of the observed outbursts agree well with the wave model. In this model, powerful convective motions develop around the nucleus shortly before its collapse, reaching the surface of the star in the form of waves and creating matter eruption in the course of energy dissipation; it is not possible to explain the high eruption rate and high mass loss using alternative models (Thorne–Żytkowa objects or pair-instability supernovas).

Source: *Nature* **494** 65 (2013)
http://arXiv.org/abs/1302.2633

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