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1. Doubly charmed baryon

The Ξ_{cc}^{++} baryon including two c-quarks and a u-quark has been registered for the first time in the LHCb experiment (CERN). The existence of this baryon had been predicted by the quark model. It was born in pp collisions 13 TeV in energy and decayed through weak interactions along the channel $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$, $\Lambda_c^+ \to pK^- \pi^+$. The Ξ_{cc}^{++} baryon corresponded to the peak in the invariant-mass distribution of the number of events, with the statistical significance of Ξ_{cc}^{++} registration exceeding 12σ. The measured baryon mass of ≈ 3621 MeV$/c^2$ was quite consistent with theoretical calculations, and the peak for the same mass was also confirmed by the LHCb data at an energy of 8 TeV. The another SELEX Collaboration had already reported the registration of a baryon with two heavy quarks Ξ_{cc}^{+} (with quark composition ccd), but this result had not been confirmed in independent experiments. The reliable Ξ_{cc}^{++} registration by LHCb is important for verification of the complicated calculations carried out in the framework of quantum chromodynamics. Theoretically, the Ξ_{cc}^{++} baryon has a planetary structure, namely, the light u-quark revolves at a certain distance from a compact pair of heavy c-quarks (a diquark). Russian researchers from several scientific institutions have participated in the LHCb collaboration. For baryons with two heavy quarks, see the review by V V Kiselev and A K Likhoded in *Phys. Usp.* **45** 455 (2002) [*Usp. Fiz. Nauk* **172** 497 (2002)].

Source: https://arXiv.org/abs/1707.01621

2. Satellite-based transmission of quantum-entangled photons

J-W Pan (University of Science and Technology of China) and his colleagues have fulfilled the transmission of photon pairs in a quantum-entangled state from the Chinese Micius space satellite onto three ground-based stations. The photons were distributed among receiving stations on Earth separated by 1203 km, and with allowance for the satellite-to-ground distances, the photons travelled in total from 1600 to 2400 km. Earlier, quantum-entangled photons could only be transmitted at distances up to ≈ 100 km because of the loss in optical-fiber and air communication lines. On board the satellite, the photons from the laser diode split into pairs in a nonlinear crystal to form photons in polarization-entangled states with a random choice among several polarization directions. The satellite- and ground-based stations had telescopes to emit and receive photons. After reception of the photons, the Bell test was performed to show that the quantum precision of photon entanglement is $f \geqslant 0.87 \pm 0.09$. In another experiment, J-W Pan and colleagues accomplished quantum teleportation of particle states at a distance of 1400 km from the high-altitude Tibet station to the same Micius satellite. And Japanese researchers under the guidance of M Sasaki (National Institute of Information and Communications Technology, Japan) carried out quantum communication — a signal with the protocol of quantum distribution of keys was transmitted from the 48-kg microsatellite SOCRATES to Earth. These experiments are of importance for practical applications in the field of quantum communication and quantum cryptography.

Sources: *Science* **356** 1140 (2017)
https://doi.org/10.1126/science.aan3211
https://arXiv.org/abs/1707.00934
https://doi.org/10.1038/nphoton.2017.107

3. Retrocausality and time symmetry

In their theoretical paper, M S Leifer (Chapman University, USA) and M F Pusey (Perimeter Institute for Theoretical Physics, Canada) have clarified the interrelation between the symmetry of physical processes under time reversal and the retrocausality conception, which is discussed as an alternative to action at a distance in quantum mechanics. The idea of retrocausality is closely connected with the question of reality of quantum states. Within this conception, future events exert a certain influence on past events. For instance, the choice of experimental conditions in the future influences the state of the measurable system in the past. However, signaling from future to the past in this way is impossible. M S Leifer and M F Pusey somewhat modified and generalized H Price's arguments claiming that the conditions of quantum state reality and time symmetry permit the effect of retrocausality. In the framework of the retrocausality conception, they formulated timelike analogs of Bell's test and found conditions when quantum processes are symmetric under time reversal. For irreversibility in quantum mechanics, see the paper by B B Kadomtsev in *Phys. Usp.* **46** 1183 (2003) [*Usp. Fiz. Nauk* **173** 1221 (2003)].

Source: *Proc. R. Soc. of London A* **473** 20160607 (2017)
https://doi.org/10.1098/rspa.2016.0607

4. Qubit-based quantum Maxwell demon

In their experiment, N Cottet (Sorbonne University, France) and colleagues have realized for the first time the conception of the Maxwell demon operating in the quantum regime with quantum superpositions of microwave photons, and from measurements of its state they observed the information-to-work conversion. The role of the demon was played by a microwave cavity that traced the state of the related superconducting qubit. The microwave pulses passed through a cavity, and it could only do work (transfer energy to photons under stimulated emission) if the qubit was in the lowest

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energy state. On the contrary, if the qubit was excited, the cavity frequency was shifted, and the cavity blocked the pulses. Thus, the Maxwell demon randomly let pulses pass, with the occupation numbers of the Fock states of the cavity itself varying. The quantum tomography method was applied to reconstruct the cavity density matrix with respect to the photon occupation numbers. It provided information on the demon memory, which has its energy cost. As was theoretically expected, the increase in the entropy corresponding to the demon memory compensated for the decrease in system's entropy. For quantum information, see the book of B B Kadomtsev, *Dynamics and Information* and his review in *Phys. Usp.* **37** 425 (1994) [*Usp. Fiz. Nauk* **164** 449 (1994)].

Source: *Proc. Nat. Ac. Sci.* **114** 7561 (2017)
https://doi.org/10.1073/pnas.1704827114

5. Negative effective mass and quantum measurements

If the coordinates and momenta of a positive-effective-mass ($m_{\rm eff}$) system are determined relative to the corresponding variables of another system with $m_{\rm eff} < 0$, the differences between these quantities will be commutative quantum variables. These can be measured simultaneously, as distinct from absolute coordinates and momenta, for which the measurement accuracy is limited by the Heisenberg uncertainty principle. Researchers from the Niels Bohr Institute of the University of Copenhagen (Denmark) under the leadership of E Polzik were the first to demonstrate this method of measurements in their experiment. Two optically coupled oscillators were used, namely, a 0.5-mm dielectric membrane with a large mechanical Q-factor and an ensemble of $\sim 10^9$ cesium atoms in a magnetic field within an optical cell which served as a spin oscillator. The ensemble could be transferred to the state with spins directed opposite to the magnetic field, and in this case the spin oscillator had $m_{\rm eff} < 0$. A laser beam passed sequentially through the ensemble of particles and lighted up the membrane, thus initiating optomechanical coupling between them. The membrane oscillation spectrum was measured by the reflection of light pulses from another laser. The reverse influence exerted by the measurement process was partially compensated for when $m_{\rm eff} < 0$, which increased the measurement accuracy by 1.8 dB. This method can be applied in measuring devices operating close to the standard quantum limit.

Source: *Nature* **547** 191 (2017)
https://doi.org/10.1038/nature22980

6. Quantum Zeno and anti-Zeno effects

In their experiment with a superconducting qubit, P M Harrington, J T Monroe, and K W Murch (Washington University in St. Louis) have demonstrated both the quantum Zeno effect slowing down the quantum transition between qubit levels owing to a sequence of frequent measurements and the anti-Zeno effect accelerating the transition. The anti-Zeno effect in the experiment with a unit qubit was observed for the first time. The superconducting qubit was placed into an electromagnetic cavity, the states of the qubit were determined, and the time before their decay was measured from the shifts of the bare pulse phases in the cavity. Given this, the quantum Zeno effect showed up according to the theory. Then, the experimental conditions were changed: the qubit was affected by electromagnetic noise with a specially structured spectrum. The presence of noise changes the number of final states accessible for quantum transition. A decrease in the number of states results in the time dilation of the transition, whereas an increase leads to its acceleration. Either the Zeno or anti-Zeno effect occurred in the experiment, depending on the difference between the cavity eigenfrequency and the average noise frequency. The experiment was repeated when 'quasimeasurements' were performed that randomized the Berry phase to misphase the state of the system, but the information on the results of measurements was not transferred to the external world. The Zeno and anti-Zeno effects were observed under these conditions, too.

Source: *Phys. Rev. Lett.* **118** 240401 (2017)
https://doi.org/10.1103/PhysRevLett.118.240401

7. Higgs mode in a two-dimensional antiferromagnet

Near a quantum critical point, instabilities (order parameter fluctuations) occur in crystals whose properties resemble those of the Higgs field in the Standard Model of elementary particles. The Higgs excited modes near the quantum critical point have already been observed in three-dimensional crystals. However, in 2D systems they are typically highly unstable and decay rapidly into pairs of Nambu–Goldstone modes, for which reason they could not be identified. T Hong (Oak Ridge National Laboratory, USA) and colleagues have used the neutron scattering method to observe for the first time the Higgs mode near the quantum critical point in the two-dimensional antiferromagnet $C_9H_{18}N_2CuBr_4$ in which this mode is stable. From the standpoint of the theory, the antiferromagnet structure can be described by a set of lattices with spins $S = 1/2$ at the lattice sites. The experiment showed good agreement of the Higgs mode properties with this model, and the numerical values of the Hamiltonian system parameters were measured.

Source: *Nature Physics* **13** 638 (2017)
https://doi.org/10.1038/nphys4182

8. Observation of individual-atom diffusion

A Widera (University of Kaiserslautern and Graduate School of Excellence Materials Science in Mainz, Germany) and his colleagues have observed the diffusion of individual ^{133}Cs atoms in a rarefied ultracold gas of ^{87}Rb atoms in an optical trap. The ^{133}Cs atoms were directed to the trap where they impinged on ^{87}Rb atoms and, gradually slowing down, found themselves in thermal equilibrium with them. Laser excitation of ^{133}Cs atoms and registration of the fluorescent light coming from them were used to determine the spatial shifts of the atoms in different time intervals after the beginning of motion, which made it possible to find the statistical distribution of atoms. It had a bimodal form as part of the ^{133}Cs atoms failed to collide before the observation. The entrapped ^{87}Rb gas was nonuniform, which allowed a simultaneous examination of many realizations with different Knudsen numbers: from $K_n \simeq 1$ in the trap center, to large K_n at the edge. It turned out that within a wide range of K_n after only few collisions with ^{87}Rb atoms the ensemble of ^{133}Cs atoms is already well described by the Langevin equation with a velocity-dependent friction factor.

Source: *Phys. Rev. Lett.* **118** 263401 (2017)
https://doi.org/10.1103/PhysRevLett.118.263401

9. Tokamak with lithium-coated walls

D P Boyle (Princeton Plasma Physics Laboratory, USA) and colleagues have performed a tokamak type experiment in which the inner walls of the chamber were lithium-coated. This permitted the plasma temperature near the walls to be heightened compared to conventional tokamaks in which divertors are utilized to remove the external layers of plasma filament. In the new experiment, a lithium layer $\sim 75 - 100$ nm thick was sputtered onto the inner walls of a spherical tokamak. The plasma was diagnosed, i.e., its temperature profile was measured, by the method of Thomson scattering of optical photons on ions during an electric discharge in plasma. The results of measurements showed for the first time that in the presence of lithium the temperature profile along the chamber cross section flattens, i.e., the temperature levels off in the central core and at the walls. This effect was predicted in 2003 by S I Krasheninnikov, L E Zakharov, and G V Pereverzev as being due to the fact that lithium binds the hydrogen atoms into lithium hydride. This reduces their reverse flux and decreases the temperature gradient and plasma turbulence. In the future, this effect may lead to an increase in the energy output in tokamaks. For the development of tokamaks, see B B Kadomtsev's review in *Phys. Usp.* **39** 419 (1996) [*Usp. Fiz. Nauk* **166** 449 (1996)].

Source: *Phys. Rev. Lett.* **119** 015001 (2017)
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10. Binary supermassive black hole

The radio galaxy 0402 + 379 is believed to host two supermassive black holes (SMBHs) rotating around each other, was observed with VLBA radio telescopes of the National Radio Astronomical Observatory (NRAO). Binary SMBHs may have been formed upon the merger of two galaxies. Such mergers are typical episodes in the evolution of most galaxies, especially in dense clusters, but only a few galaxies with binary SMBHs are known to date. The two SMBHs located near the radiation brightness peaks (cores) are separated by a projected distance of 7.3 pc. Their orbit is the closest among the orbits of those binary SMBHs that were spatially resolved. Galaxy 0402 + 379 was observed at frequencies of 5, 8, 15, and 22 GHz; the frequency dependence of the visible distance between the cores was revealed and evidence of the proper motion of the cores was possibly obtained. The former effect, which was predicted by A Königl and A P Lobanov, is associated with the structure of jets and magnetic fields at their bases. The latter effect shows that it was possibly for the first time that the proper orbital motion of the SMBH in the binary was observed in this experiment. The period of their revolution — 30 thousand years — was estimated by the velocity of their motion, the summed SMBH binary mass amounting to $\sim 15 \times 10^9 M_\odot$.

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Compiled by *Yu N Eroshenko*
(e-mail: erosh@ufn.ru)