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1. Heat transport through a quantum valve

A team of researchers from Aalto University (Finland) headed by Jukka P Pekola has manufactured a device which can become a platform for the study of some quantum thermodynamic phenomena covering, in particular, heat transport. The device consists of a superconducting transmon qubit coupled between two identical coplanar waveguide resonators, each equipped with heat reservoir in the form of a metal mesoscopic resistor. The possibility of photon propagation from one resistor to the other through the qubit depends on its quantum state, i.e., the qubit plays the role of quantum valve. Since the photons transfer heat, the heat transport between reservoirs-resistors can be examined at the quantum level. The transport efficiency depends on the relation between resonator frequencies and the set of qubit eigenfrequencies, and on the strength of couplings between the qubit, the resonators, and the reservoirs. The results are qualitatively dissimilar for different coupling regimes. Investigated in the experiment was the transferred power at different temperatures, depending on the magnitude of the magnetic flux that affects the oscillation frequency in the transmon qubit. The device operation was shown to agree with the theoretical calculations. Such a valve can be of use, in particular, for designing quantum heat engines.

Source: *Nature Physics*, online publication of July 9, 2018
https://www.nature.com/articles/s41567-018-0199-4

2. Quantum entangled state of 18 qubits

The creation of quantum entanglement of an increasingly large number of particles and the coherent control of their states are some of the central subjects of research in modern quantum informatics, for they allow the realization of more powerful quantum algorithms. In their experiment, X-L Wang (University of Science and Technology of China) and colleagues have obtained for the first time an entangled state of 18 qubits. Entanglement over several degrees of freedom, referred to as hyperentanglement, was achieved on the trajectories, polarization, and orbital angular momentum of six photons. An entangled state of 14 ions (one degree of freedom per ion) and a 10-qubit entangled state of 5 photons (two degrees of freedom per photon) were created earlier. X-L Wang and colleagues used the parametric down conversion method in a nonlinear crystal to first create three pairs of photons in entangled states. The photons passed through splitters and united in a common single-mode optical fiber, becoming hyper-entangled and having 262,144 states in toto. Measurement of the states of an individual qubit and verification of general entanglement are problems no less complicated than the creation of entanglement. These measurements were conducted in three stages: using Mach–Zander interferometers, measuring polarization, and measuring the orbital angular momentum with the aid of splitters, prisms, and interferometers. This was how the state of each qubit was individually controlled. The device had in all 30 interferometers and 48 single-photon detectors. The statistical significance of entanglement of 18 qubits exceeded 13σ.

Source: *Phys. Rev. Lett.* **120** 260502 (2018)
https://doi.org/10.1103/PhysRevLett.120.260502

3. High thermal conductivity of BAs crystals

High thermal conductivity is needed for cooling microelectronic devices. Although possessing a record thermal conductivity, diamond is not relevant for this purpose because its thermal expansion coefficient greatly differs from the corresponding coefficients of microelectronic elements. The theoretical calculations performed in 2003 by L Lindsay, D A Broido, and T L Reinecke pointed out that boron arsenide BAs single crystals must have a high thermal conductivity owing to certain properties of their phonon spectrum. L Shi (University of Texas at Austin, USA) and his colleagues have synthesized top-quality $4 \times 2 \times 1$-mm^3 BAs crystals and confirmed their high thermal conductivity up to 1000 W m^{-1} K^{-1}, which is much higher than, for example, that of copper (400 W m^{-1} K^{-1}). The measurements were carried out by both local pulsed laser heating and contact heating, with the stationary temperature distribution over the surface being also measured. The calculations show the important role of four-phonon interactions in BAs thermal conductivity. Allowance for these interactions lowers the thermal conductivity compared to the three-phonon approximation, but the calculated value remains a little higher than the experimentally measured one. In another independent experiment, Y Hu (University of California, Los Angeles, USA) and his colleagues synthesized high-quality BAs single crystals, too, and measured their room-temperature thermal conductivity, which proved to equal 1300 W m^{-1} K^{-1}. The spectroscopic data indicate that BAs shows a long mean free path of phonons and strong high-order anharmonicity in the four-phonon process.

Source: *Science*, online publication of July 5, 2018
https://doi.org/10.1126/science.aat7932
https://doi.org/10.1126/science.aat5522

4. Collective spin modes in a gas

Collective effects in quantum gases manifest themselves due to atomic interactions. S Lepoutre (Paris-13 University, France) and colleagues have investigated the collective behavior of chromium atoms in a trap in the state of a Bose–Einstein condensate. The couplings of atoms through their spins and orbital angular momenta were reached with the aid of the gradient of the magnetic field generated by several solenoids. The earlier unobserved collective spin oscillations

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of a spin gas were revealed. The atomic states were measured using Stern–Gerlach separation upon trap potential switch-off. Initially, a radio-frequency pulse was applied to turn all the spins perpendicular to the external magnetic field, so that they began precessing. If the atoms did not interact, then in an inhomogeneous magnetic field in different places they would precess independently at different frequencies around non-parallel axes. However, in the given experiment, the precession axes kept the initial position, and it was only the oscillation amplitude that depended on position, which was indicative of a collective effect associated with spontaneous generation of the trapped magnon mode. The experimental results are quite consistent with the theoretical study involving the solution of the hydrodynamic equations and 3D Gross–Pitaevskii equation. The experiment showed that, in spite of their rarefied character, spin gases can undergo collective excitations typical of solid-state ferromagnets and ferromagnetic liquids.

Source: *Phys. Rev. Lett.* **121** 013201 (2018)
https://doi.org/10.1103/PhysRevLett.121.013201

5. Microlasers

Optical loss increases with decreasing laser size, and therefore a higher pumping power is needed. A Fernandez-Bravo (Lawrence Berkeley National Laboratory, USA) and colleagues have created microlasers several micrometers in size that have the excitation threshold upon a minimum pumping power of 14 kW cm^{-2}. A microlaser is a polystyrene microsphere 5 μm in diameter. Its surface is covered with thulium Tm^{3+} nanoparticles, the electronic transitions in which are connected with the microsphere modes. Pumping was realized with a 1064-nm-wavelength laser, and wavelengths of nearly 807 nm dominated in the laser radiation spectrum. Owing to complete internal reflection, the light inside the microsphere can circulate thousands of times, forming intensity nodes in the vicinity of which lasing is generated upon transitions $^1D_2 \to {}^3F_4$ and $^1G_4 \to {}^3H_6$ in thulium. The microlasers created earlier needed a higher pumping power and hence operated in the pulsed regime only. The new microlaser, on the contrary, demonstrated continuous 5-hour operation. The property of the new laser, important for practical applications such as diagnostics, is its capacity to operate in biological media. The experiment described demonstrated laser operation in blood serum.

Source: *Nature Nanotechnology* **13** 572 (2018)
https://www.nature.com/articles/s41565-018-0161-8

6. Stereoscopic Wigner time delay in molecular ionization

Attosecond metrology allows the investigation of some fine properties of the photoelectric effect to be made. It concerns, in particular, measurement of the Wigner time delay between a light pulse and the electron escape. As distinct from atoms, molecules have a more complicated electronic structure, which presents difficulties for interpreting the results of measurements under the photoeffect on molecules. The new experiment conducted under the guidance of U Keller (Swiss Federal Institute of Technology, Zürich) examined the photoeffect on the CO molecule and measured for the first time the stereoscopic Wigner time delay characterizing the escape time depending on the electron position in a molecule. A beam of molecules was exposed to attosecond UV laser pulses. IR pulses synchronized with exciting UV pulses were utilized to measure the direction and the instant of electron escape. Through reconstruction, this provided information about the electron wave function. The electrons emitted with higher energy were located for the most part closer to the oxygen atom, and lower-energy electrons were closer to carbon. The stereoscopic Wigner ionization time delay was determined as the difference between the delays in these two cases. The result depends strongly on the molecule orientation relative to the laser pulse polarization plane. In the case of orthogonal orientation, measurements are in good agreement with the theoretical calculations, while in the parallel case, although the qualitative run of the dependence corresponds to the expected one, a certain difference is observed at low electron energies, which is possibly due to an incomplete allowance for higher electron energy levels in the molecule.

Source: *Science* **360** 1326 (2018)
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7. Universal microcavity

Resonant light–matter interaction in a microcavity is a promising area of research, because the radiative properties of materials are modified in an electromagnetic field, which paves an additional way for their study. A cavity is normally designed for only one particular substance. A universal tunable microcavity was fabricated at the Moscow Engineering Physics Institute under the guidance of Yu P Rakovich. It is suitable for the study of different substances in different regimes. The resonator consists of plane and convex mirrors separated by several hundred nanometers. One of the mirrors can be moved in three directions to choose the most convenient approximately plane-parallel region for an accurate control of distances with the help of a Z-piezopositioner with nanometer precision. This half-wave Fabry–Perot cavity can operate in the IR, visible, and UV ranges. Light comes to the cavity through a confocal lens system and is registered by a CCD matrix and a spectrometer. This universal tool is convenient for the study of chemical and biological properties of objects placed in the wave field in both the weak and strong coupling regimes. In the former case, the radiation effect on the substance in the cavity is weak, and in the latter case, the properties of substances and the course of reactions is strongly modified by radiation because of the coupling with the cavity modes.

Source: *Review of Scientific Instruments* **89** 053105 (2018)
https://doi.org/10.1063/1.5021055

8. Quantum magnetometer

Researchers from Switzerland, Russia, and Finland have applied quantum phase estimation algorithms underlying the protocols of quantum information processing to measure the magnetic field using a superconducting transmon qubit (SQUID with an additional loop and a resonator). Modified versions of the Kitaev algorithm and Fourier phase retrieval algorithm, with which one can overcome the problem of phase 2π periodicity, were applied. The qubit can be thought of as an 'artificial atom' with a set of quantum levels. It is sensitive to the external magnetic field, because it has a large intrinsic magnetic moment and can therefore serve as a magnetometer. The magnetic field is determined through the measurement of the oscillation frequency in the qubit proportional to the field magnitude. Both the algorithms make it possible to attain a sensitivity of 19.3–29.3 pT $Hz^{-1/2}$, exceeding the classical level of shot noise, and to approach the limit imposed by the Heisenberg uncertainty principle, the accuracy being mainly restricted by decoherence. It is also possible to increase substantially the sensitivity of such devices in the future. Russian scientists from MIPT (Moscow Institute of Physics and Technology) and ITP (Landau Institute for Theoretical Physics) are taking part in this research.

Source: *npj Quantum Information* **4** 29 (2018)
https://www.nature.com/articles/s41534-018-0078-y

9. 'Missing baryons' are found

The amount of baryon gas in the Universe is rather reliably predicted by the theory of primary nucleosynthesis and is calculated from observations of fluctuations in relic radiation. However, only 10% of all baryons are observed in galaxies and 60% in the intergalactic space, while the remaining 30% have been invisible. The missing baryons were assumed to be present in the intergalactic filamentary structures forming the so-called warm-hot intergalactic medium with the gas temperature of $10^5 - 10^7$ K enriched with heavy elements flowing from galaxies. This picture was obtained by R Cen, J P Ostriker, and some others, and it was confirmed by the numerical simulations performed by J M Shull and some others. The 'missing baryons' are difficult to find because they are ionized. Only weak and ambiguous evidence of their existence has up to now been obtained in observations. F Nicastro (National Institute of Astrophysics, Italy and Harvard Smithsonian Center of Astrophysics, USA) and his colleagues have investigated the oxygen (O VII) absorption lines in the quasar X-ray spectrum at a redshift $z > 0.4$. The observations were carried out using the spectrometer of the XMM-Newton cosmic telescope. The data obtained imply that a large amount of hot gas with an oxygen admixture is present in intergalactic space on the line of sight. The constancy and shape of the absorption spectrum practically exclude the possibility that the gas is connected with the quasar itself or with its host galaxy. Thus, the conclusion suggests itself that the missing 30% of the Universe's baryons have been revealed.

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