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1. Superfluid solid state in a gas with dipole–dipole interaction

States combining superfluidity and crystalline periodicity are called superfluid solid states (SSSs). The possibility of their existence was predicted theoretically by A F Andreev and I M Lifshitz (*Zh. Eksp. Teor. Fiz.* **56** 2057 (1969) [*Sov. Phys. JETP* **29** 1107 (1969)]) and G V Chester (*Phys. Rev. A* **2** 256 (1970)) and A J Leggett (*Phys. Rev. Lett.* **25** 1543 (1970)). The conditions for an SSS to appear are the presence of a roton minimum on the dispersion curve and quantum stabilization. An observation of SSSs in solid helium-4 was reported in 2004, but the result has not been confirmed. The SSS was reliably discovered in 2009 in rubidium atom gas in a periodic potential generated by the radiation field. The possibility of the roton minimum and SSS occurring was also predicted without an external periodic field. Three independent teams of researchers confirmed this prediction when they discovered the SSS in Bose–Einstein condensates of gases whose atoms have large magnetic dipole moments. An absorption image of atomic wave interference was obtained in a condensate cloud upon its free expansion. This was how periodically located phase-coherent drops of Bose–Einstein condensate were observed. Two groups guided by G Modugno (University of Florence, Italy) and T Pfau (University of Stuttgart, Germany) examined the ^{162}Dy isotope. The SSS lifetime measured by them was equal to 30 ms. This time was limited by three-body losses. 3D-modeling based on the generalized Gross–Pitaevsky equation showed good agreement between theory and experiment. F Ferlaino (University of Innsbruck, Austria) and her colleagues revealed SSSs in the gas of ^{166}Er and ^{164}Dy isotopes. An SSS lasts 30 ms in ^{166}Er and 150 ms in ^{164}Dy.

Sources: *Phys. Rev. Lett.* **122** 153601 (2019)
Phys. Rev. X **9** 011051, 021012 (2019)
https://doi.org/10.1103/PhysRevLett.122.130405
https://doi.org/10.1103/PhysRevX.9.011051
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2. Quantum spin ice in $Ce_2Zr_2O_7$

J Gaudet (McMaster University, Canada, Johns Hopkins University and NIST, USA) and colleagues have investigated the properties of the pyrochlore magnet $Ce_2Zr_2O_7$ and showed that the state of a quantum liquid is possibly attained in it in the form of spin ice. As distinct from usual substances, the spins of atoms remain disordered, even at absolute zero temperature. J Gaudet and co-authors applied neutron scattering from a source in the Oak Ridge National Laboratory for the study of spin dynamics in powder-like $Ce_2Zr_2O_7$ and in single crystals. Discovered were doublet states coupled with Ce^{3+} ions and energy separated from other excitations in the crystal. It turns out that at a temperature of 60 mK the character of neutron scattering is close to that predicted for quantum spin ice.

Source: *Phys. Rev. Lett.* **122** 187201 (2019)
https://doi.org/10.1103/PhysRevLett.122.187201

3. Test of Bell inequality using separated qubits

Although quantum entanglement of superconducting qubits connected by a long channel has already been demonstrated, the Bell inequalities for them have not been verified so far because of the difficulties in transferring states with high quantum accuracy. Such a test was only realized for qubits with local coupling. A N Cleland (University of Chicago and Argonne National Laboratory, USA) and colleagues have successfully tested for the first time the Bell inequalities by coupling two superconducting qubits with quantum accuracy $f = 0.94$ using photons through a 78-cm coplanar waveguide. The Bell inequalities were violated at a level of 9.7σ. The applied method can be used in devices of quantum information transfer.

Source: *Nature Physics*, online publication of 22.04.2019
https://doi.org/10.1038/s41567-019-0507-7

4. Laser radio transmitter

F Capassoa (Harvard University, USA) and his colleagues have designed a radio transmitter in which the near IR laser radiation is transformed into microwave-range radio waves. As distinct from other known methods of radio wave laser generation, radio emission appears directly in the laser working volume. A quantum-cascade GaInAs/AlInAs laser worked in the frequency comb regime. The beats between neighboring optical modes in the resonator formed space-time optical field variations. These variations affected the stimulated emission and absorption of photons that induced the electron motion and radio wave generation at a frequency of 5.5 GHz. The upper metal electrode had a cut and played the role of a dipole antenna for signal transmission to the external space. The signal could be modulated by useful information by varying the laser feed current. In the inverse regime, the device can also receive radio signals. This study paves the way for designing hybrid electron-photon devices.

Source: *PNAS*, online publication of 24.04.2019
https://doi.org/10.1073/pnas.1903534116

5. ISS measurement of cosmic-ray proton spectra

Using the CALET device located aboard the International Space Station, the cosmic-ray proton spectrum was measured in the energy range from 50 GeV to 10 TeV. This interval includes, in particular, hardening of the spectral region, where its slope changes. The observation of the spectrum above and

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below this region using one and the same device is important because of the absence of systematic errors. Some parts of the spectrum were measured earlier by various space detectors (PAMELA, ATIC, etc.) that revealed the spectrum hardening effect. The CALET instrument includes a charge detector and a calorimeter array. The spectrum measured by CALET agrees with the results of AMS-2 measurements, but extends to higher energies. One can see a smooth transition of the spectral index from $\gamma = -2.81 \pm 0.03$ (without solar modulation effects) in the interval of 50 to 500 GeV to $\gamma = -2.56 \pm 0.04$ at 1 to 10 TeV. Measurement of the cosmic-ray proton spectrum is important, as it provides insight into the mechanisms of the acceleration of cosmic rays and their transport in the Galaxy.

Source: *Phys. Rev. Lett.* **122** 181102 (2019)
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