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1. Pressure-induced quenching of a superconductor

Room-temperature superconductivity discovered recently in hydrides only exists under a giant pressure of 267 GPa. In this connection, the search for the possibility of lowering pressure while retaining superconductivity has become a topical problem. L Deng (University of Houston, USA) and co-authors have carried out an experiment showing, based on the example of another type superconductor — iron selenide (FeSe) single crystals — that the problem can be solved through pressure-induced quenching, i.e., an abrupt pressure removal at low temperature [1]. The superconducting transition temperature of FeSe is $T_c \sim 9$ K at atmospheric pressure and $T_c = 37$ K at a pressure of several GPa. FeSe specimens were pressed in a diamond anvil to 4.15 GPa and cooled to 4.2 K, and then the pressure was abruptly removed. After such a quenching, the specimens retained $T_c = 37$ K at atmospheric pressure for 7 days. The transition between orthorhombic and tetragonal structures of the crystal lattice, when FeSe remains in the metastable phase after quenching, is likely to explain the quenching effect on T_c. The results obtained for FeSe hold promise that pressure-induced quenching may also stabilize hydride superconductors. For high-temperature superconductors, see [2]. The 2003 Nobel Prize laureate in physics V L Ginzburg placed the creation of room-temperature superconductors on the list of the most topical problems in physics [3].

2. Townes solitons in two-dimensional systems

Calculations show that, in a two-dimensional system, solitons are only stable for a certain relation between the particle number and the value of the interaction constant. Such solitons, referred to as 'Townes solitons,' have been actively studied in nonlinear optics. B Bakkali-Hassani (Sorbonne University, France) and co-authors have obtained and investigated Townes solitons in a 2D mixture of Bose–Einstein condensates [4]. Within a small region, nearly 10% of ^{87}Rb condensate atoms in the state $|F = 1, m_F = 0\rangle$ were transferred, using a laser, to the state $|F = 2, m_F = 0\rangle$. The time variation of the obtained soliton profile was traced. For 790 ± 40 atoms, the soliton was the most stable and scale invariant. In another experiment, C-A Chen and C-L Hung obtained a set of separate Townes solitons in cesium atomic gas in a 2D trap [5]. The normalized density profile coincided with the universal Townes soliton profile in a wide range of parameters, which confirmed the predicted scale invariance. For solitons in ultracold gases, see [6, 7].

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3. Doublons in quantum metamaterial

I E Besedin (NUST MISiS and Russian Quantum Center at Skolkovo) and his co-authors have investigated bound photon pairs ('doublon' quasiparticles) in quantum metamaterial, which was a one-dimensional array of 11 superconducting qubits [8]. Topological edge states of doublons were observed experimentally for the first time. The array was made of aluminum Josephson junctions on a silicon substrate via electron beam evaporation. The coupling between qubits was in turn weak and strong, which resulted in the appearance of two bands and topological edge states. Upon increasing the pumping signal, first single-photon and then two-photon modes were excited in qubits. In both cases, photons were localized at the chain edges, which corresponds to topological edge states. For metamaterials, see [9–11].

4. Collective modes in an excitonic insulator

The possibility of the existence of excitonic insulators was predicted in 1968 by L V Keldysh and A N Kozlov [12, 13], and also independently by two foreign groups of researchers. For excitons (bound states of electrons and holes), see [14, 15]. Some evidence of the occurrence of the state of an excitonic isolator, when an exciton condensate appears in a substance, has already been obtained in experiment, but these results have been ambiguous. A Rao (Cavendish Laboratory, University of Cambridge, Great Britain) and his colleagues examined the compound Ta_2NiSe_5 and used a new method to show that an exciton condensate is likely to occur in it at room temperature [16]. The method of femtosecond spectroscopy with a resolution of 10 fs and 10 nm was used. A laser pumping pulse illuminated a 400-nm spot on a Ta_2NiSe_5 plane. Wider test beams illuminated the region around the spot, and the transmitted radiation was registered by a CCD camera. This made it possible to observe propagation of coherent oscillating waves, excited by a pumping pulse, to the region beyond the spot at a distance up to 1 μm at a velocity of 1.5×10^5 m s^{-1}. These waves are most likely to be the result of the hybridization of phonon modes of a crystal lattice and collective modes of exciton condensate, for other known mechanisms fail to explain the observed picture.

5. PeV gamma-ray sources in the galactic disc

LHAASO observatory in China at an altitude of 4.4 km above sea level records extensive air showers (EASs) induced by cosmic ray particles and gamma-ray photons. Within less than a year of observations using the array of KM2A scintillation detectors in the composition of LHAASO, 530 photons with an energy from 100 TeV to 1.4 PeV were detected. From the clusterization of these photons, 12 gamma-ray sources in the galactic disc plane [17] with angular dimensions up to 1° were revealed with $\geqslant 7\sigma$ significance. One of the sources coincides with the well-known Crab Nebula. The gamma-ray photon generation mechanism has not yet been found, but it implies the presence of high-power particle accelerators ('PeVatrons'). In the neighborhood of each source, several possible candidates exist, namely, pulsars, pulsar wind nebulae, supernova remnants, and young clusters of massive stars. However, the sources have not been identified, except for the Crab Nebula. New theoretical models of sources may possibly be needed to explain the high photon energy. Russian researchers from Institute for Nuclear Research of the Russian Academy of Science (INR RAS) and Moscow Institute of Physics and Technology (MIPT) are taking part in the LHAASO collaboration.

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