PACS number: **01.10.–m**, **01.30.–y**, **01.90.+g**

Physics news on the Internet (based on electronic preprints)

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DOI: https://doi.org/10.3367/UFNe.2021.04.038970

1. Testing the black-hole area law

Stephen Hawking showed in 1971 that, in the course of any classical process, the sum of black hole (BH) event horizon areas does not decrease with time. This statement is a consequence of the main principles of the General Theory of Relativity. Hawking's theorem implies that after the merging of two black holes the horizon area of the new black hole will be no less that the sum of the horizon areas of the original BHs. Using the characteristics of the first gravitational-wave signal of GW150914, registered by the LIGO interferometer in 2015 [1], Isi (Massachusetts Institute of Technology, USA) and his co-authors obtained the first observational confirmation of the area law [2]. The observed shape of the GW150914 signal was compared with the theoretically calculated curves of signal pulsations before and after the two BHs merged. This gave the masses, angular momenta, and areas of the BH horizons before and after merging. It was found that the sum of the initial horizon areas is less than the final area with a 95–97% probability. This conclusion is another successful testing of the General Theory of Relativity. For BHs in binary systems, see [3].

2. Stern–Gerlach interferometer

The Stern–Gerlach experiment performed in 1922 showed that projections of atomic magnetic moments onto the magnetic field direction acquire discrete values [4]. Since then, the idea of designing an interferometer on the basis of the Stern–Gerlach effect has been repeatedly discussed, but it has been concluded that it is an exceedingly difficult task, because the magnetic field needs extremely exacting control. Nevertheless, a Stern–Gerlach interferometer was realized by Y Margalit (Ben-Gurion University, Israel) and his co-authors first in the half-loop version and then with a full loop. The experiment [5] was carried out 'on a chip' with atoms of Bose–Einstein condensate transferred into the superposition of two spin states. The atoms were subjected to a pulsed action of the magnetic field gradient with the result that the wave packets of atoms in different states first separated and then came closer to each other again to form a complete interferometer loop on the space-time diagram. At the output, the absorption method was used to examine the spin level populations that explicitly showed interference. The new interferometer may be used in fundamental studies. Its realization employing macroscopic objects, e.g., diamond nanoparticles, would allow testing even quantum gravity effects.

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Uspekhi Fizicheskikh Nauk **191** (7) 783 – 784 (2021)
Translated by M V Tsaplina

3. Andreev reflection and fractional quantum Hall effect

An electron incident on a normal-metal superconductor can be reflected as a hole (the Andreev reflection effect predicted by A F Andreev in 1964), while a Cooper pair of electrons appears in the superconductor [6]. It was predicted theoretically that such an effect must also be observed at the interface of two substances in which the fractional quantum Hall effect occurs provided that the substances have different Landau level filling factors ν. M Hashisaka (NTT Fundamental Research Laboratories, Japan) and his co-authors have become the first to confirm this prediction in their experiment with a GaAs quantum wall in a magnetic field [7]. Andreev reflection showed up in oscillations of conductivity of the narrow junction between regions $\nu = 1/3$ and $\nu = 1$ under variation of its width caused by electrode potential variation. Thus, Andreev reflection has been revealed for the first time in a topological system without superconductivity.

4. Exciton–polariton room-temperature Bose–Einstein condensate

Exciton–polaritons (EPs) are strongly coupled systems of excitons and photons (see, e.g., [8]). Obtaining EP Bose–Einstein condensates is important for creating lasers with unique properties and optical logical elements. EP room-temperature condensates were already demonstrated earlier using organic systems located between two flat reflectors. J Tang (Institute of Chemistry and University of the Chinese Academy of Sciences, China) and his co-authors have obtained an EP room-temperature Bose–Einstein condensate using a new method — in extended microcavities inside an organic crystal [9]. Microcavities are used as Fabry–Perot resonators, in which a strong coupling between Frenkel excitons and photons results in EP condensate generation. The low microresonator Q-factor is compensated by a high exciton density. A controlled flux of coherent light generated in the given device was demonstrated. The results of measurements agree well with the calculations based on the Gross–Pitaevskii equation. For exciton condensation, see [10].

5. Lee–Huang–Yang correction

The Lee–Huang–Yang correction to the ground-state energy of a boson gas describes the quantum fluctuation effect. The influence of this correction was observed in several experiments. T G Skov (Aarhus University, Denmark) and his co-authors performed a new experiment with a mixture of Bose–Einstein condensates where the effect of mean-field interactions was canceled and the Lee–Huang–Yang correction became determinant [11]. It created force generating monopole condensate oscillations. Investigated was a two-component condensate of ^{39}K atoms in spin states of hyperfine splitting $|F = 1, m_F = -1\rangle$ and $|F = 1, m_F = 0\rangle$. The condensate was trapped in a spherically symmetric harmonic potential created by laser beams. Condensate oscillations were absorbed by the absorption method at the stage of free expansion after the potential was off. Good agreement was obtained with numerical simulations of condensate dynamics with allowance for the dominant role of the Lee–Huang–Yang correction.

6. Topological insulator lasers

In topological insulator lasers, optical edge mode excitation is used. Owing to the topological stability of these modes against defects and perturbations, such lasers are highly reliable and effective, but their operation typically requires cryogen temperatures or optical pumping. J-H Choi (University of Southern California, USA) and his co-authors have demonstrated for the first time a room-temperature electrically pumped topological insulator laser [12]. The device is a periodic array of micro-ring resonators on a semiconducting substrate, coupled by a nonperiodic set of auxiliary elements. Synthetic gauge fields imitated the quantum spin Hall effect for photons. In the array, the electric field excited coherent optical edge modes generating telecommunication-range room-temperature lasing.

7. Spin gyroscope

A V Akimov (Lebedev Physical Institute) and his colleagues have designed a gyroscope based on a hyperpolarized ensemble of nuclear spins of ^{14}N in NV (nitrogen vacancy) centers in diamond [13]. The gyroscopic effect was due to a stable direction of spins not subjected to external action. The states of nuclear spins were polarized and read out in the standard method using electron spins of NV centers. The new gyroscope detected rotations with an angular velocity of several ten degrees a second, and its work was verified using now existing microelectromechanical gyroscopes. The idea of nuclear gyroscopes was discussed as far back as the 1960s, and it was at that time that the first prototypes were created [14]. The spin gyroscope can be much more compact than circular laser gyroscopes based on the Sagnac effect, since the precision of the latter depends on the ring area. Therefore, gyroscopes based on NV centers pave the way to practical applications in various navigation facilities.

8. Coherence of scattered photons

S Sajeed and T Jennewein (University of Waterloo, Canada) have worked out a method of transferring quantum coherent photon pairs between a source and detector situated out of each other's field of view [15]. The state of photon polarization, which is normally used to create quantum entanglement, is frequently lost upon photon scattering. To overcome this difficulty, the authors used quantum coherence coded in time intervals, which is stable under scattering. A multimode interferometer and an array of single-photon detectors with a time resolution of ≈ 120 ps were employed in the experiment. A phase converter based on a Maikleson interferometer transferred laser pulses into pairs of successive coherent pulses, and their reflection from a sheet of white paper was examined. Scattered pulses were analyzed with a second interferometer. Although the scattering angle lay in the range from $-45°$ to $+45°$, the photon visibility remained at the level of 95%, and the signal above the incoherent noise level was singled out owing to quantum coherence. Quantum coherence of photons is of importance for quantum communication devices and for quantum probing in different fields, including biomicroscopy [16].

9. Recurrent fast radio burst source in a globular star cluster

From observations using radio telescopes and interferometers with a very long base, F Kirsten (Chalmers University of Technology, Sweden) and his co-authors have found that the source of recurrent fast radio bursts (FRBs), FRB 20200120E, is situated in the globular cluster located in the tidal bridge between galaxies M81 and NGC 3077 [17]. The probability of an occasional association with a globular cluster is $< 1.7 \times 10^{-4}$. This observation is unusual because, according to the most popular model, FRBs are generated in magnetars (young magnetized neutron stars), which is confirmed by the recent observation of bright bursts from a galactic magnetar. And these objects typically find themselves among young stars in galactic discs. They were not expected in old globular clusters. FRB 20200120E lies much closer than other known sources of extragalactic FRBs. This provided constraints on the flow of constant radio, X-ray, and gamma-ray emission from this object, which narrows the possible classes of FRB generation models. The authors assume that magnetar FRB 20200120E resulted either from a collapse of an accreting white dwarf or from a white-dwarf and/or neutron-star merging in a binary system, whereas its birth via explosion of a core-collapse supernova in a globular cluster is hardly probable. For FRBs, see [18].

10. FAST pulsar survey

The study of pulsars is of importance to analyze the state of matter under extreme conditions, to examine star evolution, and to verify gravitation theories. A new survey obtained from FAST radio telescope presents data on pulsars at an angular distance of $\pm 10°$ from the galactic disc plane [19]. With an aperture of 300 m, FAST is the most sensitive radio telescope aimed at pulsar research. A binary millisecond pulsar was revealed in the globular cluster M13, an eclipse millisecond pulsar was found in M92, and several pulsars with a high dispersion measure, including pulsar PSR J1901 + 0435 with an inverted spectrum, were investigated. Observed were several pulsars coincident with supernova remnants, 40 millisecond pulsars, 16 binary pulsers, and rotating radio transients. The released survey of pulsars will allow a more thorough study of newly found interesting objects using alternative facilities. For neutron stars, see [20–22].

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