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1. Symmetries of quantum gravity

The history of the development of quantum gravity begins with the work of M P Bronstein carried out in the 1930s at the Leningrad Physical and Technical Institute (now the Ioffe Institute of the Russian Academy of Sciences). A complete theory of quantum gravity has not yet been formulated because of fundamental theoretical difficulties. For quantum gravity and unsolved problems in this field, see the paper by G E Gorelik in *Usp. Fiz. Nauk* **175** 1093 (2005) [*Phys. Usp.* **48** 1039 (2005)]. Nevertheless, an active search for new approaches to the creation of the theory of quantum gravity is under way. In 1957, C W Misner and J A Wheeler formulated a number of conditions to be satisfied by this theory. D Harlow (Massachusetts Institute of Technology, USA) and H Ooguri (California Institute of Technology, USA and University of Tokyo, Japan) showed how these conditions can be realized in the AdS/CFT correspondence model, which is an example of the quantum holography principle. AdS/CFT makes a connection between the theory of quantum gravity in the anti-de Sitter space and the conformal field theory on the surface bounding it. D Harlow and H Ooguri showed that for consistency the theory should be free of global symmetries and the intrinsic gauge groups should be compact.

Source: *Phys. Rev. Lett.* **122** 191601 (2019)
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2. Bounds on quantum correlations

A bound on correlations of two sets of quantum measurements taken outside and inside some region in space exists along with bounds on the maximum propagation velocity of quantum information (the Lieb–Robinson bound). The magnitude of correlations depends on the area of the two-dimensional surface bounding the specified region (the area law). In their theoretical work, I Kull, P Allard Guerin, and C Brukner (University of Vienna and Institute for Quantum Optics and Quantum Information, Austria) extended the area law to the case of four-dimensional space-time regions. Considered as a model system was a finite array of spins, each having a limited scale and a limited impact on neighboring spins, as well as the propagation in such a system of mutual quantum information in the course of measurements conducted by observers during a limited time. One of the observers takes measurements inside a certain region, and the other outside this region. The maximum value of the mutual information characterizing quantum correlations was found to be proportional to the area of the three-dimensional hypersurface bounding the inner four-dimensional region. The new relationships may provide a link between quantum information and the geometry of space-time, which is of importance for the construction of the theory of quantum gravity.

Source: *npj Quantum Information* **5** 48 (2019)
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3. Quantum entanglement between a photon and a spin wave in a solid

Quantum entanglement between light and matter is of great interest for quantum information transmission. Entanglement between photons and spin excitations in ultracold gases has already been obtained earlier. K Kutluer et al. (Barcelona Institute of Science and Technology, Spain) demonstrated in their experiment a direct entanglement in time between a single photon and a single collective spin excitation in an ensemble of ions of the rare-earth element praseodymium Pr^{3+} embedded in a Y_2SiO_5 crystal. The experiment was carried out at a temperature of 3.5 K. The quantum state was analyzed through mapping the spin excitation on a photon qubit using a frequency comb and a qubit-analyzer implemented with another crystal. The entanglement was confirmed by violation of Bell inequalities at the level of two standard deviations. Such accuracy makes the device suitable, e.g., for designing quantum repeaters.

Source: *Phys. Rev. Lett.* **123** 030501 (2019)
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4. Three-dimensional quantum spin liquid

A quantum spin liquid is a state of matter such that the interacting spins of its atoms remain disordered, even upon approaching absolute zero temperature. The existence of a two-dimensional quantum spin liquid in some materials has already been observed. It was theoretically predicted that in pyrochlore $Ce_2Zr_2O_7$ a three-dimensional quantum spin liquid can exist in the Ce^{3+} ion lattice, but the available experimental data could not confirm it reliably because of the absence of large crystals. B Gao et al. (Rice University, USA) have managed to grow a sufficiently large $Ce_2Zr_2O_7$ crystal and concluded that a three-dimensional quantum spin liquid is probably present in the crystal. The study of the specific heat of the crystal showed the absence of phase transitions down to 50 mK, the measurements of muon spin relaxation time confirmed the absence of a long-range order upon cooling to 20 mK, and the X-ray diffraction method ruled out the presence of a large number of defects. Finally, inelastic neutron scattering by a single $Ce_2Zr_2O_7$ crystal revealed a spin excitation continuum down to a temperature of 35 mK. All this is highly probable evidence of the presence of a three-dimensional quantum spin liquid.

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5. Klein Paradox in SmB_6

In 1929, O Klein discovered that potential barriers can be transparent to electrons, even if the barrier height exceeds the particle energy. As interpreted by A I Nikishov (*Zh. Eksp. Teor. Fiz.* **57** 1210 (1969) [*JETP* **30** 660 (1970)], the 'Klein paradox' is explained by the creation of one of the particles of a particle–antiparticle pair beyond the barrier. Electron–hole excitations in graphene and in topological insulators are described efficiently by the Dirac equation for massless particles, which makes it possible to observe Klein tunneling at low energies, and this effect was actually observed in graphene heterostructures by S Lee et al. (University of Maryland, College Park, USA), who have reported the first observation of ideal tunneling in a topological insulator. An interface was examined between a normal metal and a topological insulator SmB_6 in which superconductivity was induced by the adjacent YB_6 layer. Electron spectroscopy showed a doubling of the conductivity value, which was indicative of ideal electron tunneling from the normal metal to the superconductor. This phenomenon is theoretically explained by ideal Andreev reflection (A F Andreev, *Zh. Eksp. Teor. Fiz.* **46** 1823 (1964) [*JETP* **19** 1228 (1964)]: the electrons could not be reflected back because of the spin-momentum locking in the topological insulator. The Klein tunneling effect can find practical application in the design of new spintronic devices.

Source: *Nature* **570** 344 (2019)
https://doi.org/10.1038/s41586-019-1305-1

6. Dzyaloshinskii–Moriya interaction in heterostructures

Dzyaloshinskii–Moriya interaction is an exchange interaction via intermediate nonmagnetic atoms by means of spin-orbit coupling. In their theoretical study, E Yu Vedmedenko et al. (University of Hamburg, Germany) have examined the Dzyaloshinskii–Moriya interaction in heterostructures consisting of two ferromagnets separated by a nonmagnetic spacer and showed that it has a fairly large magnitude and leads to the formation of a global chiral structure across the entire trilayer in three spatial dimensions. Both analytical and numerical Monte Carlo calculations were carried out. The ferromagnets were modeled by a spin monolayer. The result obtained paves the way for new applications of magnetic chirality in heterostructures. The study of heterostructures is under way, in particular, at the Ioffe Institute, where a number of fundamental results have been obtained. For double heterostructures, see *Usp. Fiz. Nauk* **172** 1068 (2002) (see also the review in *Usp. Fiz. Nauk* **188** 1249 (2018) [*Phys. Usp.* **61** 1139 (2018)]).

Source: *Phys. Rev. Lett.* **122** 257202 (2019)
https://doi.org/10.1103/PhysRevLett.122.257202

7. Organic laser diode with direct electric pump

Organic diode lasers have already been created, but they were pumped by optical radiation. Electrical pumping has not been realized because of the large optical and polaron losses. A directly electrically pumped organic diode laser has been designed for the first time at Kyushu University (Japan). A thin film of organic compound 4,4′-bis[(N-carbazole)styryl]biphenyl was used, which had a low lasing threshold. The film was coated with a vanadium cathode, allowing an efficient injection of current. The laser oscillation frequency in the blue spectral region was separated from the region of triplet and polaron absorption, which decreased losses. A fundamental contribution to laser science, including the creation of double heterostructure lasers, was made by Zh I Alferov and his colleagues at the Ioffe Physical and Technical Institute of the USSR Academy of Sciences.

Source: *Applied Physics Express* **12** 061010 (2019)
https://doi.org/10.7567/1882-0786/ab1b90

8. Cathodoluminescent lamp

Light-emitting diode lamps have recently occupied a leading position in lighting. They have an unquestioned advantage in economy, longevity, and ecological safety. However, their manufacture requires rare substances, for example, gallium and indium, whose procurement may be obstructed for some reasons. Cathodoluminescent lamps are being considered as an alternative to light-emitting diode ones. An example of cathodoluminescence is screen glow in cathode-ray TV tubes. Researchers from the Moscow Institute of Physics and Technology (MIPT) and the Lebedev Physical Institute (FIAN) designed a new type of cathodoluminescent lamp with a cathode based on a bundle of carbon fibers. The lamp had a built-in AC-to-DC converter that produces a high voltage inducing electron ejection from fibers in the course of field emission. The lamp created by E P Sheshin et al. has a triode scheme with the anode current controlled by a modulator. Aluminum sputtering serves as the anode. Electrons hit the luminophor (Y_2O_2S:Tb or something else), inducing its luminescence. The light output ratio of the lamp was 30 to 40 lm W^{-1}. As distinct from LED lamps, cathodoluminescent lamps can be manufactured from widespread substances, and they operate steadily at temperatures of $-50\,^{\circ}C$ to $100\,^{\circ}C$. The pilot sample with a consumed power of 5.5 W has a standard lamp base E27 and can already be applied for general lighting. For cathodoluminescent light sources, see the review in *Usp. Fiz. Nauk* **185** 853 (2015) [*Phys. Usp.* **58** 792 (2015)].

Source: *Journal of Vacuum Science & Technology* B **37** 031213 (2019)
https://doi.org/10.1116/1.5070108

9. Ergostars

The possibility of the existence of neutron stars was predicted by L D Landau in February of 1931 — in the period between his postgraduate course at the Leningrad Physical and Technical Institute and his work at LPTI, before the discovery of the neutron (see *Usp. Fiz. Nauk* **183** 307 (2013) [*Phys. Usp.* **56** 289 (2013]). Neutron stars were found in astronomical observations as pulsars in 1967. Calculations in the framework of General Relativity (GR) showed that rotating bodies, such as neutron stars, can have an ergoregion, i.e., a space region in which all the objects are unavoidably involved in rotation, even without the formation of an event horizon of a black hole. However, it remained unknown whether objects with an ergoregion are dynamically stable, or soon after formation they quickly collapse into black holes because of increasing perturbations. A Tsokaros et al. (University of Illinois at Urbana-Champaign, USA) have made numerical calculations and constructed for the first time dynamically stable models of neutron stars that have an ergoregion. Realistic equations of state of neutron star matter were chosen, and General Relativity calculations were carried out without simplifying assumptions. Classes of models were found which had an ergoregion, but had no event horizon and which remained dynamically stable for 30 periods of object rotation around its axis — before the end of numerical calculations. The revealed theoretically stable new type of objects were called ergostars. Such objects can appear in the course of the merging of two neutron stars. An ergoregion can play an important role in the rapid formation of relativistic jets along the rotation axis. For topical problems of neutron star physics, see the review in *Usp. Fiz. Nauk* **180** 1279 (2010) [*Phys. Usp.* **53** 1235 (2010)].

Source: https://arxiv.org/abs/1907.03765

10. Gravitational waves and a test of GR

In 2017, the gravitational-wave interferometers LIGO and Virgo registered the burst of gravitational waves GW170817 due to the merging of two neutron stars. Electromagnetic signals, including the gamma-ray burst GRB 170817A, were simultaneously observed (for cosmic gamma-ray bursts, see the review by R L Aptekar et al. (Ioffe Institute) in *Usp. Fiz. Nauk* **189** 785 (2019) [*Phys. Usp.* **62** (7) (2019)]). A multiwave observation allowed a test of GR and a constraint on parameters of some alternative gravitation theories. The LIGO/Virgo collaboration presented new constraints in parameter ranges not examined before. The first class of constraints concerns the generation of gravitational waves. Constraints were obtained on a possible contribution of dipole radiation in the strong field regime and on corrections to the post-Newtonian approximation. The second class of constraints is associated with wave propagation. Constraints were obtained on corrections to the dispersion relation, which might be due to a nonzero graviton mass. The parameters of the theories with large extra dimensions were also restricted. In such theories, gravitons must escape into an additional space, which would weaken the signal. Moreover, the gravitational wave was shown to high accuracy to have only two tensor modes of polarization.

Source: *Phys. Rev. Lett.* **123** 011102 (2019)
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