Physics – Uspekhi **61** (4) 397 – 399 (2018)

PACS number: **01.90.+g**

100 years of the *Uspekhi Fizicheskikh Nauk* journal

Physics news on the Internet (based on electronic preprints)

DOI: https://doi.org/10.3367/UFNe.2018.03.038315

1. Quantum Szilard engine with attractively interacting bosons

Under the Szilard engine is meant a thought experiment proposed in 1929 and illustrating the connection between information and work: the knowledge of the position of gas molecules in a vessel is converted into the work done by them in sliding partitions into the vessel. However, the influence of quantum effects and the interactions between particles on the properties of the Szilard engine remained largely unexplored. In their theoretical work, J Bengtsson (Lund University, Sweden) and his colleagues have shown that a Szilard engine containing bosonic particles with attractive pair interaction increases the efficiency of information-to-work conversion compared to the case of noninteracting particles. The *ab initio* calculations were performed in the full quantum-mechanical many-body problem. Considered was the working cycle of the Szilard engine for $N = 1-25$ particles, and the average work output was found to increase with increasing N. As it turned out, the temperature dependence of the work had a maximum which was absent in the case of noninteracting particles. The presence of the maximum was explained by the fact that strong interparticle correlations occur at low temperatures, which shows up efficiently as a decrease in N. For more on the relation between dynamics and information, see the review by B B Kadomtsev in *Phys. Usp.* **37** 425 (1994).

Source: *Phys. Rev. Lett.* **120** 100601 (2018)
https://doi.org/10.1103/PhysRevLett.120.100601

2. Test of fluctuation theorems

Generalized fluctuation-dissipative relations (theorems) describing the evolution and statistics of thermodynamically nonequilibrium systems were formulated in the general form for both open and closed systems by G N Bochkov and Yu E Kuzovlev in 1977–1984 [for the history of this issue see *Phys. Usp.* **54** 625 (2011) and *Phys. Usp.* **56** 590 (2013)]. Later on, various modifications and versions of these general results, in particular, the 'differential fluctuation theorem,' were reported in papers by Ch Jarzynski, G E Crooks, and others. A group of researchers from the USA and China were the first to verify experimentally the differential fluctuation theorem. Quartz particles that were kept suspended by focused laser light were used. Pulses from another laser exerted a force action on these particles in the forward and backward directions, and the instantaneous positions and velocities of particles were fixed during their Brownian random walk in the phase space. The forward and backward processes, in which the particle velocities in the final positions have different signs, were compared. The experiment revealed perfect agreement with the predictions of the differential fluctuation theorem. The generalized Jarzynski equality and the Hummer–Szabo relation were verified separately. An important applicability region of fluctuation theorems lies in microscopic molecular systems in biology, chemistry, and physics.

Source: *Phys. Rev. Lett.* **120** 080602 (2018)
https://doi.org/10.1103/PhysRevLett.120.080602

3. Terahertz interLandau level transitions in a monolayer graphene

Active research on nonlinear optic effects [see the review by L N Ovander in *Phys. Usp.* **8** 337 (1965)] began soon after the appearance in 1960 of optical lasers, which were created several years after masers, i.e., microwave-range quantum generators [see the paper by N G Basov and A M Prokhorov in *Usp. Fiz. Nauk* **57** 485 (1955) (in Russian)]. In recent years, the development of the technology for obtaining intense ultrashort laser pulses has significantly extended this research area. An interesting case of nonlinear optics is transitions between Landau levels for electrons in a magnetic field. However, nonlinearity is then possible only if the levels are nonequidistant, which is the case, in particular, in graphene. In an experiment by G Yumoto (University of Tokyo, Japan) and colleagues, a graphene layer grown by epitaxy on a substrate was placed in a superconducting magnet and was cooled to a temperature of 5 K. The sample was exposed to a linearly polarized THz pump laser beam, and the Faraday rotation of polarization of the second probe beam was analyzed. The ultrafast nonlinear suppression of Faraday rotation was revealed to be associated with transitions between the Landau levels. For more on the discovery of graphene, see the Nobel lectures by A K Geim in *Phys. Usp.* **54** (12) (2011) and K S Novoselov in *Phys. Usp.* **54** (12) (2011).

Source: *Phys. Rev. Lett.* **120** 107401 (2018)
https://doi.org/10.1103/PhysRevLett.120.107401

4. Rotons in a dipolar quantum gas

The concept of roton quasiparticles existing at a minimum energy and a finite momentum was introduced by L D Landau in 1941 to explain the properties of superfluid ^{4}He. It was considered earlier that in quantum gases, as opposed to liquid helium, phonon modes alone are excited, while rotons do not emerge because of weak interatomic interactions. In 2003, however, the possibility was predicted of roton mode excitation in a gas in two cases: in a field of nonresonant laser radiation, and for magnetic dipole–dipole interatomic interactions in Bose–Einstein condensate. Rotons have already been observed in the first case, while the second version, which had been predicted in the paper by L Santos,

Uspekhi Fizicheskikh Nauk **188** (4) 455 – 456 (2018)
DOI: https://doi.org/10.3367/UFNr.2018.03.038315
Translated by M V Tsaplina

G V Shlyapnikov, and M Lewenstein, has been realized for the first time in a new experiment led by F Ferlaino (Institute of Experimental Physics and Institute for Quantum Optics and Quantum Information, Innsbruck, Austria) and his colleagues. A condensate of erbium ^{166}Er atoms was in an elongated cylindrical optical trap [for more on Bose–Einstein condensates in a laser radiation field, see the review by L P Pitaevskii in *Phys. Usp.* **49** 333 (2006)]. In an external magnetic field, atomic spins are aligned in one direction and the scattering length of atoms and the character of their interaction were controlled by the Feshbach resonance method. Rotons occurred through a combination of attractive and repulsive interactions of atoms, depending on their mutual position. The absorption method was applied to measure the momentum distribution of bouncing apart atoms after the trap potential was off. Peaks corresponding to the roton mode were seen in the spectrum. The system was numerically simulated and the generalized Gross–Pitaevskii equation was solved. The results were quite consistent with experiment.

Source: *Nature Physics, online publication of 5 March 2018*
https://doi.org/10.1038/s41567-018-0054-7

5. Magnon transistor

Nearly 70 years have passed since the invention of the electron bipolar transistor [see the paper by W Shockley in *Usp. Fiz. Nauk* **64** 155 (1958)]. Magnonics, along with electronics, is considered to be one of the promising trends in technology [for more details, see *Phys. Usp.* **58** 1002 (2015)]. In particular, the possibility of designing a full-fledged magnon analogue of a transistor was discussed. In 2014, researchers from the Technical University Kaiserslautern (Germany) already demonstrated a prototype of the magnon transistor for the case of coherent low-frequency magnons, but for compatibility with electron devices it is desirable to design analogous setups operating with high-frequency thermal magnons. L J Cornelissen (University of Groningen, Netherlands) and colleagues were successful and demonstrated the method of magnon flux modulation in the yttrium–iron garnet (YIG) mineral with three platinum contacts. Magnons are quasiparticles transferring excitations in a system of interacting spins. They were generated by the Hall spin effect on one side of the mineral and were registered on its other side. The injection of additional magnons induced by electric current flowing through the control contact affected the magnon spin conductance. The magnon flux modulation efficiency was 1.6% mA^{-1} at $T = 250$ K. Devices operating on some other principles, which can be called magnon valves, were designed independently by H Wu and colleagues at the Institute of Physics of the Chinese Academy of Sciences, and by a German–Japanese group (J Cramer and colleagues). In their approaches, they used plane layers of magnetic substances, and the magnon flux across the layers was shown to strongly depend on their mutual orientation.

Source: *Phys. Rev. Lett.* **120** 097702 (2018)
https://doi.org/10.1103/PhysRevLett.120.097702

6. Phononic quadrupole metamaterial

The history of the study of metamaterials begins with the paper by V G Veselago in *Sov. Phys. Usp.* **10** 509 (1968), considering half a century ago the electrodynamics of substances with simultaneously negative values of electric permittivity and magnetic permeability. In recent years, such substances have been created artificially as arrays of elements with definite electromagnetic properties. M Serra-Garcia (Institute for Theoretical Physics, ETH Zurich, Switzerland) and colleagues have created a new type of mechanical metamaterial. Similarly to how the electric charges on the surface of a polarized insulator are connected with its dipole moment, the dipole moments on the edges and the charges in the corners are connected with the quadrupole moment. In the above-described experiment, a mechanical analogue of a quadrupole insulator was created on the basis of an array of silicon plates with holes. A weak mechanical constraint between the plates was realized by a set of silicon rods, and the role of charges was played by ultrasound-induced elastic strains of one direction or another. The vibrational spectrum was measured by a laser interferometer. The system had a nontrivial set of vibrational modes, including vibrations on the edges and in the corners, resembling in their properties a topological insulator.

Source: *Nature* **55** 5342 (2018)
https://doi.org/10.1038/nature25156

7. First stars in the Universe and a 21-cm absorption line

The observation of absorption in the 21-cm neutral-hydrogen radio line displaced towards the red region due to cosmological expansion provides valuable information on the physics of the early Universe in the so-called 'dark-century' epoch which set in after hydrogen recombination and lasted till its repeated ionization. The first stars and galaxies arose at the end of this epoch. The hydrogen absorption of UV photons emitted by stars populates the upper energy levels of atoms, connecting the spin and kinetic gas temperatures and thus affecting absorption in the 21-cm line. J D Bowman (University of Arizona, USA) and colleagues have performed new exact observations of the 21-cm line with two radio telescopes deployed in Australia. The absorption line profile agrees on the whole with the theoretical calculations allowing for emission from the early stars, but the signal amplitude is much larger than expected. Independent observations are needed, however, to estimate the reliability of this result. Such a discrepancy, if it does exist, implies that in the epoch considered the gas was at a minimum twice as cool as it must be in conditions of adiabatic cooling. One possible explanation may be a hypothetical interaction between baryons and dark matter particles resulting in additional gas cooling. The low-frequency front of the observed profile of the 21-cm line indicates that 180 million years after the Big Bang (red shift $z \sim 15$) stars already existed which created the background of Lyman-α photons. These may have been the first stars in the Universe (referred to as stars of population III). For the development of the notion of the internal star structure and sources of their energy, see, in particular, the papers by A S Eddington in *Usp. Fiz. Nauk* **4** 11 (1924) (in Russian) and *Usp. Fiz. Nauk* **6** 273 (1926) (in Russian), and also the papers by Ya K Syrkin in *Usp. Fiz. Nauk* **8** 675 (1928) (in Russian), A Unsold in *Usp. Fiz. Nauk* **65** 499 (1958) (in Russian), and H Bethe in *Usp. Fiz. Nauk* **96** 393) (1968) (in Russian).

Source: *Nature* **555** 67 (2018)
https://doi.org/10.1038/nature25792

8. Heating of the solar chromosphere

S D T Grant (Queen's University of Belfast, UK) and colleagues have become the first to observe the effect of solar chromosphere heating ypon Alfvén wave dissipation. It had long before been predicted theoretically that Alfven waves must rise from the visible surface of the Sun (photosphere) to the upper layers and dissipate there, releasing heat and heating the chromosphere and corona. Although there was evidence of the existence of Alfvén waves on the Sun, the effect of their dissipation had not been confirmed. In the new observations with a high-resolution solar telescope in New Mexico (USA) and using instrumentation at the cosmic Solar Dynamics Observatory (SDO), the magnetic field distribution in the sunspot was examined and, on the basis of the observation of Doppler shifts in the calcium spectrum, a picture of plasma velocities was reconstructed and the shock waves due to Alfven wave transformation to magneto-acoustic oscillations were revealed. This process leads to energy dissipation and chromosphere heating. In 1942, H Alfvén predicted the existence of the waves in plasma, named after him. For more on plasma physics and the structure of the Sun, see the Nobel lecture by H Alfven in *Usp. Fiz. Nauk* **104** 529 (1971) (in Russian) and the paper by A S Monin in *Phys. Usp.* **23** 594 (1980).

Source: *Nature Physics, online publication of March 5, 2018*
https://doi.org/10.1038/s41567-018-0058-3

9. The discovery of a planet by microlensing

Several thousand planets (exoplanets) around other stars have been discovered to date. Most of them have been found with the Kepler telescope by the transit method or through measuring radial velocities, but 65 exoplanets have been revealed from observations of the microlensing effect, i.e., gravitational focusing of distant star light. A group of researchers from Italy, Slovakia, and Russia (Sternberg Astronomical Institute, MSU) observed a bright microlensing event with the possible participation of an exoplanet belonging to the 'super Earth' type (planets with masses of 1 to 10 Earth masses). Since the event was observed from the direction towards the anticenter of the Galaxy, where the lens concentration is very low, it is rare and exclusive. The star, the source of the light, is located at a distance of 700–800 pc from Earth. Its variability showed signs indicative of the presence on the line of sight of a gravitational binary lens consisting of a star with a mass of about $0.25M_{\odot}$ and a planet with a mass of 9.2 ± 6.6 Earth masses moving along the orbit with a radius of 0.5 AU. This system lies at a distance of only 380 pc from us (the nearest microlensing event). For more on gravitational microlensing, see the paper by A F Zakharov and M V Sazhin in *Phys. Usp.* **41** 945 (1998). Notice also that the first exoplanet in another galaxy (in the Andromeda Nebula) was first discovered with the help of microlensing in 2009 [see *Phys. Usp.* **54** 1077 (2011)].

Source: *Mon. Not. Roy. Astron. Soc.* **476** 296 (2018)
https://arXiv.org/abs/1802.06659

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