PACS number: **01.90.+g**

Physics news on the Internet (based on electronic preprints)

DOI: https://doi.org/10.3367/UFNe.2018.02.038295

1. Oscillations of atmospheric high-energy neutrinos

The effect of neutrino oscillations at energies up to 56 GeV, which is an order of magnitude higher than was reported earlier, has been measured in the IceCube experiment being carried out in the ice of Antarctica at the South Pole. Muon neutrinos were registered that had been born in the interactions of cosmic rays with air molecules in the Earth atmosphere. Not only were downright flying neutrinos observed, but so were those passing through Earth. A deficit of upward flying muon neutrinos, which was related to the effect of oscillations (transformations) of muon neutrinos to tau neutrinos, was already observed earlier. A new analysis of IceCube obtained for three years gives $\Delta m_{32}^2 = 2.31^{+0.11}_{-0.13} \times 10^{-3}$ eV^2 and $\sin^2\theta_{23} = 0.51^{+0.07}_{-0.09}$ for the neutrino parameters under a normal mass ordering. Neutrino mixing is close to maximal, which corresponds to the data of the accelerator experiment T2K, but differs from the NOvA data.

Source: *Phys. Rev. Lett.* **120** 071801 (2018)
https://doi.org/10.1103/PhysRevLett.120.071801

2. Observation of quantum energy-time entanglement

Researchers from the University of Waterloo (Canada) and the University of Paderborn (Germany) have performed an experiment to observe for the first time the quantum energy entanglement of a photon with the time needed to detect a second photon, quantum-entangled with the first one. This effect had not yet been directly observed because of the high rate of the processes. In the experiment by J-P W MacLean, J M Donohue, and K J Resch, pairs of photons were born under the action of laser pulses on a nonlinear crystal. In one of the photons, an 'optical comb' was used to determine the frequency (energy), and the time of the second photon's detection was measured using the stroboscopic method. This method uses auxiliary laser pulses — time marks. Entering a nonlinear BiBO crystal almost simultaneously with such a pulse, the second photon of the pair could be converted into a photon with a higher frequency whose observation served count the time with an accuracy to 10^{-12} s. Verification of certain relations between photon frequencies and times of their detection showed the presence of quantum entanglement. The effect can find application in key distribution protocols, for synchronization, and for other purposes.

Source: *Phys. Rev. Lett.* **120** 053601 (2018)
https://doi.org/10.1103/PhysRevLett.120.053601

3. Bell's inequalities with continuous variables

Verification of Bell inequalities is a fundamental test of quantum mechanics excluding hidden parameters. Many experiments have demonstrated a violation of these inequalities using discrete quantum variables. In their experiment, O Thearle (Australian National University) and colleagues showed for the first time that Bell's inequalities are also violated for a system characterized by continuous variables represented by four polarization modes obtained in the mixing of two photons in compressed states. The results of the measurements carried out through synchronous detection clearly showed a violation of Bell's inequalities in the Clauser–Horne–Shimony–Holt version (CHSH inequalities). This experiment opens up new possibilities for using continuous variables in device-independent quantum protocols. Bell's inequalities for photons were considered in detail in the review published in *Usp. Fiz. Nauk* **163** 1 (1993) [*Phys. Usp.* **36** (1) 1 (1993)]. For experimental studies of the basic principles of quantum mechanics, see also *Usp. Fiz. Nauk* **169** 559 (1999) [*Phys. Usp.* **42** 481 (1999)] and the paper by A V Belinsky and A A Klevtsov in *Usp. Fiz. Nauk* **188** 335 (2018) [*Phys. Usp.* **61** 313 (2018)].

Source: *Phys. Rev. Lett.* **120** 040406 (2018)
https://doi.org/10.1103/PhysRevLett.120.040406

4. Multidimensional Einstein–Podolsky–Rosen steering

Einstein–Podolsky–Rosen (EPR) steering, the conception of which was introduced by E Schrödinger in 1935, has been demonstrated in recent qubit experiments. Steering means not only the quantum entanglement of two systems, but also the possibility of steering the reduction of the wave function of a remote system through the choice of the measuring basis for the near system. Theoretical papers predicted the possibility of steering when systems are quantum-entangled in a larger number of variables, $d > 2$, than in the qubit case. Q Zeng, B Wang, P Li, and X Zhang (Beijing Institute of Technology, China) demonstrated a multidimensional steering for dimensions $d = 2-5$. Information coding was realized in the orbital angular momenta of photons set with the help of a spatial modulator. Considering that the orbital angular momentum had many states, multidimensional steering was possible. Multidimensional steering was also investigated under artificial noise and its noise resistance was shown. The well-known paper by Einstein, Podolsky, and Rosen and the comments on it by Fock and Bohr were published in *Usp. Fiz. Nauk* **16** 436 (1936). For the distant steering of wave function collapses, see also the book *Dynamics and Information* by B B Kadomtsev and his paper in *Usp. Fiz. Nauk* **164** 449 (1994) [*Phys. Usp* **37** 425 (1994)].

Source: *Phys. Rev. Lett.* **120** 030401 (2018)
https://doi.org/10.1103/PhysRevLett.120.030401

5. Double superconducting interferometer

Researchers from the Institute of Microelectronics Technology and High-Purity Materials, RAS (Chernogolovka), Moscow Institute of Physics and Technology (Dolgoprudny, Russia), and the Royal Holloway University of London (Great Britain) have demonstrated a new type of superconducting interferometer which surpasses the traditional SQUIDs by more than three orders of magnitude in

Uspekhi Fizicheskikh Nauk **188** (3) 343 – 344 (2018)
DOI: https://doi.org/10.3367/UFNr.2018.02.038295
Translated by M V Tsaplina

sensitivity to magnetic field variations. The interferometer designed by V L Gurtovoi and colleagues consists of two superconducting plane aluminum loops several μm in size superimposed on each other and weakly coupled at two points by Josephson junctions. The device was cooled to 0.6 K. With external magnetic flux variation, the current circulating in the loops is much higher than the bias current running through the two loops. The high sensitivity of the new device is due to the high degree of discreteness of its energy spectrum. Upon varying the external magnetic field, periodic oscillations of current were observed, in line with the theoretical calculations, and the high sensitivity of the device was confirmed. For the Josephson effect underlying the SQUID functioning, see the paper by G F Zharkov in *Usp. Fiz. Nauk* **88** 419 (1966) [*Phys. Usp.* **9** 198 (1966)] and for supersensitive SQUID magnetometry see *Usp. Fiz. Nauk* **169** 221 (1999) [*Phys. Usp.* **42** 209 (1999)].

Source: *Nano Lett.* **17** 6516 (2018)
https://doi.org/10.1021/acs.nanolett.7b01602

6. Friction in superfluid ^{3}He

Researchers from Aalto University (Finland), J T Mäkinen and V B Eltsov, have studied the effect of friction in superfluid helium at low temperatures $T = (0.13-0.22)T_c$, where T_c is the superfluid transition temperature. Earlier, friction was only measured for $T \geqslant 0.3T_c$. Helium-3 in the low-temperature phase B was placed in a rotating quartz glass vessel, and a vortex-filament grating appeared in it. At a certain instant of time, the vessel stopped abruptly. The turbulence caused by the braking was quickly suppressed, and then a laminar motion with oscillations due to vortex cluster rotation and braking due to friction was observed for several hours. The temperature- and pressure-dependences of the measured friction parameter agree with the theoretical predictions, although its value is somewhat lower than the predicted one. The friction parameter remained finite with extrapolation to zero temperature. According to the calculations by the authors of the experiment, the decisive role in the low-temperature friction is played by Kelvin waves that penetrate from the surface of the container into the bulk and interact with fermions trapped in the cores of superfluid filaments. This interaction had been predicted by M A Silaev (Institute of Microstructure Physics of RAS, Nizhny Novgorod and The Royal Institute of Technology, Sweden) in *Phys. Rev. Lett.* **108** 045303 (2012).

Source: *Phys. Rev. B* **97** 014527 (2018)
https://doi.org/10.1103/PhysRevB.97.014527

7. Bethe strings

In 1931, H Bethe predicted that one-dimensional magnets may have bound states of two quasiparticles — magnons (for magnons and spintronics, see *Usp. Fiz. Nauk* **185** 1099 (2015) [*Phys. Usp.* **58** 1002 (2015)]). This approach was later extended to the bound states of a large number of magnons, and such excitations in the form of chains were called Bethe strings. However, the string states in solids could not be identified till recently. Z Wang (University of Augsburg and the Helmholtz Center Dresden–Rossendorf, Germany) and colleagues have become the first to find Bethe strings in the compound $SrCo_2V_2O_8$ in a magnetic field. In this substance, CoO_6 octahedra form a chain of magnetic moments. High-resolution spectroscopy was used in the terahertz range of electromagnetic spectrum. The spectrum of $SrCo_2V_2O_8$ showed singularities that correspond to Bethe strings of two and three magnons. The dependence of their properties on the magnetic field is highly consistent with theoretical calculations based on the ansatz proposed by H Bethe.

Source: *Nature* **554** 219 (2018)
https://doi.org/10.1038/nature25466

8. Dyakonov–Perel spin relaxation in platinum

Platina (Pt) belongs to metals with a high value of spin-orbital interaction of electrons that must lead to spin relaxation. A group of scientists from Emory University and the University of Tennessee (USA) has carried out a new Pt examination through measuring giant magnetoresistance at different temperatures. Studied was a Pt sample several nm thick clamped between copper layers. Such a configuration allows separation of surface and bulk effects. Measurements showed that at room temperature Elliott–Yafet spin scattering dominates in the spin relaxation effect, while at cryogenic temperatures Dyakonov–Perel spin relaxation is predominant. This effect was predicted by M I Dyakonov and V I Perel in 1971; its mechanism is based on electron spin precession around the magnetic field direction in the absence of a center of symmetry.

Source: *Phys. Rev. Lett.* **120** 067204 (2018)
https://doi.org/10.1103/PhysRevLett.120.067204

9. White dwarf with unusual variability

A Scholtz (St Andrews University, United Kingdom) and colleagues have discovered a magnetic white dwarf SDSS 160357.93 + 140929.97 — a star kept in equilibrium by the pressure of a degenerate electron gas. The emission of this dwarf varies with period $P = 110 \pm 3$ min. The color filters on the optical telescopes used for observations were changed every several minutes. This method allowed revealing the variable phase shift between luminosities in the red and blue spectral regions, which is indicative of the earlier unknown type of white dwarf variability. Researchers assumed that the variability may be due to an invisible companion which reflects part of the emission from the white dwarf or, more probably, an unusual magnetic spot with a combination of hot and cold regions exists on the star surface. In the latter case, SDSS 160357.93 + 140929.97 must exhibit the most rapid rotation among known white dwarfs.

Source: https://arXiv.org/abs/1802.02636

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