Physics – Uspekhi **65** (4) 417 – 419 (2022)

PHYSICS NEWS 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.2022.03.039171

1. 'Information conservation law' in quantum mechanics

In weak quantum measurements, when the quantum state is not disturbed, information about the quantum state is redistributed (information trade-off). The information is preserved by splitting it into extracted information, information corresponding to measured system perturbation, and reversible information that may restore the quantum state. In some experiments, the relation between pairs of indicated information channels was examined. In 2021, S-W Lee, J Kim, and H Nha derived a relation for all three channels together. This triple relation was experimentally verified for the first time by S Hong (Korean Institute of Science and Technology, South Korea) and their co-authors [1]. Laser radiation photons in quantum entangled states, which pass through interferometers with three optical channels and which are quantum cells with three possible states ('qutrits'), were used in the experiments. Quantum tomography of the states confirmed the triple relation according to which quantum information is preserved, redistributing without loss. The obtained results concerning the 'law of conservation of information' are of importance for verification of the basic elements of quantum mechanics and appear to be useful in quantum calculations and quantum communication devices.

2. Gravitational red shift at a submillimeter distance

The effect of gravitational redshift (time deceleration in a gravitational field) described by the General Theory of Relativity was verified earlier both in observations of the spectra of cosmic objects and in laboratory experiments up to a distance of 30 cm. In a new experiment, T Bothwell (University of Colorado, USA) and his co-authors have measured the gravitational redshift at a distance of less than one millimeter [2]. The atomic clock used in the experiment was based on transitions in ^{87}Sr atoms. Spin-polarized atoms cooled to 100 nK were trapped in a one-dimensional optical lattice oriented along the gravitational field. The lattice resided inside a cavity in which wavefronts were highly homogeneous, which allowed the required density of the atomic cloud to be decreased. A record optical atomic coherence of 37 s was reached in the experiment. The cloud of atoms used as the atomic clock simultaneously served as a measured system. It was vertically divided into two uncorrelated parts, the distance between their centers being less than one mm. Measured was the difference between the transition frequencies in both parts of the cloud to an accuracy of 7.6×10^{-21}, which was better by an order of magnitude than that in previous experiments. The time dilation in the lower cloud compared to the upper one exactly corresponded to the difference between gravitational potentials at different altitudes. This measuring method is expected to heighten considerably its precision and be further used to investigate other fundamental effects.

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Uspekhi Fizicheskikh Nauk **192** (4) 455 – 456 (2022)
Translated by M V Tsaplina

3. Nonlinear Meissner effect

Measurement of the magnetic field penetration length λ into a superconductor is important for understanding superconductivity processes, for λ is related to the quasi-particle distribution and the properties of the energy gap. In so-called nodal superconductors, λ is a linear function of temperature T. It was predicted theoretically that λ may also depend on the magnitude of the magnetic field H. This effect, referred to as the 'nonlinear Meissner effect,' has not yet been reliably observed. J A Wilcox (University of Bristol, Great Britain) and his co-authors undertook new studies [3] and have become the first to register the nonlinear Meissner effect in nodal superconductors $CeCoIn_5$ and LaFePO with high fidelity. The samples were placed in a copper solenoid, in which oscillations were excited by a generator on the basis of a tunnel diode, and the electromagnetic response was measured. For $CeCoIn_5$ and LaFePO, it was found that with increasing H the T dependence of λ becomes weaker, which was perfectly consistent with the theoretical predictions. The superconductor KFe_2As_2 was also examined in the experiment, but it showed an inverse dependence, probably because of the non-nodal state of KFe_2As_2.

4. Topological edge solitons

Topological insulators are systems which (owing to the presence of topologically protected edge states) are dielectrics in volume but conductors on the surface. Photon topological insulators, where light only propagates along sample edges, can show a strongly nonlinear response. An interesting manifestation of nonlinearity is the formation of edge solitons that inherit topological protection of edge states. These solitons have the form of nonlinear excitations propagating without distortion along the insulator boundary. Edge solitons have already been observed experimentally, but only under weak nonlinearity and only for unit soliton modes. In a new experiment performed by Ya V Kartashev (Institute of Spectroscopy, RAS and Barcelona Institute of Science and

Technology, Spain) and his co-authors from Lomonosov Moscow State University, the Higher School of Economics, and Spain have observed the existence of edge solitons of two different types in a topological insulator [4]. A one-dimensional array of several triple (parallel) waveguides created by laser engraving in a quartz glass was examined. This system had edge topological states with different structures and two topological gaps. Solitons were excited by laser pulses owing to nonlinearities, topological solitons being observed for the first time in a nonlinear system with more than one topological gap. In a topological insulator, predominantly phased or dephased topological solitons or both types simultaneously could be excited.

5. Detector of dark matter particles

Although dark matter (DM) is several times more abundant in the Universe than ordinary baryon matter, the origin of DM remains unclear. According to one of the most popular hypotheses, DM consists of a new type elementary particles. However, attempts to register these particles have failed (the results of the DAMA experiment, showing the annual signal modulation, have not been reliably confirmed). If DM particles experience a very weak nongravitational interaction with ordinary matter, below the sensitivity threshold of today's detectors, then new type detectors will perhaps be needed to register these particles. The detectors currently available are now seeking DM particle interaction with separate atomic nuclei or electrons. G Afek, D Carney, and D C Moore (Yale University and Lawrence Berkeley National Laboratory) have performed new calculations and suggested a theoretical justification of operation of the detector, which is intended to seek recoil momenta of macroscopic, yet rather small, objects upon particle scattering by them [5]. This idea was suggested in the general form in a 1982 paper by V F Shvartsman, V B Braginskii, S S Gershtein, Ya B Zel'dovich, and M Yu Khlopov for registration of massive neutrinos [6]. A version of such a detector, allowing operation on the basis of currently available technologies, was considered in [5]. The use of an array of dielectric nanometer spheres (for instance, of silicon oxide) suspended (levitating) in an optical field was proposed. To register the signals, the motion of sphere mass centers must be monitored. The calculations showed that the expected signal may surpass the level of background events. For sphere masses of the order of femtograms, this detector will make it possible to approach the standard quantum limit of measurements and register DM particles with masses from 10 keV — the range of masses inaccessible for available detectors. And for attogram-mass spheres, one can expect even stronger coherent scattering, i.e., quantum interaction of DM particles with the whole sphere rather than with its separate constituent atoms. The direction of DM particle arrival can be determined from the direction of recoil momentum, and diurnal modulations of recoil momentum direction may become evidence of interaction with DM.

6. Record radio galaxy

The length of relativistic jets ejected from nuclei of radio galaxies can surpass the size of the galaxies themselves by two orders of magnitude. Radio blades, i.e., giant regions of radiating gas that occur during jet deceleration in the intergalactic gas, often exist at the jet ends. Magnetohydrodynamic processes in the vicinity of supermassive black holes are a probable jet formation mechanism. Radio galaxies whose full size with jets and blades exceeds $0.7-1$ Mpc are called giant radio galaxies. A unique giant radio galaxy, Alcyoneus, has been revealed and examined in observations with the interferometric net of LOFAR radio telescopes [7]. The total size of the galaxy with jets and radio blades makes up 5 Mpc. It is the largest of the known structures formed by a separate galaxy. At the same time, the size of the galaxy itself, its low-frequency luminosity, the mass of the stellar component, and the mass of the central black hole ($(4 \pm 2) \times 10^8 M_\odot$) are typical of all radio galaxies or even a little less than average values. This shows that it is external factors, most probably the state of the intergalactic medium, that are important for the formation of long jets. A jet becomes long if it decelerates weakly in a low-density gas. The Alcyoneus galaxy is not, in fact, located in galactic clusters but it is located in a filament of a low-density large-scale structure.

7. New limits on black holes from microlensing observations

The gravitational lensing effect is based on the deviation of light beams bypassing a massive object. 'Microlensing' observations are aimed at seeking the observed brightness variation of stars whose light undergoes gravitational lensing on compact objects, such as black holes, at the line of sight. Several programs on the search for microlensing have been implemented in recent decades. Analyzing the combined data from EROS-2 and MACHO obtained over 10.6 years, T Blaineau (Pari-Saclay University, France) and his co-authors have obtained new limits on the number of objects-lenses in the mass range of 10 to 1000 solar masses in the halo of our Galaxy [8]. These objects might also be primordial black holes formed in early pregalactic epochs. The luminosity of 14.1 mln stars in the Large Magellanic Cloud have been monitored. The large masses of objects-lenses correspond to the light curves of stars with slower brightness variation. Brightness variation may have been a consequence of star variability or statistical errors, and therefore in most cases it cannot be confidently said that microlensing took place. After the use of selection criteria, only two events that are candidates for gravitational microlensing remained. A comparison with the expected number of events showed that dark objects with masses of $10-100 M_\odot$, which may have been lenses, make up no more than 15% of the mass of Galaxy's halo, while objects with masses of $\sim 1000 M_\odot$ amount to no more than 50%. These results practically exclude the possibility that all dark matter consists of primordial stellar-mass black holes. Nevertheless, if primordial black holes had made up only $0.1-1$% of the dark matter mass in the halo, the merging rate of their pairs would have been at a level sufficient to explain the gravitational wave bursts observed by the LIGO/Virgo interferometers (except for bursts with the participation of neutron stars).

References

1. Hong S et al. *Phys. Rev. Lett.* **128** 050401 (2022) https://doi.org/10.1103/PhysRevLett.128.050401
2. Bothwell T et al. *Nature* **602** 420 (2022) https://doi.org/10.1038/s41586-021-04349-7
3. Wilcox J A et al. *Nat. Commun.* **13** 1201 (2022) https://doi.org/10.1038/s41467-022-28790-y

4. Kartashov Y V et al. *Phys. Rev. Lett.* **128** 093901 (2022) https://arxiv.org/abs/2203.04576
5. Afek G, Carney D, Moore D C *Phys. Rev. Lett.* **128** 101301 (2022) https://doi.org/10.1103/PhysRevLett.128.101301
6. Shvartsman V F et al. *JETP Lett.* **36** 277 (1982) http://jetpletters.ru/ps/1334/article_20164.shtml; *Pis'ma Zh. Eksp. Teor. Fiz.* **36** 224 (1982)
7. Oei M S S L et al. *Astron. Astrophys.* **660** A2 (2022) https://doi.org/10.1051/0004-6361/202142778; arXiv:2202.05427
8. Blaineau T et al., arXiv:2202.13819