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1. Coherent elastic neutrino scattering on argon

Upon coherent elastic scattering, neutrinos undergo interaction simultaneously with all nucleons of the nucleus (with the nucleus as a whole) through the Z boson exchange with a low momentum transfer to the nucleus (see review [1]). Coherent elastic neutrino scattering on cesium and iodine nuclei had already been observed earlier. The cross section of coherent elastic neutrino scattering on lighter argon nuclei was first measured by the COHERENT collaboration at the Oak Ridge National Laboratory (USA) [2]. This allowed verifying the Standard Model prediction of the nucleus neutron-number dependence $\propto N^2$ of the cross section. A vessel filled with 24 kg of liquid atmospheric argon was viewed by two photomultipliers. Neutrinos from decays of pions and muons originating in the proton accelerator went into the vessel. One hundred fifty-nine neutrino interaction events were registered in 18 months of observations. The obtained cross section of $(2.2 \pm 0.7) \times 10^{-39}$ cm^2 agrees with the Standard Model calculations, while no nonstandard interactions were found at the attained accuracy level. Detectors based on recording coherent elastic neutrino scattering are likely to find application in remote monitoring of nuclear reactors. Russian researchers from ITEP, MEPhI, and MIPT are taking part in the COHERENT experiment.

2. Marginal Fermi glass

Of great interest in condensed matter physics are systems with an interplay of strong interactions of particles and a high disorder level. Such systems are partly described by the Landau Fermi-liquid theory and the Anderson localization theory. In 1970, Anderson suggested the name ‘Fermi glass’ for disordered systems capable of adiabatically transitioning to the Anderson insulator state. F Mahmood (Johns Hopkins University, USA) and his colleagues have used the method of 2D coherent terahertz spectroscopy to investigate 100-μm plates of Si:P (phosphorus-doped silicon) Fermi glass close to the metal–insulator transition on the side of the dielectric state [3]. Optical response to a sequence of strong terahertz electric pulses was observed, and relaxation and coherence rates were measured. Regardless of the system’s disorder, coherent excitations and strong photon echoes were detected in it. Despite expectations, the energy relaxation rate increased with increasing temperature. It was concluded that the Anderson localization effect is absent in the case of electron waves in Si:P. The authors propose that the new state be called a ‘marginal Fermi glass’. For strongly correlated systems, see [4].

3. Ion in a Bose–Einstein condensate

T Dieterle (University of Stuttgart, Germany) and his co-authors have investigated single-ion transport in a Bose–Einstein condensate of ^{87}Rb atoms [5]. To obtain a slow ion, one of the condensate atoms was transferred into a highly excited Rydberg state with the aid of a sequence of focused laser pulses. At the final stage, the atom was ionized using an electric pulse immediately followed by a pulse having the same form but opposite polarity. This allowed obtaining an initially low-velocity ion. Electrodes could generate an electric field to an accuracy of 300 μV cm^{-1}, setting the ion in motion, monitored for several ten μs, until the ion left the gas. The ion interacted with the surrounding atoms with the aid of the charge-dipole potential, which substantially exceeded in magnitude the neutral atom interaction. As a result, the ion trajectory was randomly perturbed with a characteristic frequency of several ten kHz. To collect statistics, the experiment was repeated 50 times with the same ensemble of atoms. Measurements showed that the ion came out quickly to the diffusion motion regime, and the ion mobility in the condensate was measured. For Bose–Einstein condensates, see [6, 7].

4. Diamond stability under compression

A Lazicki (Lawrence Livermore National Laboratory, USA) and their co-authors have used the X-ray diffraction method to examine the structure of diamond under laser compression to a pressure of 20 mln atmospheres (2 TPa) [8]. The method of slowed shock compression upon laser heating of the target was used, thus preventing sharp sample heating and melting. A laser pulse inducing sample compression simultaneously evaporated a nearby foil, generating bright quasi-monochromatic X rays. This allowed synchronization to a nanosecond accuracy of compression and diffraction X-ray measurements. Theoretical calculations predicted that, in the region of ~ 2 TPa, an ordinary face-centered cubic diamond must be transformed into a body-centered or two simple cubic modifications. However, in the described experiment, the diffraction peaks corresponding to these modifications were not observed. This means that an ordinary diamond remains metastable under compression. A possible reason for such high stability is the presence of a large number of strong interatomic carbon sp^3-bonds. For the properties of diamond, see [9–12]. The pressure of 2 TPa exceeds the pressure

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Uspekhi Fizicheskikh Nauk **191** (3) 335 – 336 (2021)
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in Earth's center by more than 5 times. Investigations of high-pressure carbon properties may provide insight into the intrinsic structure of recently discovered carbon-enriched exoplanets [13].

5. Modification of liquid crystal

H Mundoor (University of Colorado, USA) and his colleagues have studies liquid crystal (LC) modification with an added colloidal solution of disc-like particles 1.2–2.2 μm in diameter and 10 nm thick [14]. The initial LC had a usual structure of rod-like particles. After the discs were added, phase transitions to different LC states became possible, including uniaxial and monoclinic, whose properties can be controlled by varying temperature and the magnetic field. The LC was studied by fluorescent radiation of the discs using 3D visualization. With increasing temperature, an unusual transition from a less ordered to a more ordered state was observed. The possible control of LC properties is likely to find useful technical applications. Similar behavior of a modified LC was reproduced in mathematical simulations. For LCs with impurities, see [15].

6. Autonomous quantum error correction

Quantum operation error correction is essentially important for the creation of quantum computers. J M Gertler (University of Massachusetts Amherst, USA) and his co-authors have demonstrated experimentally a new correction method called 'autonomous quantum error correction' [16]. The method is based on monitoring quantum-state occupation number parity. If a particle is lost because of an error, an odd set will become even, and vice versa. A special quantum operator (an error syndrome operator) monitors the parity, and as soon as it changes, adds the lost particle to the set. This method was realized in the multiphoton state of a Schrödinger cat in a superconducting resonator in a system of two frequency combs. The resonator was in contact with an auxiliary transmon qubit used for passive monitoring of the dissipation-based state. As distinct from the active methods of quantum error correction requiring a periodic monitoring of the system, the new method allows errors to be corrected as soon as they appear. The application of this method has been shown to increase the qubit coherence time by a factor of two.

7. Superposition of quantum communication channels

One of the main problems with communication channels, in which quantum information exchange takes place, is noise-induced quantum state decoherence. This problem can be solved by using several (two at a minimum) channels between which quantum superposition is possible. The efficiency of this method has already been demonstrated in experiments. G Rubino (University of Vienna, Austria) and their co-authors have performed a new experiment. They compared different ways of superposition of quantum trajectories in the presence of different types of noise [17]. The experiment with photon polarization was carried out in a Mach–Zehnder interferometer, and noises were introduced with the aid of liquid-crystal wave plates. It was established that an optimum scheme for information transfer with minimum losses and maximum protection is the one with both a superposition of quantum trajectories and quantum-controlled operations in the channels. The method of superposition of trajectories needs many fewer resources than the current methods of quantum error correction in communication channels. For quantum technologies, see [18, 19].

8. Blue jets in the stratosphere

Blue jets are rare jets of electric discharges escaping from the upper part of thunderclouds upwards to the stratosphere. Many characteristics of this phenomenon remained unknown because of the complexity of their ground-based observations. Five nearly 10-μs blue bursts above the Pacific Ocean were examined at the international Space Station [20]. One of the blue bursts was accompanied by a pulsating blue jet that reached stratopause, i.e., the interface between stratosphere and ionosphere at an altitude of 50–55 km. Along with the bursts, 'elfs' were observed, i.e., glowing expanding rings in the ionosphere. The main role in the formation of blue jets is played by leaders, that is, conducting channels occurring at the moment of electric breakdown in the air between charged layers. The leaders' spectrum in the red region was measured by an ISS spectrometer. Self-radiation of the leaders is rather weak, but they initiate bursts and blue jets generated by localized streamer ionization waves in the stratosphere. For investigations of lightning, see [21–25].

9. Central object in the globular cluster NGC 6397

On the basis of observations of star motion in the globular star cluster NGC 6397, it was earlier concluded that an intermediate-mass $(600 \pm 200)\,M_{\odot}$ black hole exists in its center. (For intermediate-mass black holes, see [26]). However, in their new study [27], E Vitral and G A Mamon have shown that not a single black hole, but a cluster of compact objects (white dwarfs, neutron stars, and stellar-mass black holes) with a total mass of $(1000-2000)\,M_{\odot}$ and a radius of several percent of the whole cluster radius, is likely to exist in the center of NGC 6397. This conclusion was based on dynamic models and on the investigation of star motion in NGC 6397 using the Hubble Space Telescope, the MUSE spectrograph on the VLT complex telescope, and data from the Gaia space observatory. Upon relaxation, the most massive black holes must have subsided towards the cluster center to form a dynamically isolated subsystem. Collisions of compact objects in such globular clusters may contribute to the gravitational wave events detected by LIGO/Virgo interferometers [28].

10. Quasar lifetime

The presence of supermassive black holes in the centers of most modern galaxies [29–31] testify to the fact that, at an early stage of their evolution, galaxies may have gone through a quasar stage, when the central black hole absorbed gas intensively, and the accretion disc showed powerful luminosity. However, the details of these processes are not yet clear. It is assumed that the beginning of the quasar stage may have consisted of merges of galaxies accompanied by tidal gravitational forces directing gas flows towards black holes. Of interest is also the question of the duration of the quasar stage of galactic evolution. I S Khrykin (University of Tokyo, Japan) and his co-authors have determined the activity time distribution of quasars [32]. The radii of the regions of 24 quasars at red shifts $2.7 \leqslant z \leqslant 3.9$, where gas was notably ionized by quasar emission, were measured using the Hubble

Space Telescope. On the basis of these data, the quasar active-phase timescale can be estimated by numerical simulations and solving transfer equations of ionizing radiation. It was discovered that the lifetime distribution of quasars has a log-normal form, and the average time of quasar activity amounts to 1 to 3 mln years. The investigation of quasars is important for clarifying supermassive black hole formation mechanisms. Quasar emission may also have influenced the ionization and the thermal history of intergalactic gas.

References

1. Akimov D Yu et al. *Phys. Usp.* **62** 166 (2019); *Usp. Fiz. Nauk* **189** 173 (2019)
2. Akimov D et al. *Phys. Rev. Lett.* **126** 012002 (2021); https://doi.org/10.1103/PhysRevLett.126.012002
3. Mahmood F et al. *Nature Physics*, online publication of January 12, 2021; https://doi.org/10.1038/s41567-020-01149-0
4. Kuchinskii E Z, Nekrasov I A, Sadovskii M V *Phys. Usp.* **55** 325 (2012); *Usp. Fiz. Nauk* **182** 345 (2012)
5. Dieterle T et al. *Phys. Rev. Lett.* **126** 033401 (2021); https://arxiv.org/abs/2007.00309
6. Pitaevskii L P *Phys. Usp.* **49** 333 (2006); *Usp. Fiz. Nauk* **176** 345 (2006)
7. Kagan M Yu, Turlapov A V *Phys. Usp.* **62** 215 (2019); *Usp. Fiz. Nauk* **189** 225 (2019)
8. Lazicki A et al. *Nature* **589** 532 (2021); https://doi.org/10.1038/s41586-020-03140-4
9. Savvatimskii A I, Onufriev S V *Phys. Usp.* **63** 1015 (2020); *Usp. Fiz. Nauk* **190** 1085 (2020)
10. Brazhkin V V *Phys. Usp.* **63** 523 (2020); *Usp. Fiz. Nauk* **190** 561 (2020)
11. Filonenko V P et al. *Phys. Usp.* **62** 207 (2019); *Usp. Fiz. Nauk* **189** 217 (2019)
12. Ekimov E A, Kondrin M V *Phys. Usp.* **62** 199 (2019); *Usp. Fiz. Nauk* **189** 208 (2019)
13. Marov M Ya, Shevchenko I I *Phys. Usp.* **63** 837 (2020); *Usp. Fiz. Nauk* **190** 897 (2020)
14. Mundoor H et al. *Nature* **590** 268 (2021); https://doi.org/10.1038/s41586-021-03249-0
15. Aranson I S *Phys. Usp.* **62** 892 (2019); *Usp. Fiz. Nauk* **189** 955 (2019)
16. Gertler J M et al. *Nature* **590** 243 (2021); https://arxiv.org/abs/2004.09322
17. Rubino G et al. *Phys. Rev. Res.* **3** 013093 (2021); https://arxiv.org/abs/2007.05005
18. Trushechkin A S et al. *Phys. Usp.* **64** (1) (2021); *Usp. Fiz. Nauk* **191** 93 (2021)
19. Molotkov S N *Phys. Usp.* **49** 750 (2006); *Usp. Fiz. Nauk* **176** 777 (2006)
20. Neubert T et al. *Nature* **589** 371 (2021); https://doi.org/10.1038/s41586-020-03122-6
21. Iudin D I et al. *Phys. Usp.* **61** 766 (2018); *Usp. Fiz. Nauk* **188** 850 (2018)
22. Gurevich A V, Zybin K P *Phys. Usp.* **44** 1119 (2001); *Usp. Fiz. Nauk* **171** 1177 (2001)
23. Sosnin E A et al. *Phys. Usp.* **64** (2) (2021); *Usp. Fiz. Nauk* **191** 199 (2021)
24. Babich L P *Phys. Usp.* **63** 1188 (2020); *Usp. Fiz. Nauk* **190** 1261 (2020)
25. Babich L P *Phys. Usp.* **62** 976 (2019); *Usp. Fiz. Nauk* **189** 1044 (2019)
26. Fabrika S N et al. *Phys. Usp.* **49** 324 (2006); *Usp. Fiz. Nauk* **176** 339 (2006)
27. Vitral E, Mamon G A *Astron. Astrophys.* **646** A63 (2021); https://doi.org/10.1051/0004-6361/202039650
28. Reitze D H *Phys. Usp.* **60** 823 (2017); *Usp. Fiz. Nauk* **187** 884 (2017)
29. Dolgov A D *Phys. Usp.* **61** 115 (2018); *Usp. Fiz. Nauk* **188** 121 (2018)
30. Ivanov P B et al. *Phys. Usp.* **62** 423 (2019); *Usp. Fiz. Nauk* **189** 449 (2019)
31. Cherepashchuk A M *Phys. Usp.* **59** 702 (2016); *Usp. Fiz. Nauk* **186** 778 (2016)
32. Khrykin I S et al., https://arxiv.org/abs/2102.04477