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1. Anomalous magnetic moment of the muon

Since 2006, elementary particle physics has faced the problem of the anomalous muon magnetic moment: the $g-2$ value measured at the Brookhaven Laboratory differed markedly from the theoretically calculated one [1]. This difference, if it really exists, may indicate the contribution of new physics beyond the Standard Model. The Muon $g-2$ Collaboration, conducting an experiment at Fermilab (USA), has presented the results of new $g-2$ measurements, which showed a factor of two improvement in precision compared to the results of 2021 [2]. The difference between the cyclotron frequency and the precession frequency of antimuon spins in the magnetic field in an accumulative superconducting ring was measured. The accuracy has improved mainly owing to reducing the systematic errors and increasing the data volume. The new result of $g-2$ measurement differs from the predictions of the Standard Model at a level of 5σ. In the coming years, an even more significant increase in the accuracy of the experiment and the completion of new theoretical calculations are expected, which may clarify the problem.

2. Tetraquarks

Particles called 'tetraquarks' are hadrons consisting of four quarks. Previous reports on recording tetraquarks, whose quarks have different flavors, were incomplete (an isospin partner was not found) or not yet confirmed in independent experiments. The LHCb Collaboration has reported on a sufficiently reliable recording of two new tetraquarks with composition $(c\bar{s}u\bar{d})$ and $(c\bar{s}\bar{u}d)$ [3] and masses of $\simeq 2.9$ GeV. This doubly charged open-charm tetraquark $\bar{s}$ and its neutral partner obviously belong to one and the same isospin triplet. Proton-proton collisions at energies of 7.8 and 13 TeV were investigated. Tetraquarks were identified as intermediate resonances in the decays $B^0 \to \bar{D}^0 D_s^+ \pi^-$ and $B^+ \to \bar{D}^- D_s^+ \pi^+$ related by isospin symmetry.

3. New isomeric states in ^{136}Cs nuclei

Xenon-based detectors are used to search for dark matter particles, neutrinoless double beta decay, and low-energy neutrinos. Neutrinos can interact with ^{136}Xe nuclei through charged currents, and registering photons emitted by excited $Cs^{(*)}$ nuclei allows the neutrino energy to be measured. S J Haselschwardt (Lawrence Berkeley National Laboratory, USA) and his co-authors have discovered new low-lying isomeric states in ^{136}Cs nuclei [4]. Recorded in the experiment was gamma-ray emission in the ^{136}Xe(p, n)^{136}Cs reaction. From these data, a large number of new nuclear transitions and two levels of ^{136}Cs nuclei with a lifetime of the order of 100 ns were found. The existence of such states provides unique possibilities for recording rare events on the basis of a delayed-coincidence tag suppressing background.

4. Rare ^{40}K nucleus decay

When decaying, ^{40}K isotope nuclei are transformed into ^{40}Ar nuclei in the process of electron capture with a probability of 10%. The predominant part of such decays goes to the excited state of ^{40}Ar nuclei. Predicted was the existence of another rare channel for the decay of ^{40}K into the ground state of ^{40}Ar nucleus with the capture of an electron, but this channel has not been observed earlier. As distinct from the decay into excited states, the decay into the ground state is not accompanied by a further emission of γ-photons. The theory does not yet allow reliably calculating the probability of such a decay, and, as a rough estimate, the probability was most often assumed to be 2%. The KDK collaboration has performed a new experiment and become the first to reliably register ^{40}K decays into the ground state [5]. Highly sensitive gamma-ray and X-ray photon detectors were employed operating by the coincidence and anticoincidence methods. As a result, the probability of ^{40}K decays into the ground state was measured to be one half of that typically expected, and the hypothesis of their absence was excluded at the level of 4σ. The background from the decay of ^{40}K nuclei is an important factor in many experiments on searching for dark matter particles and neutrinoless double beta decay, and an unknown probability introduced some uncertainty into the experimental results. Moreover, the above-mentioned double error had led to several-ten-million-year errors in geological dating by the potassium-argon method.

5. Direct observation of nonlocal fermion pairing

The Fermi–Hubbard model describes successfully a crossover type transition from the local fermion pairing in Bose–Einstein condensates to the nonlocal (spatially separated) pairing in the Bardeen–Cooper–Schrieffer mechanism. The most interesting is the 'pseudo-gap' near the crossover, where, even at temperatures above the critical superfluidity temperature, pairs are formed. T Hartke (Research Laboratory of Electronics, Massachusetts Institute of Technology, USA) and his co-authors have become the first to directly observe the process of nonlocal fermion pairing in the 'pseudo-gap' regime [6]. They placed interacting fermionic potassium atoms at a temperature of the order of nK into an optical

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Uspekhi Fizicheskikh Nauk **193** (9) 1023 – 1024 (2023)
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lattice and used a quantum microscope to obtain several thousand images showing spin directions at the lattice sites. The correlation analysis revealed the formation and spatial ordering of nonlocal fermion pairs in the case of two-dimensional attracting Hubbard gas.

6. Kapitza trap

The Kapitza pendulum is a mechanical pendulum whose oscillations are dynamically stabilized through rapid vibrations of the suspension point [7]. This stabilization effect is widely used in various fields of physics. The Kapitza pendulum effect has already been used in the Paul trap of charged particles and for light confinement in a dielectric structure. On the basis of this effect, J Jiang (Kaiserslautern University of Technology, Germany) et al. have created for the first time a trap for ultracold atoms and called it the 'Kapitza trap' [8]. The trap is based on two laser beams focused through a lens, which have special frequency shifts and are modulated by periodic signals. The resultant Gaussian potential contained a Bose–Einstein condensate of ^{87}Rb atoms. An absorption image of a cloud of atoms was obtained through the same lens, and a characteristic configuration was seen, theoretically predicted on the basis of the Gross–Pitaevskii theory for the case of the Kapitza trap. Observed was not only a spherical annular layer but also its asymmetry at the level of 1%, also predicted by the theory. The created Kapitza trap can be used to study quantum tunneling effects, chaos phenomena in the classical and quantum regimes, as well as other fundamental processes.

7. Turbulence statistics

In 1941, Kolmogorov put forward a hypothesis that turbulence in the so-called inertial region at large Reynolds numbers Re has a universal form, when characteristic velocities depend in a power-law manner on the scale of turbulent pulsations. Turbulence originates on the largest scales, then the energy is transferred to medium scales, and finally dissipates on small scales due to viscosity. C Kuchler, G P Bewley, and E Bodenschatz have performed at the Max Planck Institute for Dynamics and Self-Organization (Germany) a new large-scale experiment to study turbulence in the air [9]. In a tunnel with a volume of 88 m^3, turbulence with different initial scale distributions was excited using individual controlled blades, and Re was varied over a wide range by changing the air pressure. The evolution of turbulent air movements was examined by the effect of air flows on nanofilaments. The 2nd order structure functions turned out to have an effective exponent differing from the Kolmogorov 2/3 law and depending on the scale even in the inertial regime, but independent of Re themselves. This result has not yet been completely explained theoretically. For incorrect premises in the derivation of the power-law form of the structure functions and for the conception of stretching vortex filaments, see [10]. The results obtained show that the turbulence physics in the inertial range is more sophisticated than expected. For atmospheric turbulence, see [11].

8. New test of the equivalence principle

V V Singh (G W Leibniz University of Hannover, Germany) and his co-authors have carried out a new test of the equivalence principle underlying the General Relativity Theory, with the use of lunar laser ranging [12]. In this method, the distance from the Moon to Earth was measured with high precision using Moon-based mirrors placed in 1969. The difference between the passive-to-gravitational mass ratio for iron and aluminum shows up in a different tidal effect of the Earth to Moon mantle, consisting of basalts with excessive iron, and the core consisting of excessive aluminum (the Moon's internal structure has been studied by seismic data). This would cause an additional correction to the Moon's orbital velocity and to the distance to it. V V Singh at al. managed to lower, compared to the previous result of 1986, the upper limit on the combination of quantities, playing the role of the Etvesh parameter, by two orders of magnitude. According to the data of the MICROSCOPE space experiment, which was carried out on microsatellites, the accuracy of the recent test of equality of inert and passive gravitational masses under other conditions reaches 10^{-15}.

9. Dark-matter deficient galaxy

Almost all galaxies contain invisible dark matter (DM) with a mass exceeding by several times the mass of ordinary baryon matter (stars, gas, and dust). However, some galaxies have an anomalous visible-invisible component ratio. S Comeron (University of La Laguna and Canary Islands Institute of Astrophysics, Spain) et al. have investigated the galaxy NGC 1277 using data from the 2.7-m telescope of the McDonald Observatory and performed numerical simulations of its dynamics within the anisotropic Jeans model [13]. The massive galaxy NGC 1277 belongs to the early Hubble type and is probably a so-called relic galaxy that avoided merging with other large galaxies. An unexpected result was that, within a radius of 6 kpc, the DM mass in NGC 1277 is $< 5\%$ of the total mass, whereas in the standard cosmological model it must be 60%. The reason for an almost complete lack of DM in the galaxy has not yet been exactly clarified, and the mechanism of the birth of this galaxy is unknown. According to one of the hypotheses, the galaxy might have lost DM in a collision with another galaxy (as in the case of the 'Bullet' cluster).

10. Search for cosmic neutrino sources

In recent years, the IceCube and Baikal-GVD detectors have registered high-energy astrophysical neutrinos. The IceCube data have recently identified the galactic component of neutrino flux, but most neutrinos are of extragalactic origin. Some neutrino sources have not yet been identified, although indications exist that neutrinos might have been produced in active blazar galaxies. In particular, this is evidenced by the observation of correlations of neutrinos with radio emission from blazars [14]. The Baikal-GVD collaboration performed a new search for correlations between neutrinos and known astrophysical objects [15]. The use of Baikal water as the working substance of the detector in Baikal-GVD allows a more accurate measurement of the neutrino arrival direction compared to ice-based experiments. The new studies concerned cascade events of interaction of neutrinos with energies exceeding 100 TeV. At the moment, the volume of statistical data does not allow reliable conclusions, but it was a coincidence of cascades with several bright and flaring blazars (2023 + 335, 2021 + 317, 2050 + 364, 0529 + 075, TXS 0506 + 056, 0258-184, 1935-179) observed by VLBI telescopes and with galactic sources LSI + 61303 and Swift J0243.6 + 6124.

References

1. Logashenko I B, Eidel'man S I *Phys. Usp.* **61** 480 (2018); *Usp. Fiz. Nauk* **188** 540 (2018)
2. Aguillard D P et al. (The Muon g–2 Collab.) "Measurement of the positive muon anomalous magnetic moment to 0.20 ppm", https://muon-g-2.fnal.gov/result2023.pdf
3. Aaij R et al. (LHCb Collab.) *Phys. Rev. Lett.* **131** 041902 (2023)
4. Haselschwardt S J et al. *Phys. Rev. Lett.* **131** 052502 (2023); arXiv:2301.11893, https://doi.org/10.48550/arXiv.2301.11893
5. Stukel M et al. (KDK Collab.) *Phys. Rev. Lett.* **131** 052503 (2023)
6. Hartke T et al. *Science* **381** 82 (2023)
7. Kapitza P L *Usp. Fiz. Nauk* **44** 7 (1951)
8. Jiang J et al. *Phys. Rev. Lett.* **131** 033401 (2023)
9. Küchler C, Bewley G P, Bodenschatz E *Phys. Rev. Lett.* **131** 024001 (2023)
10. Zybin K P, Sirota V A *Phys. Usp.* **58** 556 (2015); *Usp. Fiz. Nauk* **185** 593 (2015)
11. Lukin V P *Phys. Usp.* **64** 280 (2021); *Usp. Fiz. Nauk* **191** 292 (2021)
12. Singh V V et al. *Phys. Rev. Lett.* **131** 021401 (2023)
13. Comerón S et al. *Astron. Astrophys.* **675** A143 (2023)
14. Plavin A, Kovalev Yu Y, Kovalev Yu A, Troitsky S *Astrophys. J.* **894** 101 (2020)
15. Allakhverdyan V A et al., arXiv:2307.07327, https://doi.org/10.48550/arXiv.2307.07327; *Mon. Not. R. Astron. Soc.* **526** 942 (2023) https://doi.org/10.1093/mnras/stad2641