Physics – Uspekhi **66** (11) 1174 – 1175 (2023)

PHYSICS NEWS

PACS numbers: **01.10. – m**, **01.30. – y**, **01.90. + g**

Physics news on the Internet: November 2023

Yu N Eroshenko

DOI: https://doi.org/10.3367/UFNr.2023.10.039573

1. Quantum entanglement of t-quarks

The effect of low-energy quantum entanglement has been examined in many experiments for both elementary particles and macroscopic systems. High-energy quantum entanglement in the t-quark - t-antiquark pair has been observed for the first time with the ATLAS detector at the Large Hadron Collider [1]. The idea of such an experiment was suggested by Y Afik and J R M de Nova in 2020 [2]. The maximum degree of quantum entanglement in spins was observed near the $t\bar{t}$-pair production threshold in pp-collisions. For the quantity D characterizing entanglement on the basis of the analysis of t and $\bar{t}$ decay products, the experiment gave the value $D = -0.547 \pm 0.002$ stat. $\pm\, 0.001$ syst. (in the case of entanglement, one has $D < -1/3$). Thus, quantum entanglement of spin states in a $t\bar{t}$-pair is confirmed at $> 5\sigma$ confidence level. This result puts the studies of quantum entanglement and quantum information into the area of high-energy physics with broad manifestations of relativistic effects and various fundamental symmetries, opening new possibilities, in particular, of searching for new processes beyond the Standard Model of Elementary Particles.

2. Fall of antimatter in a gravitational field

The General Theory of Relativity (GTR) includes the weak equivalence principle, which states that bodies move similarly in a gravitational field unless other forces are present. This principle has been tested for ordinary matter to an accuracy of $\sim 10^{-15}$, but we cannot yet be sure of its universal applicability. Moreover, according to some hypotheses, ordinary matter (particles) does not attract but repels antimatter (antiparticles) by its gravitational field. It is very difficult to verify this assumption for individual antiparticles, since even very weak magnetic fields disturb their motion. In their CERN experiment, E K Anderson (Aarhus University, Denmark) and her ci-authors have become the first to investigate the fall in a gravitational field of antihydrogen $\bar{H}$ atoms consisting of antiprotons and positrons [3]. In a cylindrical magnetic trap, the antihydrogen atoms were affected by a magnetic field, creating an additional acceleration from $-10g$ to $10g$, where $g = 9.81$ m s^{-2}. In the upper and lower parts of the trap, $\bar{H}$ were registered by their annihilation upon collision with the walls. Owing to the presence of thermal velocities, there are always flows of antiatoms moving up and down, but, as shown by the asymmetry of the escape curve (the dependence of an atomic flow on the magnetic field), $\bar{H}$ atoms fall predominantly down, that is, the gravitational field of Earth equally affects matter and antimatter. The measured free fall acceleration of $\bar{H}$ made up $(0.75 \pm 0.13 \pm 0.16)g$, where 0.13 is a combination of statistical and systematic errors and 0.16 is associated with uncertainties of the experiment modeling. This result is consistent with the acceleration of $1g$, predicted by GTR, and the probability that $\bar{H}$ are repelled from Earth with an acceleration of $-1g$ is estimated at a level of only 10^{-15}.

Yu N Eroshenko Institute for Nuclear Research,
Russian Academy of Sciences,
prosp. 60-letiya Oktyabrya 7a, 117312 Moscow, Russian Federation
E-mail: erosh@ufn.ru

Uspekhi Fizicheskikh Nauk **193** (11) 1248 (2023)
Translated by N A Tsaplin

3. Control of excitons

Quasiparticle excitons (bound states of electrons and holes) look like a promising information carrier due to low ohmic losses. However, for practical applications, it is necessary to learn how to control exciton flows. H Lamsaadi (University of Toulouse, France) and his co-authors have found that a disordered (isotropic) flow of excitons becomes unidirectional when passing through a room-temperature $MoSe_2$–WSe_2 heterojunction [4]. The study was carried out by a spectroscopic method based on photoluminescence with a near-tip amplification. It is shown that the jump in the energy gap at the heterostructure generates a discontinuity in the exciton density similar to the temperature discontinuity at the interfaces (the Kapitza resistance effect). This leads to the appearance of a directed flow at distances exceeding the transition width by two orders of magnitude. For excitons, see [5–7].

4. Highly sensitive Rydberg antenna

The use of Rydberg atoms with an outer electron in a highly excited state for recording microwave vibrations was first experimentally demonstrated in 2012 by J Sedlacek et al. [8]. Rydberg ^{87}Rb atoms in the form of rarefied atomic vapor were placed in a glass container and transilluminated by a laser. Radio emission split the energy level responsible for the induced vapor transparency. In this way, the microwave signal was converted into an optical signal read by lasers. The container with Rydberg atoms could also be scanned remotely through optical fiber, but the presence of optical fiber made the device more cumbersome and led to signal losses. Researchers from the University of Otago (New Zealand) improved the Rydberg antenna by using a remote diagnostic technique with laser beams propagating in the air [9]. A container with room-temperature atomic vapor equipped with a reflector (an angular cubic prism) can be scanned with a laser from a distance of more than 30 meters, which substantially widens the possibility of using this device.

5. Multiple active galactic nuclei in the early Universe

Active galactic nuclei (AGNs) contain supermassive black holes generating powerful radiation upon gas accretion. As was predicted by the theory of formation and merger of galaxies, 1 to 5% of AGNs must be dual with a separation of less than 30 kpc, and several dual AGNs were already known. M Perna (Spanish Astrobiology Center) et al. have found five new multiple AGNs separated by 3 to 28 kpc [10]. Four dual AGNs were revealed by observations with the James Webb Space Telescope, and a triple nucleus was revealed from a combination of the data from the James Webb Space Telescope and the VLT. With allowance for the observed number and the AGN recording probability, it was concluded that the number of multiple AGNs in the early Universe amounts to $\sim$20–30%, which exceeds greatly the expected value. The reason for the difference between the expected and observed number of these objects and the processes inducing such frequent galaxy mergers are still unknown.

References

1. ATLAS Collab., https://atlas.web.cern.ch
2. Afik Y, de Nova J R M *Eur. Phys. J. Plus* **136** 907 (2021)
3. Anderson E K et al. *Nature* **621** 716 (2023)
4. Lamsaadi H et al. *Nat. Commun.* **14** 5881 (2023)
5. Keldysh L V *Phys. Usp.* **60** 1180 (2017); *Usp. Fiz. Nauk* **187** 1273 (2017)
6. Semina M A, Suris R A *Phys. Usp.* **65** 111 (2022); *Usp. Fiz. Nauk* **192** 121 (2022)
7. Glazov M M, Suris R A *Phys. Usp.* **63** 1051 (2020); *Usp. Fiz. Nauk* **190** 1121 (2020)
8. Sedlacek J A et al. *Nat. Phys.* **8** 819 (2012)
9. Otto J S et al. *Appl. Phys. Lett.* **123** 144003 (2023)
10. Perna M et al., arXiv:2310.03067, https://doi.org/10.48550/arXiv.2310.03067