

LATEST FUNDAMENTAL RESEARCH IN THE FIELD OF NUCLEAR PHYSICS, ACHIEVEMENTS AND FUTURE PLANS

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Abstract. The article reviews the most important fundamental research, achievements and future prospects of nuclear physics for 2024–2026. The main areas are: thorium-229 nuclear clock technology, new measurements of quantum tunneling and resonances, quark-gluon plasma (QGP) research, antiproton spin control, records achieved in fusion, as well as the latest results of accelerators such as RHIC and LHC. The article is based on the results of international laboratories (CERN, RHIC, NIF, EAST, PhET, etc.). Future plans for AI integration, the creation of new generation accelerators and fusion power plants are discussed.

Key words: nuclear physics, thorium-229 nuclear clock, quark-gluon plasma, quantum tunneling, antiproton spin control, fusion, RHIC, LHC, QGP, “Digital Uzbekistan – 2030”.

НОВЕЙШИЕ ФУНДАМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ В ОБЛАСТИ ЯДЕРНОЙ ФИЗИКИ, ДОСТИЖЕНИЯ И ПЛАНЫ НА БУДУЩЕЕ

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Аннотация. В статье рассматриваются наиболее важные фундаментальные исследования, достижения и перспективы ядерной физики на 2024–2026 годы. Основные направления: технология ядерных часов на основе тория-229, новые измерения квантового туннелирования и резонансов, исследования кварк-глюонной плазмы (КГП), управление спином антипротона, рекорды, достигнутые в термоядерном синтезе, а также последние результаты работы ускорителей, таких как RHIC и LHC. Статья основана на результатах международных лабораторий (CERN, RHIC, NIF, EAST, PhET и др.). В статье обсуждаются планы на будущее по интеграции

ИИ, созданию ускорителей нового поколения и термоядерных электростанций.

Ключевые слова: ядерная физика, ядерные часы на основе тория-229, кварк-глюонная плазма, квантовое туннелирование, управление спином антипротона, термоядерный синтез, RHIC, LHC, QGP, «Цифровой Узбекистан — 2030».

YADRO FIZIKASI SOHASIDAGI SO'NGGI FUNDAMENTAL TADQIQOTLAR, YUTISHLAR VA KELAJAKDAGI REJALAR

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Annatsiya: Maqolada 2024–2026 yillarga mo'ljallangan yadro fizikasining eng muhim fundamental tadqiqotlari, yutuqlari va kelajakdagi istiqbollari ko'rib chiqiladi. Asosiy yo'nalishlar: toriy-229 yadro soati texnologiyasi, kvant tunnel va rezonanslarning yangi o'lchovlari, kvark-glyuon plazmasi (QGP) tadqiqotlari, antiproton spin nazorati, sintezda erishilgan yozuvlar, shuningdek, RHIC va LHC kabi tezlatgichlarning so'nggi natijalari. Maqola xalqaro laboratoriyalar (CERN, RHIC, NIF, EAST, PhET va boshqalar) natijalariga asoslangan. Sun'iy intellekt integratsiyasi, yangi avlod tezlatgichlari va sintez elektr stansiyalarini yaratish bo'yicha kelajakdagi rejalar muhokama qilinadi.

Kalit so'zlar: yadro fizikasi, toriy-229 yadro soati, kvark-glyuon plazmasi, kvant tunneli, antiproton spinini boshqarish, termoyadroviy sintez, RHIC, LHC, QGP, "Raqqamli O'zbekiston – 2030".

The field of nuclear physics has been developing at a rapid pace in recent years. Several fundamental breakthroughs were recorded between 2024 and 2026: precise measurements of the thorium-229 nuclear transition, the first control of the spin of an antiproton, new properties of the quark-gluon plasma, as well as record plasma temperatures and energy outputs in thermonuclear fusion.

These breakthroughs are not only enriching theoretical physics, but also opening up new opportunities for quantum computing, precise time measurement, new energy sources, and cosmological models.

International laboratories (CERN, Brookhaven RHIC, Lawrence Livermore NIF, China's EAST tokamak) and startups (Helion, Commonwealth Fusion Systems) are leading the way in this field. As part of Uzbekistan's "Digital Uzbekistan - 2030" strategy, opportunities are emerging to join nuclear physics research using digital simulations and AI tools.

Key achievements (2024–2026)

Thorium-229 nuclear clock technology (2024–2025) In 2024, a team from TU Wien (Vienna University of Technology) created the world's first nuclear clock. In 2025, the stability of the fine structure constant (α) was tested with unprecedented precision using this technology. The result: the nuclear transition energy was determined to be 8.35574(5) eV (Nature Communications, 2025). This achievement laid the foundation for new tests of quantum mechanics and the variability of fundamental constants.

First control of the spin of an antiproton (BASE experiment, CERN, 2025) The BASE collaboration has brought the spin of a single antiproton under quantum control for the first time. This is a major breakthrough in antimatter physics, opening up new possibilities for tests of CPT symmetry and the Standard Model. Result: Physics World included in the Top 10 achievements of 2025 (Nature, 2025).

Quark-Gluon Plasma (QGP) research (RHIC and LHC, 2025–2026)

✓ RHIC (Brookhaven) completed its final operation in 2025 and collected more than 60 billion collision data. The STAR experiment revealed the QGP splash effect and interaction with jets.

✓ The LHC performed the first proton-oxygen, oxygen-oxygen, and neon-neon collisions in 2025, confirming the bowling pin shape of neon nuclei and demonstrating the formation of QGP.

✓ The ALICE experiment collected 2 nb⁻¹ heavy ion data – a record efficiency.

Fusion Progress (2025–2026)

✓ China's EAST tokamak broke the plasma density limit in early 2026 and maintained a stable high-density plasma.

✓ Helion Energy achieved a plasma temperature of 150 million °C in 2026 and tested a proprietary tritium-powered device for the first time.

✓ NIF (USA) achieved an output energy of 8.6 MJ in 2025 (4 times the input).

✓ Wendelstein 7-X stellarator achieved an energy cycle of 1.8 GJ.

Future Plans (2026–2035)

- The Future of CERN and the LHC: The High-Luminosity LHC (HL-LHC) will start operating in 2029, accelerating the search for Higgs boson self-interaction and new particles.

- New accelerators: FCC (Future Circular Collider) project – 100 km ring, 100 TeV energy.

- Fusion: ITER first plasma in 2035, then DEMO power plant. Private companies (Helion, CFS) promise commercial reactors in the 2030s.

- Nuclear clocks and quantum technologies: Thorium-229-based clocks are used in quantum computing and navigation.

- AI and numerical simulations: Models and supercomputers such as Grok, ChatGPT are used to predict QGP and nuclear models.

The years 2024–2026 marked the beginning of a new era in nuclear physics: nuclear transitions were precisely measured, antimatter was controlled, new properties of QGP were discovered, and fusion approached the commercial stage.

In the future, these achievements will play an important role in understanding new energy sources, quantum technologies, and the initial state of the universe. There are opportunities for Uzbek scientists to actively participate in this field through digital platforms (Colab, PhET), AI tools, and international collaboration.

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