Rachek K.O., Kyrtoka T.V., Ivanova I.M.
National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»,
Kyiv, 37, Prospect Beresteiskyi, email:im_ivan@ukr.net

ANTIHYDROGEN: EVOLUTION OF STUDY IN UKRAINE AND WORLDWIDE

Abstract. *Antihydrogen, an atom composed entirely of antimatter particles, provides a unique opportunity to study fundamental symmetries of the Universe, particularly CPT symmetry, which predicts identical behavior of matter and antimatter under certain transformations. Its synthesis and study have been pivotal in advancing our understanding of antimatter.*

Анотація. *Антиводень – атом, повністю складений із частинок антиматерії, надає унікальну можливість для дослідження фундаментальних симетрій Всесвіту, зокрема CPT-симетрії, яка передбачає, що матерія й антиматерія повинні поводитися ідентично при перетвореннях заряду, парності та часу. Синтез і вивчення антиводню відіграють ключову роль у поглибленні нашого розуміння антиматерії.*

Keywords: *antimatter, antiparticles, antiproton, positron, antihydrogen,*

Ключові слова: *антиматерія, античастинки, антпротон, позитрон, антиводень.*

An anti-atom is an atom made of antimatter particles, similar in structure to a regular atom but with antiparticles: antiprotons, antineutrons, and positrons instead of protons, neutrons, and electrons.

The first antiparticle was discovered by Carl David Anderson in 1931 when he observed its track using a Wilson cloud chamber. He slowed the particle down with a thin metal plate to study its properties, which caused a spiral trajectory. The particle was called a positron [1].

The antiproton was first created in 1955 by physicists Owen Chamberlain and Emilio Segre [2]. They used the Bevatron proton accelerator to collide high-energy protons with a target, resulting in the creation of antiprotons.

Antihydrogen was first synthesized at CERN [3] in 1995 during the PS210 experiment led by Walter Oelert. Antiprotons were decelerated in a thin metallic foil and subsequently captured in a Penning trap — an electromagnetic device that confines particles using combined magnetic and electric fields. Inside the trap, antiprotons interact with electrons, which cool via cyclotron radiation.

The positrons are easy to obtain from radioactive sources. In the ATHENA experiment, positrons are accumulated using a technique developed by Cliff Surko and his team at the University of California, San Diego. They are slowed down by collisions with nitrogen molecules and then collected in a Penning trap for 200 seconds before being transferred to another trap holding antiprotons within the same magnetic field.

Antiprotons are introduced into positron plasma to create an antihydrogen. About 15% of antiprotons interact with positrons, forming antihydrogen nuclei.

Antihydrogen is a unique probe for testing CPT symmetry, which predicts identical behavior of matter and antimatter under charge conjugation (C), parity inversion (P), and time reversal (T). In this framework, antiparticles are viewed as particles moving backward in time.

Alongside Dirac's prediction of the positronin 1928 [4], the issue of negative energy solutions in the Dirac equation led to two interpretations. Paul Dirac proposed the "Dirac sea" model, where negative energy states are filled with electrons, preventing transitions from positive energy states. A "hole" in this sea, representing the absence of a negative energy electron, is perceived as a positron.

Feynman [5] and Stueckelberg [6] explained negative energy solutions as particles moving backward in time. In quantum electrodynamics, positrons are seen as electrons going backward in time, as shown in Feynman diagrams.

Since quantum mechanics describes systems evolving forward in time, reversed time paths are interpreted as antiparticles. This idea remains theoretical and lacks clear meaning in the Hamiltonian approach.

Time reversal is still debated, especially in connection with entropy and irreversibility. So far, it has neither been confirmed nor disproven experimentally.

The GBAR project [7] aims to measure the free-fall acceleration of ultracold neutral antihydrogen in Earth's gravity to test Einstein's equivalence principle, which states that gravity is independent of a particle’s internal structure. Results, which may clarify how antimatter interacts gravitationally, are still expected, and antigravity remains unconfirmed.

Ukrainian scientists also contributed to the technology of creating antihydrogen. In 2016, M.M. Diachenko [8], O.V. Khelemelia, and O.P. Novak received the Presidential Award of Ukraine for research on cooling proton and antiproton beams using magnetized electron gas with anisotropic temperature — an important component of the electron cooler for the HESR ring at the FAIR facility.

From 2009 to 2017, the UA9 collaboration at CERN confirmed the stochastic deflection mechanism of high-energy charged particle beams predicted by Grinenko and Shulga [9]. This enables precise control of both positively and negatively charged particles and is planned for use at PETRA IV (DESY) and in future electron-positron colliders.

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