
Antimatter in the Universe

S. SAHOO,¹ R. K. AGRAWALLA² AND M. GOSWAMI³

¹Department of Physics, National Institute of Technology,
Durgapur 713209, West Bengal, India.
sukadevsahoo@yahoo.com

²Department of Engineering Physics,
Bengal College of Engineering and Technology,
Durgapur 713212, West Bengal, India.

³Department of Physics, Regional Institute of Education,
Bhubaneswar 751022, Orissa, India.

ABSTRACT

The matter-antimatter asymmetry in the Universe is one of the most evasive and fascinating enigmas in physics. Antimatter, a mirror image of matter, is an idea so revolutionary that even its discoverer initially feared its consequences. In particle physics, antimatter extends the concept of the antiparticle to matter. If a particle and its antiparticle come into contact with each other, the two annihilate – they may be converted into other particles with equal energy in accordance with Einstein's equation $E = mc^2$. This gives rise to high-energy photons (Gamma rays) or other particle-antiparticle pairs. In this article, the existence of antimatter in the Universe is briefly discussed.

1. Introduction

The history of antimatter begins in 1928 with a young British theoretical physicist named Paul Dirac.^{1,2} He combined quantum theory and

special relativity in his theory of electron. He developed a relativistic equation for the electron, now known as *Dirac equation*. This equation has two solutions: one described the electron (with a negative charge); the other a

similar particle but with a positive charge. This positive particle was experimentally found in 1932 by Carl D. Anderson while studying cosmic rays, known as *antielectron* or *positron*. Anderson received Nobel Prize in physics for the “discovery of positron” in 1936. Dirac’s theory applies to all quarks and leptons, and their antiparticles are collectively known as *antimatter*. Antimatter is sometimes called as “*Contraterrence Matter*”. In 1898, Sir Arthur Schuster first coined the phrase antimatter. Before Schuster, Karl Pearson suggested negative matter in 1892. Even prior to Pearson, William Hicks discussed the idea of negative matter in the 1880s.³

Twenty three years after the discovery of positron, the next antiparticles were discovered. In 1955 Owen Chamberlain and Emilio Segre found the *antiproton* after a series of experiments where they collided protons together at the University of California. They examined 5 million signals from pions before they found just 100 signals from antiprotons.⁴ Chamberlain and Segre shared the Nobel Prize for physics in 1959. In 1956, *antineutron* was discovered by B. Cook, G. R. Lambertson, O. Piconi and W. A. Wentzel by passing antiprotons through matter.⁵ In 1965, *antideuteron* was discovered. The antideuteron is a nucleus of antimatter made out of an antiproton and an antineutron. This was discovered by two teams. One led by Antonino Zichichi, using the proton Synchrotron at CERN, and the other led by Leon Lederman, using the Alternating Gradient Synchrotron (AGS) accelerator at the Brookhaven National Laboratory, New York. An antiparticle is denoted by adding a *bar* over the symbol for the particle. For example, proton and antiproton are denoted by p and \bar{p} respectively. Another way of writing an antiparticle by changing the electric charge of the particle. For example, the electron and positron are denoted by e^- and e^+ respectively.

2. Artificial Production of Antimatter

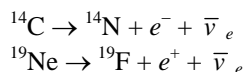
In 1995 an international team headed by Walter Oelert at CERN created nine atoms of *antihydrogen*. The nine atoms were produced over three weeks by colliding antiprotons with xenon atoms. The antiprotons are first produced by accelerating protons using a linear accelerator and then a synchrotron. The protons then hit a beryllium target as a result of which some of the proton-antiproton pairs are produced. Some of these antiprotons are then sent to LEAR (Low Energy Antiproton Ring) where they are decelerated. To create antihydrogen, the previously created antiprotons were sent around LEAR, passing through a jet of xenon gas. An antiproton occasionally converts a small part of its own energy into an electron and a positron, while passing through a xenon atom. In rare cases, the positron’s velocity approaches very close to the velocity of an antiproton for the two particles to join – creating an atom of antihydrogen.⁶

In 1996 and 1997, at Fermilab, 99 antihydrogen atoms were observed.⁷ In the late 1990s, two Collaborations, ATHENA and ATRAP, were formed to study the creation of less energetic (Cold) antihydrogen. The first *cold antihydrogen* was produced in CERN by ATHENA project in September 2002. Now-a-days ATHENA and ATRAP are trying to cool the antihydrogen atoms by subjecting them to an inhomogeneous field. Antihydrogen atoms are electrically neutral and their spin produces magnetic moments. These magnetic moments vary depending on the spin direction of the atom, and can be deflected by inhomogeneous fields regardless of electrical charge.

Recent data released by CERN states that it can produce 10^7 antiprotons per second when operated fully with 100 % capacity. With the optimal conversion of antiprotons to antihydrogen, it would take two billion years to produce 1 gram of antihydrogen.

3. Natural Production of Antimatter

(i) Antimatters are produced everywhere in the Universe where high-energy particle collisions take place. High-energy cosmic rays impacting Earth's atmosphere produce antimatter in the resulting particle, which is immediately destroyed by contact with nearby matter. (ii) Antimatters are produced in the centre of the Milky Way Galaxy and other galaxies, where very energetic celestial events occur. (iii) Antimatters are also produced in any environment with a sufficiently high temperature (Particle energy should be greater than the pair production threshold). During Big Bang, when the Universe was extremely hot and dense, matter and antimatter were created equally. (iv) Antimatter is also produced in some radioactive decays. For example, when ^{14}C decays, a neutron decays into a proton plus an electron and an electron antineutrino, $\bar{\nu}_e$. When ^{19}Ne decays, a proton decays into a neutron plus a positron, e^+ , and an electron neutrino, $\bar{\nu}_e$.



4. Uses of Antimatter

(i) Antimatters are used in medical diagnostics. Positrons are used to identify different diseases with the Positron Emission Tomography (PET scan).⁸ (ii) Antimatters can be used to propel a car or a spaceship. If we have a gram of antimatter, we can drive our car for about 100,000 years. (iii) Antimatters can be used in military to build an antimatter weapon. But in practice it is very difficult because the production of antimatter is very difficult. Spacecraft and antimatter weapon would need a huge amount of antimatter; it would take millions and millions of years to produce such amount. The current antimatter production rate is between 1 and 10 nanograms per year, and this is expected to increase to between 3 and 30

nanograms per year by 2015 or 2020 with new superconducting linear accelerator facilities at CERN and Fermilab.

5. Big Bang Theory and Antimatter

The currently accepted picture of the origin of the Universe is referred to as the *Big Bang Picture*.⁹⁻¹² Big Bang implies: (i) Equal amount of matter and antimatter must have created, and (ii) They should have annihilated with each other. But in our present Universe, we observe more matter than antimatter ("*Baryon Asymmetry*"). In 1967 Andrei Sakharov¹³ explained that: a baryon symmetric Universe at the time of the Big Bang could have evolved into an asymmetric condition if three conditions were necessarily met: (a) CP Violation (b) Baryon number non-conservation (c) Thermal non-equilibrium. Thus, CP Violation is one of the keys to the origin of matter and antimatter asymmetry in the Universe. Charge Conjugation (C) does not affect the external properties of a particle such as its spin, but it reverses its internal properties such as its electric charge, changing it into antiparticle. Parity (P) does not affect the internal properties but it reverses its spin.

In 1964 Christenson, Cronin, Fitch and Turlay¹⁴ observed that the decay of neutral kaon violates CP-symmetry minutely. In 1973, Kobayashi and Maskawa¹⁵ pointed out that CP violation would appear in the standard model if it was extended to include six quarks. At that time only three quarks were known – up, down, strange. The fourth quark "charm quark" was seen experimentally in 1974. The suggestion of Kobayashi and Maskawa required two more quarks should exist. According to them weak nuclear forces involve mixtures of different quarks with different coupling strengths. The interactions between the six types of quark are specified by nine complex numbers that can be arranged in a 3×3 matrix (Kobayashi-Maskawa matrix). If there

were only four quarks, a 2×2 matrix of real numbers would be enough. But in the 3×3 version for six quarks, the nine complex numbers include an imaginary “phase” and it is this term which is responsible for the origin of CP violation in the Kobayashi-Maskawa model.

In 1977, the fifth quark – bottom (or beauty) – was discovered at Fermilab near Chicago. The sixth quark, top quark, was also discovered at Fermilab in 1995. In 1976,¹⁶ it was shown that, according to Kobayashi-Maskawa model, effects of CP violation should also be seen in the amplitudes for K_S and K_L decays into pairs of neutral pions and pairs of charged pions. Twenty years later, this was confirmed by experiments at CERN and Fermilab.

6. Conclusions

The matter-antimatter asymmetry is one of most mysterious phenomenon of our Universe which still did not find a satisfactory explanation in physics. Antimatter has fuelled the imaginations of science fiction enthusiasts for decades. Antimatter is the mirror image of the matter. It annihilates with ordinary matter, disappearing in a puff of energy. The existence of antimatter would be very important not only for cosmology but also for particle physics. We expect that future observations along with theoretical developments will be able to decide this matter and shed some new light on the antimatter. It is hoped that antimatter can be used as fuel for interplanetary travel or

possibly interstellar travel, but it is also feared that it can be used for the construction of antimatter weapons.

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