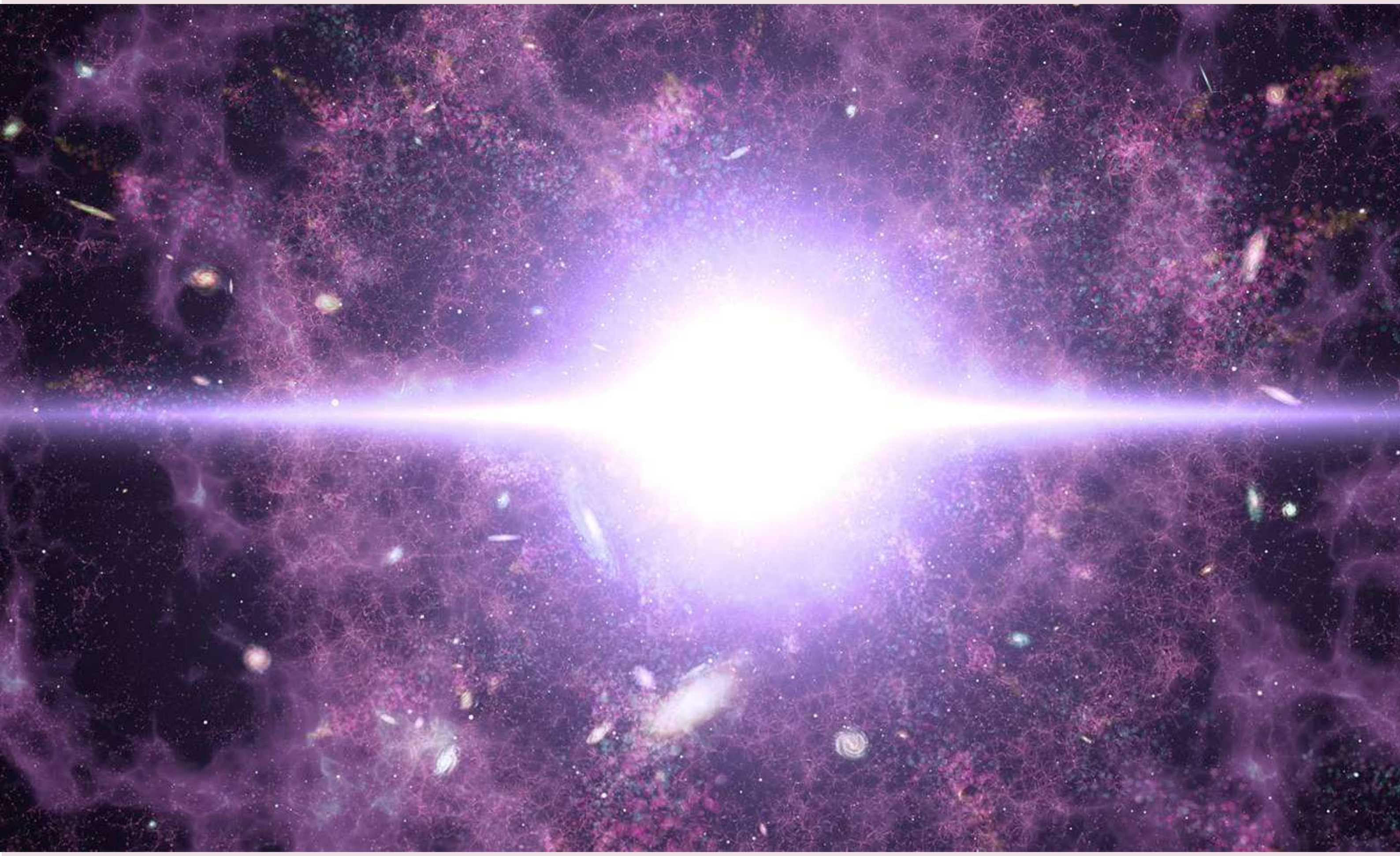
Antimatter

De Bron & Liceo Statale G. Ricci Curbastro



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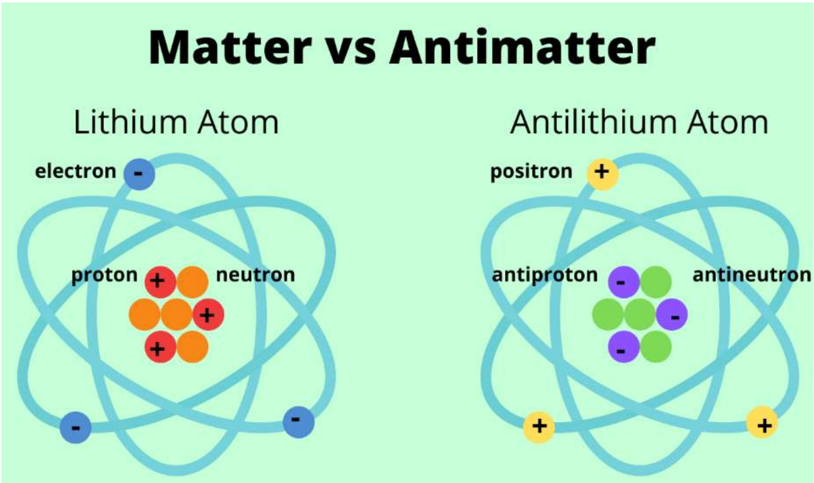
Antimatter was one of the most exciting physics discoveries of the twentieth century, predicted by the British physicist Paul Dirac. The theory was formed as a result of the combination of two great ideas of early modern physics: relativity and quantum mechanics. Since then, it has been picked up in fiction by writers such as Dan Brown, causing many people to think of it as an unrealistic theoretical idea. In reality, it is produced every day. The research on antimatter even helps us understand how the universe works.

Antimatter versus ordinary matter

Matter and antimatter particles are always produced as a pair. Antimatter could be described as a mirror image of matter. To understand this, you have to know that matter exists of particles. These particles have counterparts called antiparticles. Positrons (e+), antiprotons (p), and antineutrons (n) are viewed as particles corresponding to electrons, protons and neutrons. The only real difference between antimatter particles and their matter counterparts are the charge and spin, which are opposite. They share the identical mass.



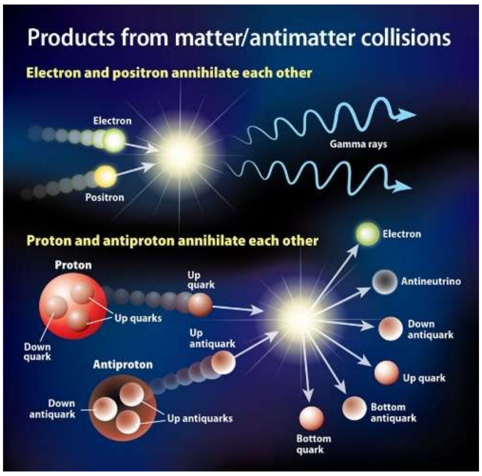
The existence of antimatter


Paul Dirac

Paul Dirac was the first to propose anti-particles. He did this in 1928 after formulating his Dirac equation. It’s a relativistic quantum mechanical wave equation and describes the elementary spin ½ particles, for example electrons. This corresponds to the principles of quantum mechanics as well as to those of special relativity. The equation implicitly indicated the existence of a new form of matter, called antimatter. Diracproposed that every atomic particle has an antiparticle that shares the same mass, but has the opposite electric charge and other quantum differences. However, Dirac only thought that this was the case, but could not prove it himself. The first person who really discovered antimatter was Carl Andersen. In 1932, he started experiments on cosmic rays. In what is called the Anderson Cloud Chamber, Anderson discovered that a very small part of that cosmic rays contains antiparticles such as the positron, the antiparticle of the electron.

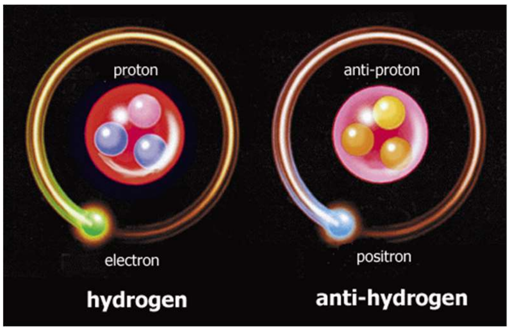
Antimatter is just as stable as ordinary matter, if it doesn't come into contact with matter. However, it blows up instantly if those two encounter each other. Antimatter can only last on earth for a fraction of a second without special precautions but can last months in the right container. Consequently, antimatter can last just as long as matter… forever. At least until it turns into a different form of energy upon collision with ordinary matter.

When antimatter meets ordinary matter



An encounter between a particle and its anti-particle will lead to annihilation. In this process both particles will be destroyed, and a large amount of energy will be released. This happens immediately, this explains why antimatter doesn't live long.

Quantity and types of antimatter



Antimatter is a real substance. Currently CERN's scientists, even if they use their accelerators, can produce no more than about 1 billionth of a gram per year. The total amount of antimatter produced in CERN's history is less than 10 nanograms, so this would generate just enough energy to power a 60-watt lightbulb for around four hours.

Concerning the types of antimatter,the first antimatter's particle was discovered in 1932 and it was called the positron, the antiparticle of the electron. The first discovery and production of antiprotons happened in 1955 at the University of California at Berkeley. The research team led by Emilio Segrèbombarded a copper target with high-energy protons from the proton synchrotron. Then the first antiatoms were created in laboratories, first attempts concerned anti-hydrogen, the simplest antiatom. Anti-hydrogen atoms were created at CERN and Fermilab by Prof. Walter Oelert and an international team from Jülich IKP-KFA, Erlangen-Nuernberg University, GSI Darmstadt and Genoa University between 1995 and 1996: however, they were not sufficient to study the properties of antimatter.

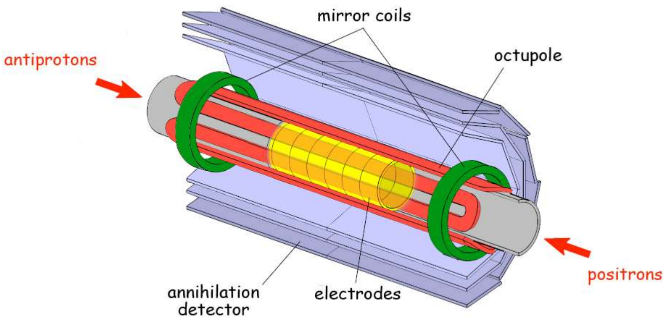
Nine of these atoms were produced in collisions between antiprotons and xenon atoms. Each one travelled at nearly the speed of light over a path of ten metres and then annihilated with ordinary matter, annihilation showed that the anti-atoms had been created. In 1997 the experiment Athena was born, and 40 physics tried to produce large quantities of antihydrogen using the Antiproton Decelerator.

Between 2002 and 2004 the Athena team produced around 2 million of them combining antiprotons and positrons and revealing individual antiatoms one by one, thanks to a sophisticated detector. Then in 2016 at CERN the experiment ASACUSA managed to produce and trap antihydrogen atoms. For the first time scientists were able to compare antihydrogen atoms with their hydrogen counterparts in order to find their differences and to make new discoveries.

Normal gravitation or anti-gravitation

What goes up must come down, the saying goes. But this theory might work a little differently with antimatter. The Standard Model predicts that gravity should have the same effect on matter and antimatter. However, this has yetto be seen. Experiments such as AEGIS, ALPHA and GBAR are hard at work trying to find out. It's not easy to observe the effects that gravity has on antimatter. These experiments in order to be successful have to trap antimatter and decelerate it by reducing its temperature just above absolute zero. Physicists must use neutral antimatter particles to avoid the interference by electrical forces that are more powerful. All this because gravity is one of the weakest forces.

Containers for antimatter



Antimatter container

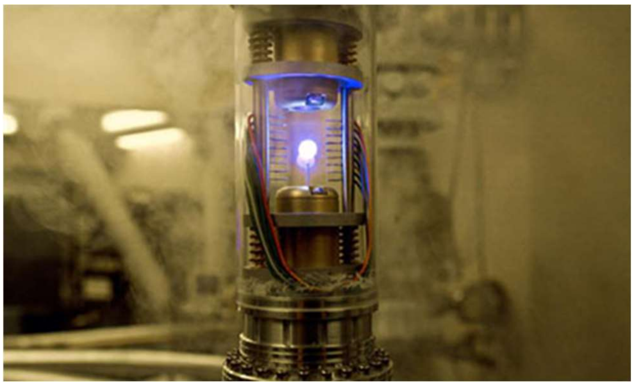
Creating antihydrogen was one of the major achievements of this century, however the atoms created were too energetic and "hot" to be easily studied. The Antiproton Decelerator established at CERN in the late 1990s began providing slower moving, lower-energy antiprotons for antimatter experiments, but it wasn't enough: they needed to be trapped. Trapping antimatter atoms proved to be extremely difficult, even more than creating them.

In June 2011, the ALPHA collaboration, an international team of scientists working at CERN, was the first group to trap and store these atoms for over 16 minutes, giving the physicists time to take measurements and to find more answers to the antimatter mystery. The ALPHA project succeeded by using a specially designed magnetic bottle called a Minimum Magnetic Field Trap. The main component is an octupole (eight-magnetic-pole) magnet whose fields keep anti-atoms away from the walls of the trap, preventing them from annihilating.

A more recent project called PUMA (antiProton Unstable Matter Annihilation) aims to trap a record of one billion antiprotons at the ELENA facility, one of the structures of CERN, and keep them confined for several weeks. Such a long storage time would allow the trapped antiprotons to be loaded into a van and transported to the nearby facility, called ISOLDE. In order to trap the antiprotons long enough for them to be transported and used at ISOLDE, PUMA plans to use a 70-cm-long “double-zone” trap inside a one-tonne superconducting solenoid magnet and keep it under an extremely high vacuum (10-17 mbar) and at cryogenic temperature (4 K). The PUMA project was launched in January 2018 and the head of the team, Alexandre Obertelli, aims to build and develop the solenoid, managing to trap and to detect the antiprotons within two years, while the final results of the experiment are expected not earlier than 2022.

Antimatter factory in France (CERN)

Representation in media



Antimatter in Angels and Demons (2009)

Angels and Demons is a Hollywood thriller based on a book by Dan Brown. In this movie a secret society called “Illuminati” operate in order to destroy the Vatican using an antimatter bomb. Real physicists are using the movie as an opportunity to talk about antimatter in real life. In the movie a quarter of a gram of antimatter is stolen from CERN by this organisation. Many fans have asked themselves if this plan could actually work in reality.

Physicist explained that when antimatter comes into contact with matter, they both annihilate, releasing enormous amounts of energy. The Big Bang created equal quantities of matter and antimatter, but only the first one survived while the last disappeared. Now however, scientists at CERN are creating antimatter of their own. They conclude by saying that in reality it is not possible to realize this plan for two main reasons.

The first one is that much more energy is needed. It would take billions of years to produce enough antimatter for a bomb having the same destructiveness as normal hydrogen bombs. Meanwhile in the movie, they switch on the LHC, the large hadron collider, and it produces one gram in a few minutes. In the book, a quarter gram of antimatter was thought to be the equivalent of 5,000 tonnes of dynamite, enough to destroy a city. Scientists said that the number was correct, but it is not likely to be used in any bomb because it would take too long to produce the amount which is used in the movie. Currently the largest producer of antimatter is Fermilab, which creates about 2 nanograms of antiprotons per year.

The other reason is that it is not practical at all. Antimatter is not portable in real life, although in the movie scientists transport it from Geneva to Rome. Moreover, another important discrepancy is the choice to use the LHC as the particle accelerator where the antimatter is produced because it is a dynamic and attractive machine. In reality, the antimatter that CERN has produced was made in the Antiproton Decelerator.

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