International Particle
Physics Outreach Group

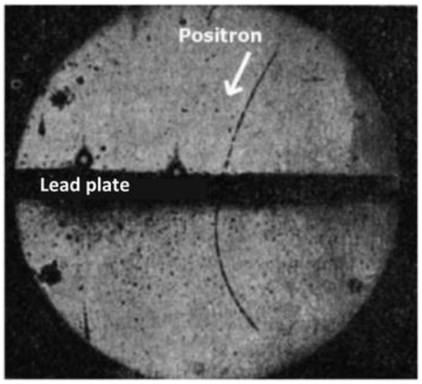
PASSPORT TO THE INFINITE

Antimatter

Antimatter isn’t just sci-fi imaginary: physicists study it in cosmic rays or particle accelerators. As both a reflection and the opposite of ordinary matter, antimatter is far from having revealed all its secrets, notably the reasons for its near absence from our Universe.

Anderson’s discovery of the positron in 1932

This historic photograph shows the track left by a particle in a ‘simple’ but extremely ingenious detector. A magnetic field bends the trajectories of the charged particles; the shape of the track obtained can be used to identify the particle’s nature, in this case, an ‘antielectron’. The trajectory is straighter over the lead plate than below it. This altered curvature is due to the energy loss when the particle goes through the obstacle, therefore, the particle traveled downwards (see arrow). For a (negative) electron, the track should have been curved in the other direction. Anderson thus discovered a ‘positive electron’, or positron, the first antimatter particle.



Credit: C.D. Anderson

Far from being a figment of artists’ imagination, antimatter exists in reality. As its name suggests, it is the ‘opposite’ of the ordinary matter on which our world is based. Just as matter is made up of particles, antimatter is made up of... antiparticles, with very similar properties. For every fundamental particle there is an antiparticle with the opposite electrical charge (e.g. the antielectron, or positron, has a positive charge) but the same mass and lifetime.

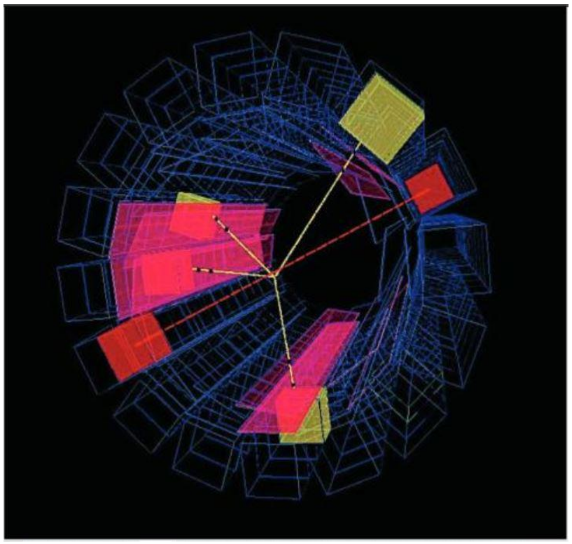
Antimatter first appeared in science in 1927, in an equation written by the theorist Paul Dirac. The prediction was confirmed five years later by Carl Anderson, who detected a positron in cosmic rays. Theoretical calculations make no distinction between matter and antimatter: particles and antiparticles are produced simultaneously when energy is transformed into mass according to Einstein’s formula $E = Mc^2$.

Particles and antiparticles cannot coexist. When they collide, they disappear and convert into photons or particle-antiparticle pairs. These can differ from the initial particles. For instance, an electron and a positron can annihilate to form a muon and an antimuon. Physicists are currently investigating the differences between particles and their associated antiparticles. For example, they have observed significant variations in the behaviour of mesons containing a b (anti)quark.

Antimatter is extremely rare in the Universe, where matter is largely predominant. This observation remains a real mystery today, as modern cosmology supposes that at the time of the Big Bang matter and antimatter were created in equal amounts.

We know how to produce antiparticles in accelerators during high-energy collisions. Another challenge, which is technically even more complex, is to produce antiatoms whose nucleus and electronic cloud are made up of antiparticles. The difficulty lies in reassembling the puzzle by putting an antielectron into orbit around an antiproton to create antihydrogen. This is currently possible at CERN thanks to the 'antiproton decelerator'. The antihydrogen produced is used, among others, to compare the effects of gravity on matter and antimatter. Gravitation is expected to act in the same way on particles and antiparticles, but this behaviour has never been validated experimentally. Through experiments such as AedIS and GBAR, carried out at CERN, we can test this hypothesis.

What are the applications for antimatter? Let's start by disappointing some people: at the moment, using antimatter as a source of energy is not an option. Indeed, its production requires a billion times more energy than its annihilation with matter would provide. Producing one gram of antimatter would for example swallow up France's budget over several millennia while only supplying mankind with energy for a few minutes! However, an application for antimatter is currently found in medical imaging, in particular, tomography. A radioactive marker is fixed to the examined area (a potential tumour, for example). The marker emits positrons, which annihilate with electrons from the tissue, producing characteristic pairs of photons that are detected outside the body and provide information about the size of the structure.



Credit: CERN

Annihilation of an antihydrogen atom

In this image obtained in CERN's ATHENA experiment, the hydrogen antiatom decayed when it reached the wall of the 'particle trap' (not shown here), which of course consists of ordinary matter. The interaction between the antiproton and a proton of matter produces four charged pions (yellow paths) that are then detected (pink areas and yellow cubes). The positron annihilates with an electron to produce two photons of specific energies that are emitted back-to-back (red paths) and are also observed (red cubes).

Translated from 'L'antimatière',* **Passeport pour les deux infinis**, *IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG