

Antimatter

A 100-year-old puzzle of matter

From the beginning of the Universe, it seems there was a **subtle favouritism** for the matter that makes up the world we live in today. Without it we would not exist - there would be no stars, no planets and no people - just energy.

It all started in the intense heat of the Big Bang, where particles of matter were forged out of pure energy. But for every particle of matter created, a 'twin' was also born - an 'antiparticle' identical in mass but with **opposite electric charge**.

For the first few instants of its existence the Universe was balanced, with matter and **antimatter** created in equal abundance. Then just one second after the Big Bang, the antimatter had all but **disappeared**, together with almost all the matter, leaving a minute amount of matter alone to form everything that we see around us - from the stars and galaxies, to the Earth and all life that it supports.

So **what happened** to all the antimatter? This is one of the great puzzles of particle physics and one that physicists at **CERN** are working to try and solve.

A puzzling equation

In 1928 a young physicist named Paul Dirac created an equation to describe the behaviour of an electron. But there was something odd – he found it could have two solutions, one for the electron and one for an almost identical particle, with opposite electric charge. Four years later Dirac's extraordinary theory was proved right, when the first anti-electron (called a positron, because of its positive charge) was discovered among the tracks of cosmic rays.

$$(i\gamma^{\mu}\partial_{\mu} - m)\psi = 0$$

Through the looking glass

In fact, all matter particles have an antiparticle. Like a mirror version of normal matter, these antiparticles can come together to form antimatter. Dirac even suggested that there could be whole regions of the Universe composed entirely of antimatter: complete anti-galaxies with anti-stars and anti-planets. But we could never live in such antimatter worlds. If you ever set foot on an antimatter planet you would disappear.

Complete annihilation

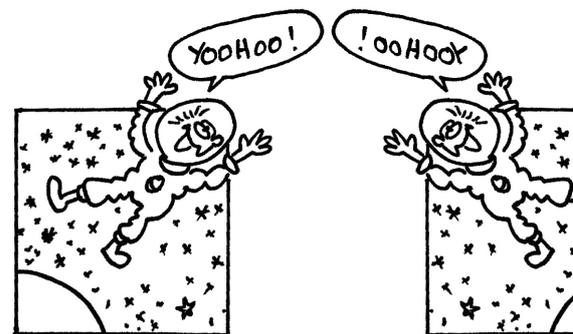
When matter and antimatter come into contact they completely annihilate. This explosive relationship raises some intriguing questions. If matter and antimatter were created in equal quantities during the Big Bang, why do we find ourselves living in a Universe that seems to be made only of matter? Could some unknown mechanism have stepped in to prevent matter and antimatter from completely annihilating each other? Or could vast clusters of antimatter still exist in some far-flung corner of the Universe, as Dirac thought?

A natural favouritism

Today there is still no evidence for large-scale clumps of antimatter in the Universe, but experiments performed over the past 40 years have shown a small difference in behaviour between some particles and their antiparticles. This slight asymmetry (known as CP violation) has a subtle 'favouritism' for normal matter, but it is not enough to explain why antimatter has disappeared from the Universe.



The LHCb experiment



If you ever met an anti-you, in the blink of an eye you would both vanish, destroying one another and leaving behind a flash of energy.

The missing antimatter

To help unravel the mystery of the missing antimatter we first need to create antiparticles. These can be created in particle accelerators that simulate the high-energy conditions that existed at the beginning of the Universe, but it is still far from easy to make antimatter. Only in 1995 did an experiment at CERN make the first few atoms of antihydrogen.

Broken symmetry

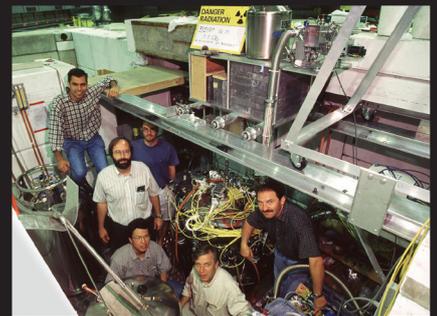
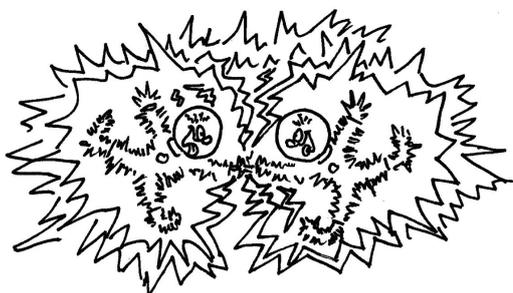
Inside the Large Hadron Collider (LHC) exotic antiparticles will be created as particles collide head-on at nearly the speed of light. All of the four large LHC experiments will be on the look out for antimatter, but LHCb in particular is devoted to this task. The experiment is studying 'CP violation' through a slight difference in decay between the beauty quark and its antiparticle. Elsewhere at CERN the NA62 experiment will also be looking for decay differences between unstable particles called kaons and their antiparticles. These differences show that matter and antimatter aren't perfect opposites: there is a 'violation' of the symmetry between them. Studying this asymmetry between particles and antiparticles might help to reveal why antimatter has disappeared.

Capturing antiparticles

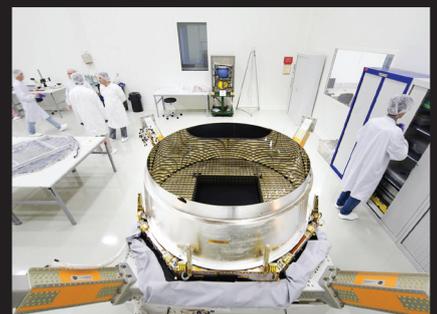
The Antiproton Decelerator (AD) looks a lot like CERN's other particle accelerators, but in fact it slows particles down! High-energy antiprotons made during collisions of ordinary matter are collected and slowed to almost a standstill, before being trapped inside magnetic cages. Using this method in 2002 the ATHENA and ATRAP experiments at CERN combined 'trapped' antiprotons with anti-electrons (positrons) to make thousands of antihydrogen atoms. Now ATRAP together with new experiments, ALPHA and AEGIS, will study antihydrogen to see whether it behaves just like hydrogen.

Into the unknown

Under assembly at CERN, the AMS experiment will be sent up to the International Space Station to hunt for antiparticles coming from space, in the hope of finding evidence of huge 'clumps' of antimatter out in the cosmos, such as entire anti-galaxies.



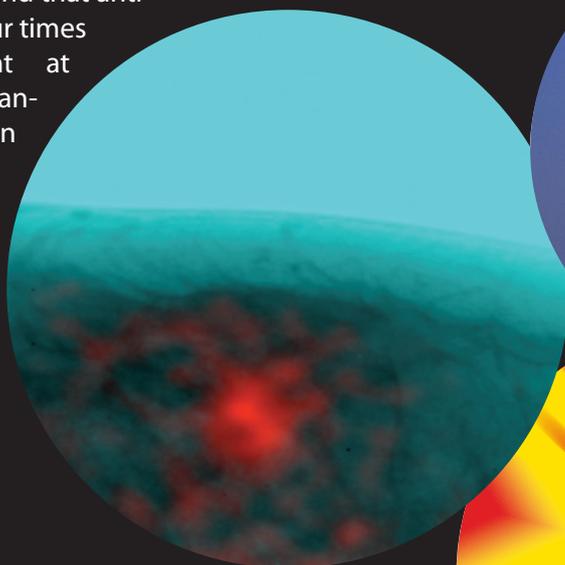
The ATRAP experiment



The AMS experiment

Is antimatter useful?

At CERN antimatter is mainly used to study the laws of nature, but this research can lead to new applications. Anti-electrons (positrons) are already used in Positron-Emission Tomography (PET) scanners for medical imaging in hospitals. One day it might even be possible to use antiprotons for tumour irradiation, the first stages of which are being studied at the Antimatter Cell Experiment (ACE) at CERN. It has already found that anti-protons are four times more efficient at destroying cancerous cells than protons.



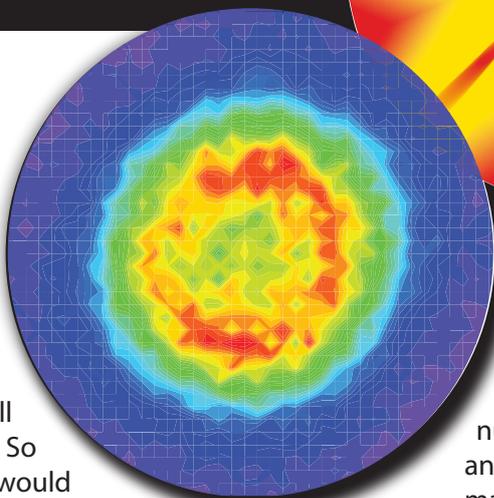
Could antimatter power vehicles in the future, like the Starship Enterprise?

There is no possibility to use antimatter as an energy 'source'. Unlike solar energy, coal or oil, antimatter does not occur in nature; we first have to make every single antiparticle, and we have to invest much more energy than we get back during annihilation.



Could antimatter be stolen from CERN?

Impossible! It is very difficult to contain antiparticles, because as soon as they touch normal matter they will immediately annihilate. So to steal antimatter you would also need to take the storage machines. These 'magnetic traps' need a superconducting magnet and cryogenic equipment weighing several tonnes, and even this can only store less than a trillionth of a gram of antimatter.



Can we make antimatter bombs as in the story 'Angels and Demons'?

At the current rate of production it would take over 2 billion years to produce enough antimatter (about one gram) for a bomb with the same destructiveness as a 'typical' nuclear bomb. In fact if we could assemble all the antimatter ever made at CERN and annihilate it with matter, we would only have enough energy to light a single electric light bulb for a few minutes.

CERN
European Organization for Nuclear
Research
CH-1211 Geneva 23

Communication Group, February 2009
CERN-Brochure-2009-001-Eng

CERN, the European Organization for Nuclear Research, was founded in 1954. It has become a prime example of international collaboration, with currently 20 Member States. It sits astride the Franco-Swiss border near Geneva and is the biggest particle physics laboratory in the world.

