Modern Physics

ANTIMATTER

by

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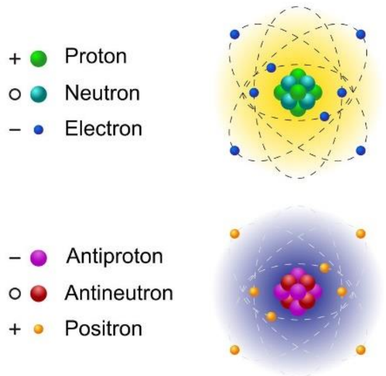
INTRODUCTION

Antimatter could be described as one of the greatest and most exciting discoveries of the last century. According to various research, antimatter is in fact "the mirror of common matter", so we could talk about antimatter's ability to create an universe equal to ours, but entirely made of antimatter: an anti-universe. The reason why we still don't know much about this topic is because, as Paul Dirac stated throughout his studies, experts have been focusing only on the surface we are already common with, missing the actual one to be looked at: antimatter's. Nonetheless, it all led to an explanation of the topic, for it can be described by common matter's means as well. Antimatter is the same as matter but with the oppositive charge.

We can now define antiparticles. If we are given an electron, just as experiments show, we are also given its opposite partner, called "positron" because it has the same properties but a positive charge. The same happens with a proton and an anti-proton. Otherwise, neutrinos may probably be their own antiparticles, since they have no electrical charge. This will help us later, when we'll deal with famous mysteries concerning antimatter.



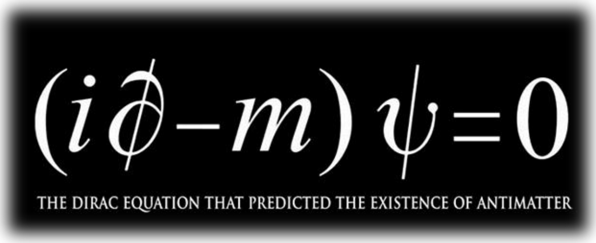
But how is antimatter created? Stated by all chances it was created alongside with usual matter during the Big Bang, there are many other ways to synthesize it in our own world. For example, by using ultra-high-speed collisions in huge particle-accelerators. This is what happened at CERN accelerator in Geneva, employing its LHC (Large Hadron Collider) system. Although, antimatter is produced naturally as well, through thunderstorms' energy, which is able to make positrons, and then again when cosmic rays enter Earth's atmosphere. Lastly, various anti-particles get together due to radioactive decays, taking place in hospitals PET scanners ("Positrons Emissions Tomography").

Considering antimatter is complementary to matter, when the two of them meet, they annihilate and consequently disappear in bursts of light. This makes antimatter be the key to understand the world: how do we even exist if antimatter makes matter fade?

ANTIMATTER: HISTORY

It all began in 1928, when Paul Dirac, a British physicist, published “The quantum theory of the electron”, predicting the existence of an anti-electron, known as the positron. His first purpose was to write down an equation that would combine quantum theory and special relativity to describe how an electron moves at a relativistic speed. The paper won him the Nobel prize in 1933, but soon it became clear that the equation seemed to have a problem: if we consider the equation x^2=4, we can easily affirm that it has two solutions, 2 and -2.

The same happens with Dirac’s equation: it has two solutions, one with negative and one with positive energy. It seemed impossible, since the energy of a particle should always be positive, but Dirac hypothesized that every particle has a corresponding one, with the same energy but opposite charge.



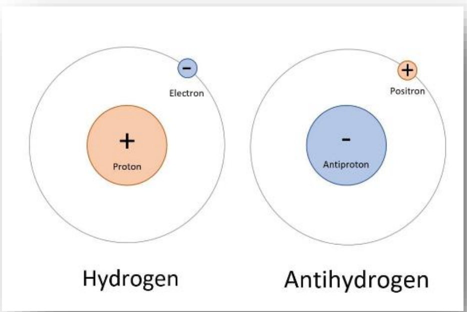
Dirac’s equation

This remarkable prediction speculated the existence of another universe made entirely of antimatter.

In 1932, Carl Anderson officially discovered the positron. While he was studying showers of cosmic particles in a cloud chamber, he observed the presence of "something positively charged, and with the same mass as an electron". Eventually he confirmed that the impact produced by the cosmic rays in the cloud chamber originated both an electron and a positron.

Later on, in 1955, the scientific team led by Emilio Segrè and Owen Chamberlain published the paper “Observation of antiprotons”, stating the existence of a particle identical to the proton as well, but with opposite charge. This discovery seemed to be another proof of the matter-antimatter symmetry.

However, in 1964, the result the experiment led by James Cronin and Val Fitch demonstrated that matter and antimatter don’t have a fully symmetrical behaviour, violating a fundamental principle of physics. This phenomenon, called CP violation, led to a major problem: if the Big Bang created both matter and antimatter in equal quantity, why didn’t they completely annihilate each other? This “mystery” will be scanned through later on.

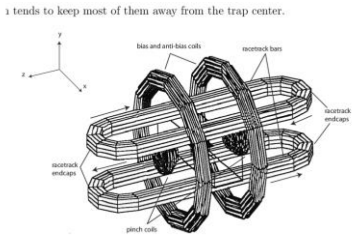


In 1995 research teams from CERN and Chicago’s Fermilab managed to artificially synthesize the antimatter version of the hydrogen atom, the antihydrogen. In conclusion, antiparticles are created as the counterparts when energy is converted into particles through energy collisions.

ANTIMATTER: APPLICATIONS

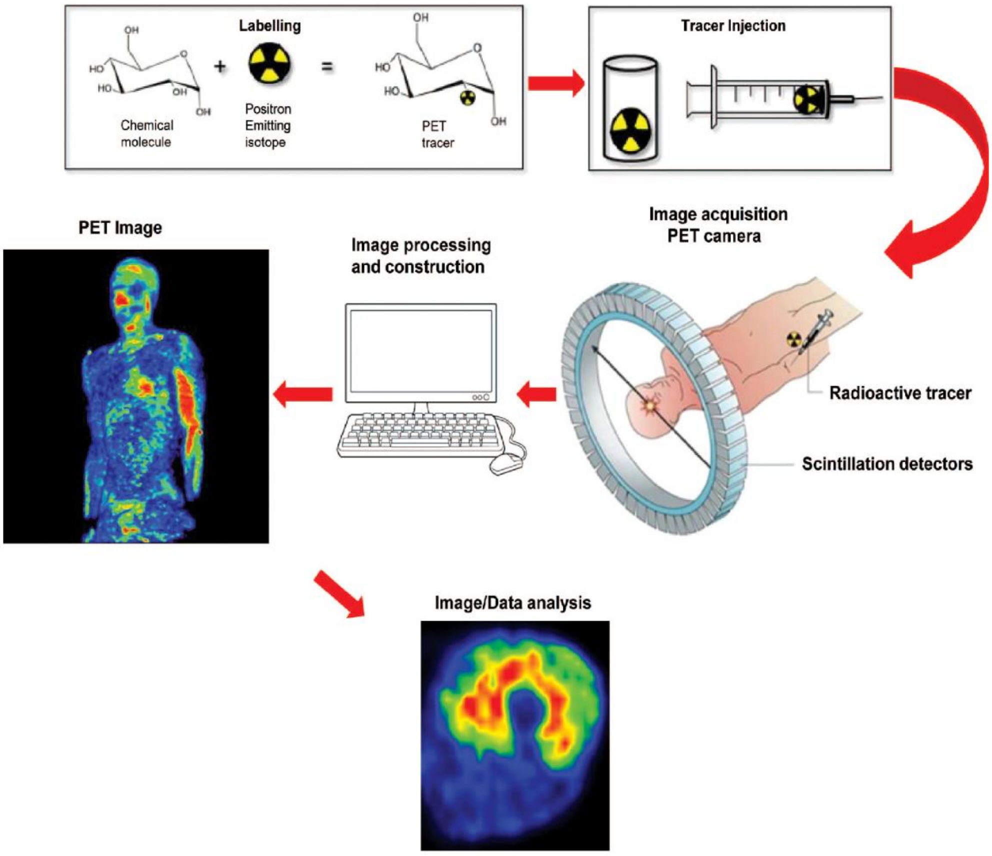
Before we can employ the antimatter for use, we first need to be able to store it for some time in order to make use of it. Therefore, there is something known as an antimatter trap.
You must keep antimatter from annihilating with matter if you want to examine it. Scientists have developed methods to accomplish this. For example, penning traps are devices that can hold charged antimatter particles like positrons and antiprotons. These are similar to micro-accelerators.

Particles inside the trap spiral around as magnetic and electric forces prohibit them from colliding with the trap's walls. However, penning traps will not operate on neutral particles like an antihydrogen atom, since it consists both of a positron and an antiproton. Electric fields cannot restrict antihydrogen Ioffe traps, which work by producing a zone of space in which the magnetic field grows in all directions.



Ioffe Trap

Up to this day we've solely been using it for PET, which is a technique of scanning, mainly applied in hospitals to find tumors or other diseases in various organs, as it allows to take precise images within the human body. It is carried out by inserting biologically active molecules, these carry a radioactive positron-emitting isotope which than sends out positrons when it decays, which emits gamma rays once it's annihilated which can be detected by a scanning device. With the data the device collects, the insides of the patient's body can be imaged, so detected.



PET scan

ANTIMATTER: POSSIBLE APPLICATIONS

Antimatter is being researched as a possible fuel for spacecraft, for it can provide a massive amount of power with just a few atoms, making it a common fuel for futuristic vehicles in science fiction (or maybe a very useful one in reality, later in time). Antimatter rocket propulsion is theoretically viable; the main sticking point is how to obtain enough antimatter. Currently it cannot be mass-produced or collected in the volume required for this application due to technological limitations. Yet, a few researchers have done propulsion and storage modeling tests, including Ronan Keane and Wei-Ming Zhang respectively from Western Reserve Academy and Kent State University, as well as Marc Weber and his colleagues at Washington State University. Their research could one day enable antimatter-propelled interplanetary travel to become a reality.

"*Critically, a nuke will only explode if you want it to, whereas antimatter is always trying to explode whether you want it to or not.*" - Cracked.

Concluding out of the previous quote, antimatter is extremely dangerous and explosive. Consequently, it can be said that it could be theoretically used for explosive weapons, too. Once again, its problem is that it is extremely hard to keep. This is because antimatter reacts with anything made up of matter, so containing it in some sort of container will make it explode, react with the trap itself. Unlike with uranium, that will only react and explode either if we want it to or if some accident happens.

Let us remember the "Little Boy" nuclear bomb, the one that completely vanished Hiroshima. It happens to be rather small in comparison to antimatter power. Dropped in 1945, the bomb was built from 64 kilograms of uranium. Its explosion resulted in an energy release of 'only' 64 terajoules (10^{12} J).
If we were to take just one gram of antimatter, we would have a 92 terajoules release of energy.

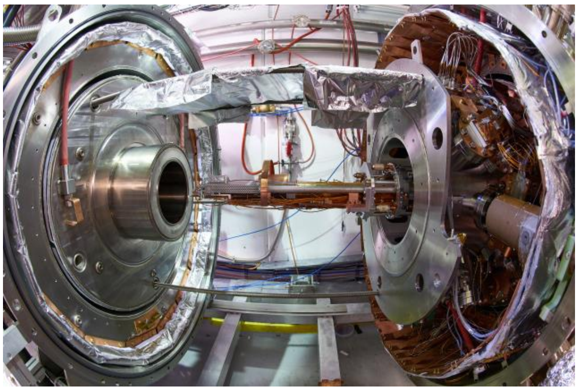
ANTIMATTER: MYSTERIES

Theoretically speaking, the Big Bang should have created equal amounts of matter and antimatter, which should have consequently annihilated, leaving nothing behind. Nevertheless, the cosmos, as we know it, is made up of only matter, resulting in an asymmetry between matter and antimatter. Why this unbalance exists in the first place? Where did all the antimatter go?

According to the calculations, less than one in every billion particles managed to survive and formed our matter universe, deriving from a theoretical slight difference between matter and antimatter masses. In this regard, depending on experiments led in 1998 by CERN, the kaon, a unique particle, seemed to turn into its antiparticle easier than the reverse process would happen. In 2001 the asymmetry got eventually confirmed by discovering it also in B mesons, kaon heavier cousins.

Moreover, physicists are trying to find out if neutrinos are their own antiparticle, claiming it is possible that the unbalance mentioned above is exactly due to the way they perform.

The fact that an amount of matter managed to escape the grasp of antimatter and created the universe we live in, could imply the presence of anti-stars and anti-galaxies. Afterall it is not unlikely that antiparticles would do the same. This suggests the existence of an “anti-world”. Though, once again, we cannot be so sure that such a thing happened, especially because if a galaxy and an antigalaxy came to the point of annihilating each other there would be a massive dispersion of gamma rays, which would surely not go unnoticed. Nonetheless, we should also be taking into consideration that the antimatter rule would plausibly affect a very distant area from us.



AEgIS antihydrogen production trap

Finally, how is antimatter affected by gravity? For a fact, matter falls down and, according to Einstein's theory, antimatter should do the same. To find an answer, the AEgIs collaboration instaurated at CERN’S Antiproton Decelerator is fundamental, as it’s trying to gain some information by using recent techniques, keeping in mind nothing is completely sure about antimatter.

Should any difference be found, it would question the reliability of Einstein’s equivalence principle.

ANTIMATTER: POP CULTURE

Although still a relatively new discovery in science, antimatter has been used in a lot of science fiction movies and universes.

One of the most notable examples is Star Trek, in which antimatter is used as a common energy source.

Antimatter powered reactor (Star Trek)

Negative Zone (Marvel Universe, comics)

Another interesting use is in the MU, also known as the Marvel Universe. This is the universe in which all stories about Marvel superheroes happen. Stories about Spider-Man, Iron Man, The Avengers, Thor, they all happen in this universe. Most people nowadays know these superheroes from the MCU, which is the part of the Universe the recent Disney movies were made about. Antimatter however, hasn't appeared in these movies yet, so what we are referring to here is antimatter that was shown in the comic books. In the Marvel Universe, there is a dimension called the "negative zone". This dimension first appeared in 1966, and is basically a parallel universe that is made out of antimatter. The negative zone is mostly used to get rid of difficult villains to beat.

Isaac Asimov, a famous American science-(fiction) writer, had robots with positronic brains created, and there are a lot of other cases in which antimatter was used in literature, like in the book "Angel and Demons" written by Dan Brown.

Once more, there are also some games which revolve around antimatter, the most famous of which is probably "Pokémon Diamond and Pearl: Word of God". Here, the legendary Pokémon Giratina is thought to be the living personification of antimatter itself.

In animation series antimatter is mentioned as well. For example, there is a Scooby-Doo episode in which an antimatter-powered car explodes. Then again, in one episode of "The Transformers", the main antagonist of the series Megatron steals an "antimatter formula".

In pop culture, antimatter is often depicted as an extremely rare and yet immeasurably powerful material, whilst in reality it's a lot more common 'substance'. We just need to find it.

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