Antimatter: The Mirror Universe

Introduction

At first there was nothing. Then, in a huge flash of pure energy, the universe was born. Exactly what happened next is unknown, but what is known is that matter and its counterpart, antimatter, were created in exact symmetry. For some reason, matter had an advantage over antimatter and became the dominant material in the universe. Everything, as far as we can see, is made of matter; the antimatter seems to have evaporated into nothingness somewhere in the last 14 billion years since the universe began. Since antimatter was discovered in the 1920s, the world of science fiction distorted the facts to use antimatter as a plot device. In the realm of science-fact, antimatter is an all-destroying substance that is largely misunderstood thanks to its role in science fiction. However, antimatter is a mysterious material whose secrets are only just now being understood.

The Story Behind Antimatter

$E = mc^2$. Einstein's famous equation for mass-to-energy equivalence and general relativity has been the hallmark of advanced physics ever since its conception in 1905. It has described many mysteries of the universe, from motion to the Big Bang. And in 1928, the famous equation helped physicist, Paul Dirac, uncover the mysterious mirror-universe of antimatter. Ironically, Dirac described antimatter with his equation without ever intending to. Instead, he wanted to create an equation that would describe electrons traveling at relativistic (close-to-light) speeds.

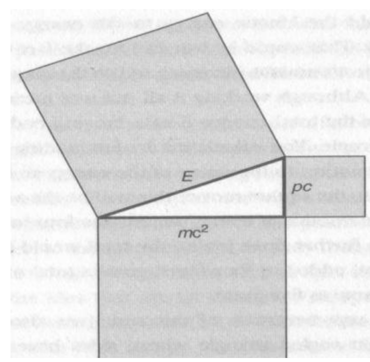

Figure 1. *Each side of the triangle represents Energy and its components.*

The equation $E = mc^2$ is a measure of the total energy stored within matter at rest, where mc^2 is the energy trapped within the mass. Simply put, mass is a condensed form of energy. However, the version of Einstein's equation that is universally known covers only half of the energy sources for an object. To describe the full energy, the term *pc* must be added to represent the energy from motion, kinetic energy. The equation becomes closely akin to the Pythagorean Theorem at this point (Figure 1), each term being in proportion to the square of a side in a right triangle (Close 29-30). With that in mind, the square root of both sides must be found to evaluate the total energy, *E*. However, the square root of the E^2 in the equation is ±*E*, seeming to suggest that there existed negative energy within matter. Dirac wanted to work around the -*E*, so he intended to rework the equation so it did not use squares but was still equal to $\pm E = \sqrt{mc^2 + pc}$. In order to do this, Dirac had to use two-dimensional numbers called matrices to describe the proportions of mc^2 to pc. The solution had earth-shattering implications: everything about the equation suggested a natural duality in the universe (Close 152-157).

With this newfound duality, Dirac proposed that the fundamental building blocks of atoms –protons, neutrons, and electrons –had opposites. This is where antimatter truly enters the story. Once its existence was confirmed using cloud chambers in 1932, the world's scientists subjected antimatter to intense research. Although vast amounts of knowledge about antimatter remain unknown, scientists have been able to describe its basic properties. Every particle, from familiar protons, neutrons, and electrons to strange "charm quarks" and muons, has an opposite anti-particle. Antiparticles seem to interact similarly to regular particles. Just as quarks bond together to form protons and neutrons, antiquarks create antiprotons and antineutrons, anti-atoms can be made identically to the way regular atoms are made, and so on. The key distinguishing characteristic between particles and their antiparticle doppelgangers is charge. Antimatter particles exhibit an opposite charge from their regular matter counterparts. Where electrons exhibit negative charge, positrons (anti-electrons) have positive charge. Aside from that, matter and antimatter are theorized to look outwardly identical; there is no telling between a regular-matter apple from an antimatter apple just by looking ("Antimatter").

One property of antimatter has piqued particular interest: annihilation. As described by Einstein in his energy equivalence equation, mass is condensed energy. Because of this, matter and antimatter can be spontaneously generated from bundles of energy called photons; however, gamma radiation is the only type of photon energetic enough to do this. Photons appear to be uncharged, but they actually have equal amounts of opposite charge. When photons turn into mass, the charge is split up so that one charge goes to matter and the opposite charge to antimatter. Just as pure energy can become material, material can become pure energy (Figure 2).

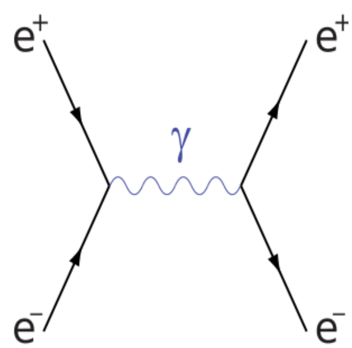

Figure 2. *Feynman Diagrams show matter and antimatter can become photons and back again. This one uses electrons* (e-) *and positrons* (e+).

When a particle and its antiparticle come into close proximity, their opposite electromagnetic forces attract each other. Once they are close enough, the two particles' "strong nuclear force" (the force that holds quarks together in protons and neutrons) causes them to orbit each other, all the while emitting high-energy gamma radiation. The instant that the particle and antiparticle unite, all the energy trapped inside the mass is released. The quarks and antiquarks combine to make mesons, which self-destruct the instant they are formed. All that remains is pure energy traveling outward from the point of annihilation at the speed of light. If the radiation from the annihilation is powerful enough, additional electrons and positrons can be formed. The entire process is over in less than one hundredth of a second (Close 77-79). The 100% mass-to-energy conversion of antimatter annihilation is of high interest to weapons developers; such releases of energy would have huge explosive power on larger scales.

The Antimatter Fact-ory

Antimatter is not in large supply in our corner of the universe. Nearly everything around us is either regular matter or energy, so antimatter must be, for the most part, fabricated. There are trace amounts of naturally occurring antimatter on Earth, but these miniscule particles are quickly annihilated by nearby matter. As mentioned before, mass is condensed energy. The energy produces a particle of matter and its corresponding antiparticle. Just what causes the gamma radiation to turn into mass is unknown, but it is theorized that its particle-like behavior in a vacuum plays a role. Besides that, it is still unknown *how* the gamma radiation turns into mass at all. Several theories have been suggested. An early one proposed by Paul Dirac, who solved the math behind antimatter, is dubbed the “Dirac Sea” (Landua).

The Dirac Sea plays off of the negative energy described in the equation $\pm E = \sqrt{mc^2 + pc}$. When negative energy was first conceptualized, it was deemed impossible to exist. If negative energy existed, then matter would constantly drop to a lower energy state; everything would be unstable and cease to exist. That is, unless all the negative energy states were already filled up with particles. No two particles can ever occupy the same energy state, so if all the negative energy states are filled, the remaining matter would have positive energy.

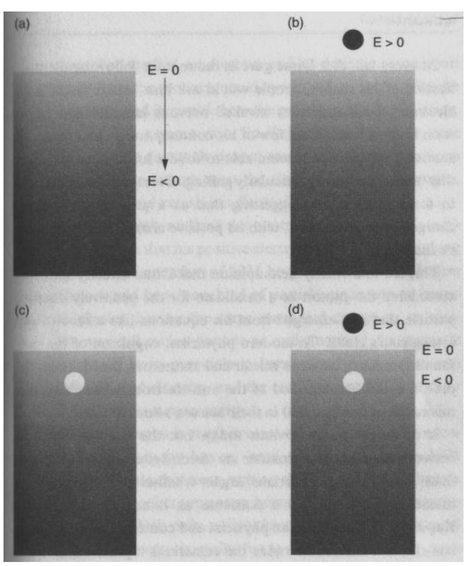

Figure 3. *Diagram of the Dirac Sea. The black circle is a +E electron. The white circle is a “hole” in the vacuum.*

That concept is the foundation for the Dirac Sea. Dirac uses the analog of an undetectable, infinitely deep “sea” of energy to describe a vacuum Below sea-level represents negative energy (Figure 3a), and above sea-level represents positive energy (Figure 3b). A ladder’s rungs represent the different possible energy states, called quanta, in positive and negative energy. All of the negative energy quanta are already filled by various particles, like electrons, which will be used for this example. When a gamma ray strikes one of these electrons, it is given positive energy and jumps above sea-level. When the electron jumps to positive energy, it leaves a "hole" in the negative energy that behaves as a particle. This hole appears as a positive energy and positive charge particle because of the absence of negative energy and charge (Figure 3c and 3d). The same concept applies to other particles like protons and neutrons. The Dirac Sea has never been proven; it is merely a theory that tries to make sense of the unknown (Close 41-48).

From what scientists can tell, positrons are the most common form of naturally occurring antimatter in our part of the universe. They are the smallest antimatter particles, so they take the least energy to produce. From what we can tell, most antimatter in the universe is produced in the huge stellar furnaces of stars, our Sun included. In a star's core, the immense heat and pressure can cause particles to fuse together. The most common type is when two protons smash together to form deuteron, a hydrogen atom with one proton and one neutron. When the two protons fuse together, one proton gets rid of its positive charge as a positron to become a neutron (Figure 4). This ensures that the deuteron is stable. The positron that is produced is quickly destroyed by electrons. About 10% of the sun's energy is caused by this positron-electron annihilation (Close 62). On a more earthly scale, positrons are produced in much the same way. In certain kinds of radioactive decay called "positron emission" or "beta plus", a proton sheds its positive charge to keep its atom stable. The atom's orbiting electrons promptly destroy the newly formed positron (Close 61-62).

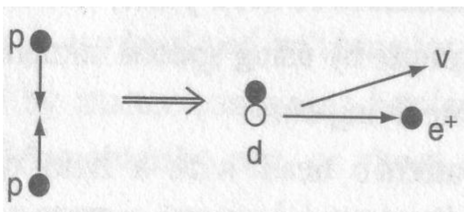

Figure 4. *Solar fusion causes a proton* (p) *to shed its charge as a positron* (e+) *to become a neutron. The* v *is a neutrino.*

One thing that troubles scientists is the apparent asymmetry of matter and antimatter in the universe. Gamma rays create matter and antimatter in the same amounts, so scientists wondered why everything in the universe seems to be made of matter. This dilemma takes us back to the Big Bang, when all the matter and antimatter were produced. Theoretically, the two should have been in perfect symmetry. If this were the case, then everything would have annihilated itself. However, scientists have proved that matter and antimatter are not perfectly symmetrical (Figure 5). A property called "Charge Parity Violation" shows that antimatter decays faster than regular matter, so from the beginning, matter had a slight advantage over antimatter and became the universe's dominant material (Roach).

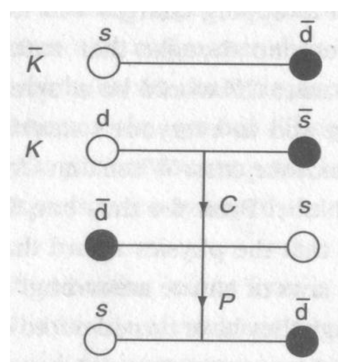

Figure 5. *Kaons* (K) *are less likely to decay into antikaons* (K with a line) *than antikaons into kaons.*

Because antimatter is not readily available on Earth for study, it has to be produced artificially. Today, most antimatter is made using particle accelerators at CERN in Switzerland. Before accelerators, antimatter was studied using devices called cloud chambers to observe its interaction with magnets. The invention of the "Bevatron" particle accelerator in 1955 revolutionized particle and antiparticle research, and since then, leaps and bounds have been gained in that field of study (Mondardini).

In CERN's modern accelerators, miles in diameter and deep underground, particles are smashed together at 99.9% of the speed of light to generate enough energy for antimatter production, usually antiprotons. The antiprotons produced are extremely energetic. If it weren't for powerful magnets, the antiprotons' high energy and repulsive electromagnetic forces would send them hurtling towards the accelerator's sides and annihilate. As the antiprotons are hurtled around the accelerator, clouds of electrons are used to absorb the antiprotons' energy. Only an antiparticle's counterpart particle can annihilate with it, so electrons pose no threat to antiprotons. When the antiprotons are "cooled" enough, they are sent to various chambers for study (Manglunki).

Antimatter's Practicality

As antimatter was first being studied, scientists discovered its basic properties. It is similar in all regards to matter except in its opposite charge. It is created, along with matter, from pure energy. And it can be likewise converted into pure energy when unified with matter. The latter has piqued particular interest. Matter-antimatter annihilation, known as "pair-annihilation" in physics jargon, generates a 100% conversion of mass into energy, easily making it the most efficient energy source in the universe. Steam engines and internal combustion, even fission and fusion, do not compare to the energy output of annihilation; much of the energy from those sources is lost as friction, heat, and leftover mass. If humans could harness the awe-inspiring power of antimatter, global energy problems would be a thing of the past, space travel would be far more efficient, and weapons would be revolutionized. If only.

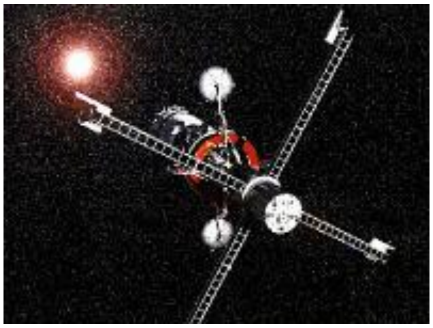

Figure 6. *Concept art of a possible NASA antimatter spacecraft.*

For Captain Kirk and the starship *Enterprise*, antimatter is the preferred fuel to "boldly go". Since October 2000, NASA has been exploring the possibilities of making its own antimatter powered ships to explore space (Figure 6). Pair annihilation of positrons and electrons would be used to generate the thrust. One half kilogram of antimatter can power all of the United Kingdom for three days. Pair annihilation is 10 billion times more efficient than the current liquid oxygen combustion in space shuttles and rockets. Only 1 millionth of a gram of positrons contains all the energy needed to make a 1 year round-trip to Mars. With enough positrons, that time can be slashed to 1 month. The antimatter production and storage are the major obstacles to creating an antimatter spaceship. Scientists already have the means to store antimatter in magnetic devices called Penning Traps, but not for the time or in the quantities needed for space travel. On average, CERN only produces one to two pictograms (trillionths of a gram) of antimatter every year. That's enough to power a 300 watt light bulb for three seconds. Producing a viable supply of antimatter fuel for space travel is simply not possible with our current technology (Bonsor).

While NASA hopes to someday explore the stars with antimatter, the United States Air Force is more concerned with antimatter's weapons potential. Since the height of the Cold War, the Air Force has funded research on antimatter and is now considering the possibility of antimatter weapons. These weapons would be the most powerful bombs created since the atomic and hydrogen bombs. By bomb standards, antimatter bombs would be "clean"; they emit no radioactive fallout, just high energy gamma rays. Calculations have shown that an antimatter bomb would be 10 billion times more explosive than current high explosives (Davidson). One millionth of a gram of antimatter has the explosive equivalence of 84 pounds of TNT. 50 millionths of a gram of antimatter equates to the explosive force of the 1995 Oklahoma City bomb, which was over 4,000 pounds of explosives. One gram of positrons annihilating with one gram of electrons would produce about the same amount of energy as 23 space shuttle fuel tanks firing at the same time. The energy output of pair annihilation is astounding. Antimatter bombs would easily become the most powerful weapon any nation has ever wielded, if it were possible to practically make them. Antimatter is the most valuable substance on the planet. The price tag for 100 billionths of a gram of positrons is about $6 billion. That, and the difficulty of storing antimatter for extended periods of time, means that any hopes the Air Force has of producing antimatter weapons are a long ways off (Davidson).

At the current time, dreams of antimatter spaceships and bombs are not coming true anytime soon. Humanity simply lacks the technology to develop viable antimatter tools. Most antimatter on Earth is found in the upper atmosphere, inside CERN's particle accelerators, and in hospitals. CERN uses antimatter to create a better understanding of the universe and its origins, whereas hospitals use antimatter to save lives. The antimatter produced in stars and particle accelerators contain extremely high amounts of energy. The radioactive decay, positron emission, usually produces relatively low energy positrons. In Positron Emission Tomography (PET), these low-energy positrons are used to monitor brain activity. To perform a PET, a radioactive isotope is used to create extremely small samples of positrons, which are injected into the patient. Once inside the body, these positrons annihilate with electrons. Images are generated based on the energy concentration of the annihilation and are used to monitor the patient's brain activity (Figure 7). PET is a relatively low-tech technique and simple concept compared to antimatter's other uses, but it is antimatter's only application practical for everyday use ("Antimatter Everyday").

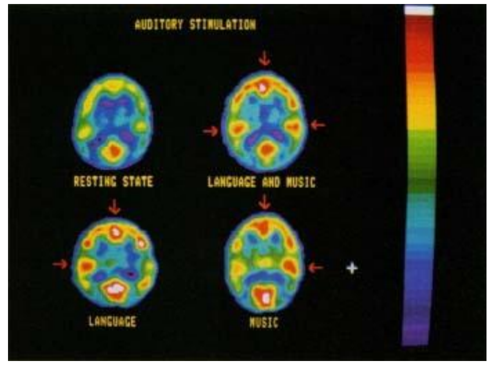

Figure 7. *PET scans of brain activity with different stimuli.* (i.e.: music)

Conclusion

Light and dark. Good and evil. Yin and Yang. Matter and antimatter. Our universe is founded on balance. Antimatter is testimony to that. Few things in this world have fascinated us with its power and mystery as much as antimatter. Humanity sought to discover the secrets of antimatter and to harness its potential. We have discovered a great deal, but still know little. One thing, however, remains certain: In a universe of mysteries, antimatter is the key to unlocking those mysteries.

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