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Review of Antimatter: A Mirror Image of Matter

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***Abstract*—** For years antimatter has been one of the most recognised and attractive words in science fictions but scientist' understanding of antimatter as a real and powerful energy force has vastly improved in recent years.The paper gives a review of the existence of antimatter in the Universe. Antimatter is mirror image of matter it extends the concept of the antiparticle to matter. This idea is so revolutionary that even its discoverer initially feared its consequences. If a particle and its antiparticle come into contact with each other, the two annihilate – they may be converted into other particles with equal energy in accordance with Einstein's equation $E = mc^2$. This gives rise to high-energy photons (Gamma rays) or other particle-antiparticle pairs. The antimatter if used in certain fields, could give rise to highly innovative possibilities in regards to those fields. But the production of antimatter and its storage still remains very expensive as well as challenging too.

Keywords- *Antimatter, Annihilation, Antihydrogen, Penning Trap*

I. INTRODUCTION

Particles and antiparticles go together. One cannot be made without making the other; that is they are complimentary of each other. Laws of physics predict that Antimatter and Matter were created in equal amounts in the Big Bang, however antimatter cannot be found today.

Antimatter, the opposite of matter was predicted by Paul Dirac a theoretical physicist, in 1928. Using equations to explain electron behaviour, Dirac noticed that there were two possible solutions, similar to the positive and negative solutions resulting from the quadratic formula. First he believed that the positive solution was the mathematical representation of the proton. However, after experimentation in 1932, Dirac and Carl Anderson, American physicist showed found that the predicted positive particle was not a proton, but it instead had the same mass as an electron. Hence, the particles predicted by Dirac are called antielectrons, or positrons. Positrons are the antimatter equivalent of the electron.[1]

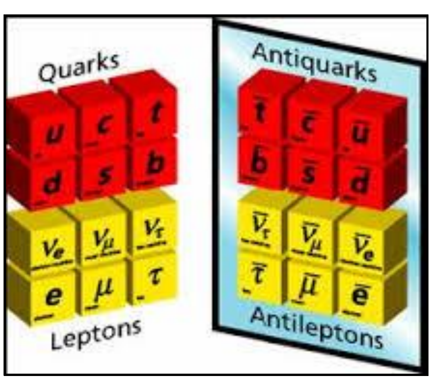

Figure 1. Quark and Lepton

The world is made of matter. The matter consists of three types of particles called electrons, protons and neutrons, each with a specific mass and electric charge. Though Antimatter particles have the same mass as the matter particles, they carry the opposite charge. The two most fundamental types of particles of matter are quarks and leptons. The quarks and leptons are divided into 6 flavors corresponding to three generations of matter.

A. Quarks

Most of the matter is made up of protons and neutrons which are composed of quarks, a type of matter particle. The antiquarks that makeup antiprotons carry opposite charges to the quarks that make up protons. There are six quarks, but physicists usually talk about them in terms of three pairs: up/down, charm/strange, and top/bottom. Also, for each of these quarks, there is a corresponding antiquark. Quarks have the unusual characteristic of having a fractional electric charge, unlike the proton and electron, which have integer charges of +1 and -1 respectively.

B. Leptons

Leptons are another type of matter particles .There are six leptons, three of which have electrical charge and three of which do not. They appear to be point-like particles without internal structure. The best known lepton is the electron (e-). The other two charged leptons are the muon(μ) and the tau(τ), which are charged like electrons but have a lot more mass. The other leptons are the three types of neutrinos (ν). They have no electrical charge, very little mass, and they are very hard to find. For each lepton there is a corresponding antimatter antilepton.

Quarks are sociable and only exist in composite particles with other quarks, whereas leptons are solitary particles. [2]

Collisions between particles and antiparticles lead to the annihilation of both, giving rise to variable proportions of intense photons (gamma rays), neutrinos, and less massive particle–antiparticle pairs. The total consequence of annihilation is a release of energy available for work, proportional to the total matter and antimatter mass, in accord with the mass–energy equivalence equation, E = mc2.[3] CERN scientists are exploring big mysteries such as if matter and antimatter were created in equal amounts during the Big Bang, and matter and antimatter annihilate, then

- Why is all this matter left-over to form our Universe?
- Where did all the antimatter go?

To unravel this mystery, scientists at plan do gravitational and spectroscopic experiments with antimatter. The simplest example is antihydrogen.

In particle physics, antimatter is a material composed of antiparticles, which have the same mass as particles of ordinary matter but opposite charges, as well as other particle properties such as lepton and baryon numbers and quantum spin.

Antiparticles bind with each other to form antimatter, just as ordinary particles bind to form normal matter. For example, a positron (the antiparticle of the electron) and an antiproton (the antiparticle of the proton) can form an antihydrogen atom. Physical principles indicate that complex antimatter atomic nuclei are possible, as well as anti-atoms corresponding to the known chemical elements. Studies of cosmic rays have identified both positrons and antiprotons, presumably produced by collisions between particles of ordinary matter.

Small amounts of antimatter constantly rain down on the Earth in the form of cosmic rays, energetic particles from space. These antimatter particles reach our atmosphere at a rate ranging from less than one per square meter to more than 100 per square meter. Scientists have also seen evidence of antimatter production above thunderstorms.

But other antimatter sources are even closer to home. For example, bananas produce antimatter, releasing one positron—the antimatter equivalent of an electron—about every 75 minutes. This occurs because bananas contain a small amount of potassium-40, a naturally occurring isotope of potassium. As potassium-40 decays, it occasionally spits out a positron in the process.

Our bodies also contain potassium-40, which means positrons are being emitted from you, too. Antimatter annihilates immediately on contact with matter, so these antimatter particles are very short-lived.

The body of a person weighing 80 kg emits 180 positrons per hour. This comes from the decay of potassium-40, a naturally occurring isotope that is ingested by drinking water, eating food and breathing.[4],[5]

II. PRODUCTION OF ANTIMATTER

Attempts have been made to create antimatter artificially with limited success. Humans have created only a tiny amount of antimatter.

The first form of antimatter observed in nature was the positron. The observation was made possible because of the many natural processes which produce these particles, thus increasing the chance of observing them. To observe other antimatter particles which are not so frequently produced in nature such as the antiproton or antineutron, scientists built large, specialized machines that aimed to produce and detect these particles.

However, creating antimatter is not easy as it requires large quantity of energy. According to Albert Einstein's famous formula $E = mc^2$, mass is nothing by energy in a very condensed form. This means that matter can be transformed into energy and energy can be transformed into matter. The process can be observed in nature regularly, for instance, in the combustion of stars. In the sun, 600 million tons of hydrogen turns every second into 595 million tons of helium and 5 million tons of energy.

The technique used to produce antimatter entails accelerating particles smaller than the atom to high speeds and smashing them against a metal block or against one another. Some of the energy released in the crash transforms into matter and antimatter. However in order to achieve this effect, the subatomic particles (normally protons) have to move at speeds infinitesimally close to the speed of light which is achieved in the so-called Particle Accelerators, enormous devices that accelerate particles to high speeds by means of electric fields.

The first production of antiprotons was accomplished in 1955 by bombarding a copper shield with high energy protons in the particle accelerator, Bevatron. It was a ring capable of accelerating protons to an energy of 6.2 GeV.. In 1956, a third antiparticle, the antineutron was discovered.

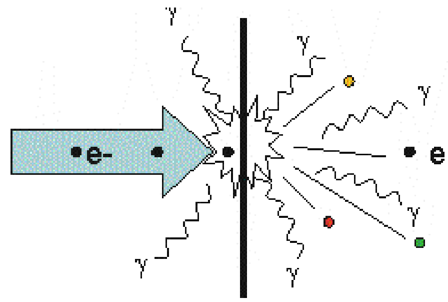

Figure 2: Impact of electrons (e-)on the metal and production of antiparticles (e+) and gamma rays (g)

Once the existence of these three antiparticles (antielectron, antiproton and antineutron) had been proven, the efforts shifted to the production of the first antimatter atomic nuclei leading to the observation of the antideuteron In 1965. It was the nucleus of the atom of antideuterium which contained an antiproton and an antineutron.

The goal shifted to the production of whole atoms of antimatter, instead of just nuclei. For this purpose the hydrogen atom was chosen, because besides it being the simplest element (with just one electron and one proton in its structure) , Hydrogen is also one of the best studied elements, and constitutes three-fourths of the universe.

30 years later, in 1995, the first antihydrogen atoms were produced at CERN with the help of Low Energy Antiproton Ring (LEAR). This device decelerated the antiprotons produced in the particle accelerator and stored them in a ring for further studies and also to combine them with positrons to produce stable atoms .A year later the a laboratory Fermilab announced similar production of antihydrogen atoms as well.

In after the production of the first nuclei, a team of researchers from Germany and Italy finally announced the production of the first production of Antihydrogen atom. It was experiment PS210 and it was carried out at CERN. The experiment was possible bcause of a new machine: the Low Energy Antiproton Ring (LEAR). This device decelerated the antiprotons produced in the particle accelerator and stored them in a ring, so that scientists could study them at their leisure and, for instance, combine them with positrons to produce stable atoms. A year later the laboratory Fermilab announced similar production of antihydrogen atoms as well. [6]

But these experiments allowed neither direct investigation of the characteristics of antimatter, nor direct comparison with conventional matter. This was because a) Only a few atoms of antihydrogen had been produced. B) These atoms travelled at a speed close to the speed of light, thus too fast to analyze their properties c) The atoms annihilated near instantly and disappeared.

So now the focus shifted to the production and storage of large quantities of "cold" hydrogen In order to conduct future detailed studies of the anti-atoms.

Today, with current technology, the particle accelerators at CERN can produce bunches of about 50 million antiprotons every minute. These antiprotons are slowed down (cooled) in an Antiproton Decelerator (AD), which is capable of reducing the temperature of the antiprotons from billions of degrees to temperatures usable to perform experiments. These bunches of cold antiprotons allow for the creation of thousands of atoms of antihydrogen.

Producing antihydrogen requires, together with the antiprotons provided by CERN, the participation of positrons (positively charged electrons). the Positrons in the ALPHA experiment are produced from the special radioactive sodium. These particles which possess electric charge are then easily trapped and stored using magnetic and electric fields and later combined with antiprotons to form anti hydrogen. [7]

III. STORAGE OF ANTIMATTER

For years, ATHENA project of CERN had been able to create antihydrogen by mixing together positrons and antiprotons. Since hydrogen is electrically neutral, the electronic trap is unable to contain newly formed atoms which quickly drift away to be annihilated. Also they had a very high velocity making trapping them impossible. Now the successor to ATHENA, the ALPHA (Antihydrogen Laser PHysics Apparatus) project has made capturing antihydrogen a reality by the development of a new method of very gently driving the antiprotons into the positrons using a frequency sweep technique. . This proved to be vital element which provided enough very low energy antihydrogen atom which were easy to be trapped. There they are nudged together by an oscillating electric field to form low energy antihydrogen. Though antihydrogen is electrically neutral it does posses a magnetic moment, so the key of trapping them was to use the new ALPHA trap built using state of art superconducting materials to create magnetic field.

Ideally, these traps are so effective that particles can be stored for months, without even encountering matter. The world record of storing antiparticles is held by the TRAP experiment at CERN where a single antiproton was kept in a Penning trap for 57 days.

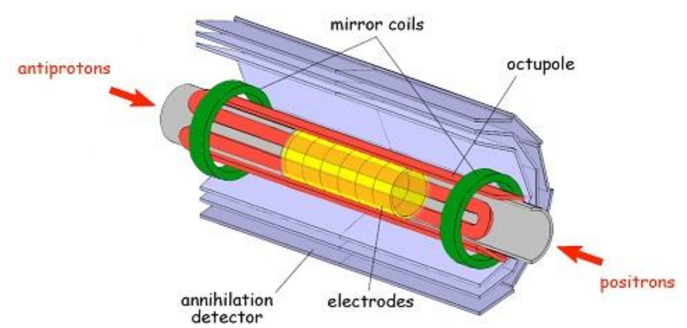

Figure 3.Penning Trap

Antiprotons and positrons are brought into the ALPHA trap from opposite ends and held there by electric and magnetic fields. Brought together, they form anti-atoms neutral in charge but with a magnetic moment. If their energy is low enough they can be held by the octupole and mirror fields of the Minimum Magnetic Field Trap.

Here the positron and antiprotons are cooled by means of electric and magnetic fields and held in separate sections in a near perfect vaccum that keeps them away from regular matter of what researchers are calling a minimum magnetic field trap.

Currently the only way to know whether antimatter was actually trapped is to let it annihilate with regular matter. When the magnets are switched off, the antihydrogen atoms escape their trap and quickly annihilate with the sides of the trap. Silicon detectors pick up the energetic flare to pinpoint the antiatom’s position. Only then can the physicists be sure that they had trapped antihydrogen.

In June 2011, ALPHA reported that it had succeeded in trapping antimatter atoms for over 16 minutes. On the scale of atomic lifetimes, this was a very long time — long enough to begin to study their properties in detail. By precise comparisons of hydrogen and antihydrogen, several experimental groups hope to study the properties of antihydrogen and see if it has the same spectral lines as hydrogen. One group, AEGIS, will even attempt to measure, the gravitational acceleration constant, as experienced by antihydrogen atoms.

The longer these experiments can trap antihydrogren, the more accurately they can measure it, and physicist will be closer to demystifying antimatter.

Also scientists are working on ideas to use magnetic bottles (with in homogeneous magnetic field acting on the magnetic moment), or optical traps (using LASER) but these are still under development.[8],[9]

IV. THE COST OF ANTIMATTER

About one billion times more energy is required to make antimatter then is finally contained in its mass thus lowering the efficiency of the production of the antimatter and its storage. Using E = mc2, we find that 1 gram of antimatter contains:

0.001 kg x (300,000,000 m/s)2 = 90,000 GJ = 25 million kWh

Thus, taking into account the low production efficiency, nearly 25 million billion kWh will be required to produce just one single gram. Hence, the cost of production even at a discount price for electric power, will be in the range of a million billion Euros.

Antimatter annihilates with ordinary matter producing photons and other particles like mesons which in turn decay into more photons, electrons. These secondary particles will be absorbed by surrounding matter resulting in the heating of the absorbing material. Thus, in principle even if one could use a beam of antimatter to heat up water to make steam and run a turbine to generate electricity. From an economic point, it would not be viable as the cost of generating the antimatter exceeds the payback by many orders magnitude. [6]

V. APPLICATIONS OF ANTIMATTER

If a reliable supply of antimatter is made available, then its field of uses will be unlimited such as in the area of biomedical radioisotopes generation which could be used in PET (Positron Emission Tomography) helps to detect various form of cancer, maps activity in the brain and helps to understand diseases such as Alzheimer. It can be used for advanced propulsion systems which will play a vital role in deep space missions. An antimatter plasma gun can be used for igniting nuclear fusion reactions. [3]

CONCLUSION

Antimatter, the mirror image of matter looks very promising as it has wide range of applications. Hence Scientists would like to perform many experiments on antimatter, from studying its properties with spectroscopic measurements to testing how it interacts with gravity. But to perform these experiments, they first need some antimatter.

It has been investigated from various papers and journals that various researchers have worked for years to get antimatter. They have reported numerous techniques for production and storage of antimatter . However, they have produced only a minuscule amount of antimatter.All of the antiprotons created at Fermilab's Tevatron particle accelerator add up to only 15 nanograms. Those made At DESY in Germany, approximately 2 nanograms.At CERN less than 10 nanogram of positrons have been produced to date.

This paper reports that earlier the antimatter, whose existence was only theoretically, has been proved to exist on a practical basis. Though there are many significant characteristics have come to light, the production and storage of antimatter, still remains challenging and expensive overture. But if these two hindrances are overcome, the possibility of use of antimatter in various fields would be revolutionary and thus concluded the main feature to be concentrated on is to make possible, the production of significant amount of antimatter economically.

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