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Antimatter as an Energy Source

Ansh Mehta

Abstract
This paper provides a critical evaluation of the use of antimatter as an energy source. Antiprotons and positrons are constantly generated in space, upper levels of the atmosphere and often created artificially by humans on Earth. In this paper the creation, storage, and uses of antimatter are analyzed. It then aims to evaluate the feasibility of using the energy from a matter – antimatter annihilation. More specifically, it looks at whether a cost-efficient machine/reactor or method can be created to use the energy from the above-mentioned phenomenon. Then some drawbacks and future prospects are also discussed.

Keywords: *Antimatter, antimatter annihilation, antimatter production, Penning's trap, antimatter power generation, Gerald Jackson.*

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I. INTRODUCTION

Antimatter is material composed of antiparticles, particles with similar properties, but opposite charge. It is theorized that every particle has an antimatter companion that is almost identical to itself, but with the opposite charge. For example, a proton has a positive charge. But its antiparticle called an antiproton has the same mass but a negative charge. There is no intrinsic difference between particles and antiparticles and the laws of physics are the same for both. But when a particle and its antiparticle meet, they annihilate each other releasing energy in the form of photons and gamma rays along with other antimatter. This occurs due to the laws of conservation in physics. Since you can't discharge an elementary particle and the net charge on this system is 0, the only solution is to make these elementary particles "vanish". Similarly, many properties of the system will be 0 as the values for the electron and positron will cancel out. The only possible solution is that the two particles should annihilate each other and release an equivalent amount of energy according to the equation e=mc^2. The energy released from a proton antiproton annihilation (1.8 x 10^14 J per gram of reactants) is 10^10 times greater than that from an oxygen hydrogen combustion and 100 times greater than that from fission or fusion. This reaction has the highest energy density which is why there is the possibility that it can be an excellent energy source. This source if utilized can be converted to power anything and its applications are infinite. Energy generation and space travel would see the greatest uplift.

1.1 Methods

The search included a review of the current methods of producing and storing antimatter. Along with this, there is also a detailed analysis of devices and methods in the making or already in use which can help utilize the annihilation energy. This research also assessed the challenges and future opportunities for further development of the technology in this field. A Google, google scholar and PubMed search for relevant articles was done using the keywords mentioned above. Sample research papers were also used for references which were all cited below. Online resources were tapped to learn more about antimatter, its storage and future possibilities in the field.

II. DISCUSSION

1.2.1 Antimatter

Antimatter was one of the most enigmatic physics discoveries of all time. After being theorized, many people thought it was more of a science fiction idea and not a true phenomenon- unaware that it actually exists. In 1928, British physicist Paul Dirac formulated an equation that combined quantum theory and special relativity to describe the behavior of an electron moving at a relativistic speed. The equation which won Dirac the Nobel Prize in 1933 was peculiar. Just as the equation x^2 = 100 has two possible solutions (x = 10 or x = −10), Dirac's equation also had two solutions. One was for an electron with a positive charge and one for an electron with negative charge. This dual solution led Dirac to believe that for every particle there exists a corresponding antiparticle, exactly matching the particle but with opposite charge. Proof of the existence of antimatter was found experimentally on 2 August 1930. During an experiment Carl Anderson observed a particle with the same mass as an electron but the particle bent the "wrong" direction in a magnetic field. This

was due to the fact that its polarity was the opposite of that of an electron so it would bend the other or "wrong" way in a field. Anderson called the particle a "positron".

As mentioned before, antimatter and matter are basically identical with opposite electric charges. They have similar characteristics and the laws in physics also hold for them and it is these laws which cause them to annihilate matter on contact with it. This reaction is the most energy dense reaction known to mankind. Due to this annihilation, there is also a lack of anti-matter around us. This is also called the matter-antimatter asymmetry. Our understanding of the early universe tells us that after the big bang, equal amounts of matter and antimatter were produced. But today we see a vast imbalance in matter and antimatter levels. Why is it so? A popular theory is that originally, the universe was extremely hot and dense which would have propagated the natural creation of anti-matter. But as it expanded the temperature cooled down, which caused the rate of production of antimatter to reduce. This would start a butterfly effect and what started as a miniscule difference would have resulted in the world of matter we know today.

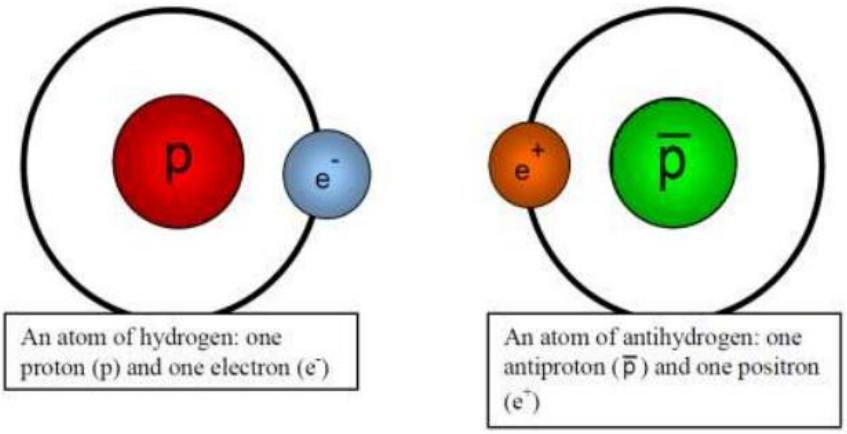

Figure1: Structure of hydrogen and antihydrogen

1.2.2 Natural production of Antimatter

There are a few natural sources of antimatter but none are viable. Antimatter is produced wherever there are high-energy particle collisions taking place. If a collision meets the energy requirement, antimatter is created. In a way, this is the backwards reaction of a matter antimatter annihilation. Cosmic rays impacting Earth's atmosphere produce antimatter in the upper levels but it gets annihilated almost immediately. Antiparticles are also produced naturally in β decay of naturally occurring radioactive isotopes like potassium – 40 which is found in abundance in bananas. Due to this, a banana gives out an antiparticle, approximately, every 75 minutes. But once again, the antimatter will annihilate immediately and in this case the amount created is also insubstantial.

Antimatter is also created during thunderstorms. The strong electric fields of thunderstorms push electrons upwards at nearly the speed of light. When these electrons impact atoms, gamma rays are emitted and when those gamma rays, in turn, impact other atoms a positron and an electron are released. This process repeats multiple times to create gamma rays and antimatter during thunderstorms.

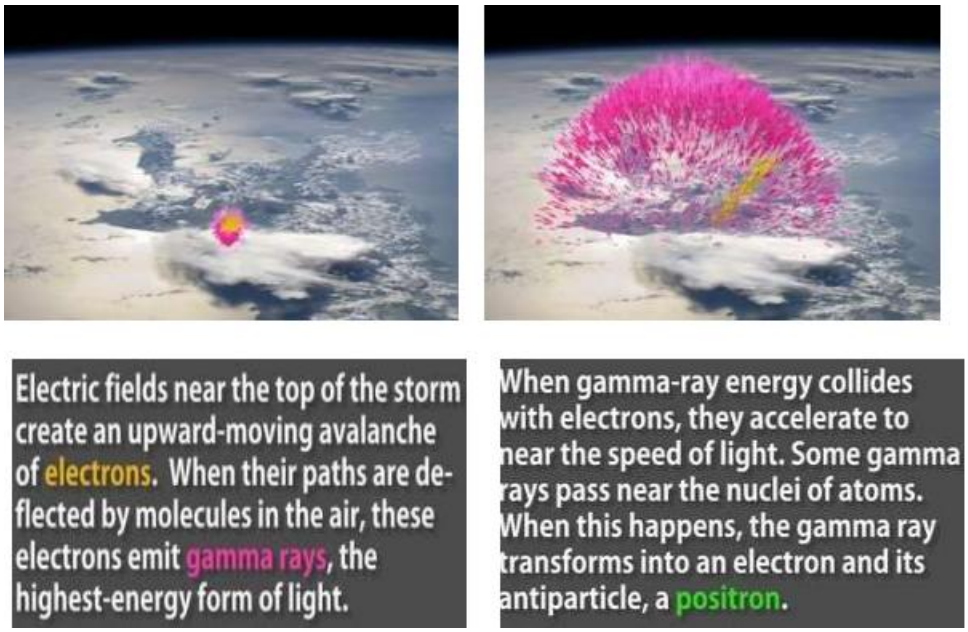

Figure 2: Production of antimatter during thunderstorms

1.2.3 Artificial production of Antimatter

The "trend" of particle accelerators in physics was started as a means to an end. It began as a way to confirm the existence of antiproton. The principle behind this is that when elementary particles collide head-on at almost the speed of light, matter is formed. This is as a fraction of the energy due to the speed of the accelerated particles gets converted into matter during the collision according to the equation e=mc^2. When matter is produced from energy, equal amounts of particles and antiparticles are created. In 1954, the Nobel Prize-winning physicist Earnest Lawrence built the Bevatron. It was a massive particle accelerator that could collide together two protons at a high enough speed that the energy produced was enough for matter production. As new matter is being created from energy, matter and antimatter are produced in equal amounts. A magnetic field can then be used to direct the negatively charged anti-proton away.

Then in the early 1990s, scientists at CERN managed to create antihydrogen. This was done by accelerating antiprotons at relativistic speeds alongside regular atoms. When passing close to the nucleus of the atom, the energy would be sufficient to force the creation of an electron-antielectron pair. Then that antielectron would attract the passing antiproton, creating a single atom of antihydrogen. 5 years later, CERN confirmed that it had successfully created nine antihydrogen atoms. Soon after that, they were given competition by competitors Fermilab who created 100 atoms of antihydrogen. The only issue was that the creation happened at very high speeds and temperatures so this made it hard to study and observe properties. This problem led to the birth of the Antiproton decelerator. It produces low-energy antiprotons for creation and studies of antimatter. A proton beam is fired into a block of metal. The proton-atom collisions create elementary particles, including lots of antiprotons. Now comes the important job of the Antiproton Decelerator, it uses 3 very strong electromagnets to create the path, direct and slow down the antiprotons. Once they reach 10% of the speed of light, they are sent to one of the many Antiproton decelerator experiments where antimatter is produced at low energy and studied.
In January 2014, scientists at CERN created a beam of antihydrogen containing 80 antimatter atoms. This was a big step in helping us understand the enigma that is the antimatter. With each passing year the cost of production decreases while the rate of production increases. Novel findings and improvements in the production of antimatter are quite frequent. Because of this, the number of atoms of antimatter being studied are increasing exponentially. Current projects at CERN are AEGIS (Antihydrogen Experiments: Gravity, Interferometry, Spectroscopy), ALPHA (Antihydrogen Laser Physics Apparatus) and more which all use the Antiproton decelerator.

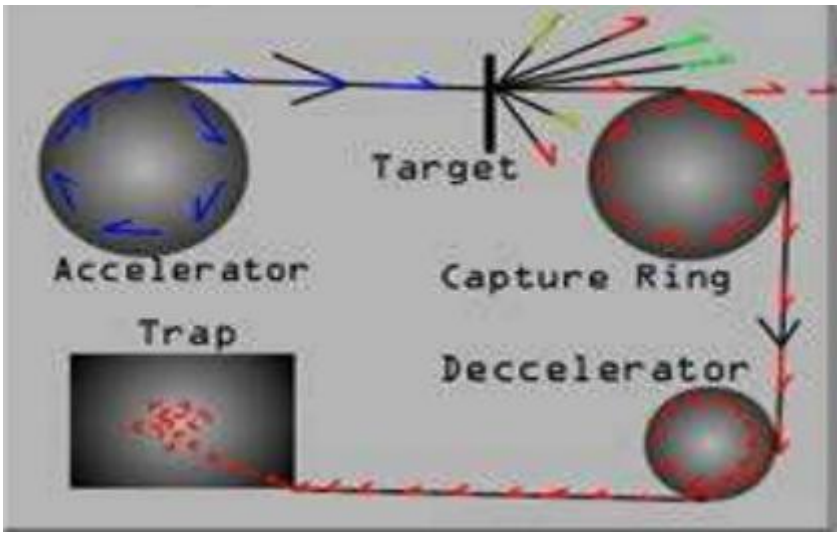

Figure 3: Production then storage of antimatter

1.2.4 Storage of Antimatter

Since antimatter annihilates on contact with matter, it can't be stored like any other substance. It has to be stored in such a way that it is in contact with no matter. This is done by using the property of spin magnetic moment which antimatter has. By using magnetic and electric fields, a force is applied on the antimatter which directs it away from any matter. We have to ionize the antimatter into gas and then store it in a magnetic bottle which doesn't allow the antimatter to impact the sides of the container.

Another apparatus used to store antimatter is the Penning's trap which uses the same principle of using magnetic and electric fields to direct the antimatter. These are like miniaturized accelerators inside which, particles move around as the magnetic and electric fields keep them from colliding with the walls of the container.

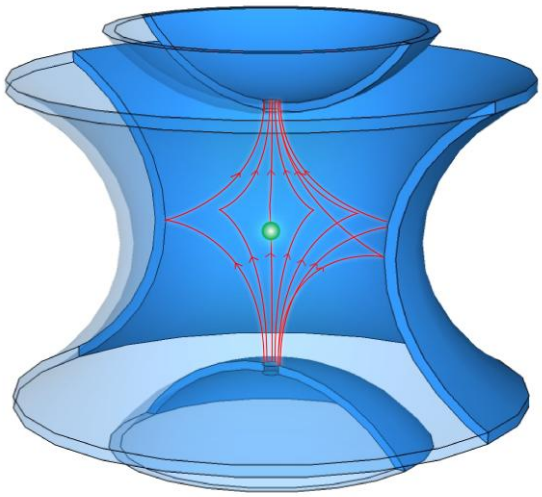

Figure 4: Penning trap

1.2.5 Antimatter Generator

The principle behind using antimatter as an energy source is that the photons and gamma rays released must be converted into electricity or any other usable form of energy. Scientist Alberto Molina Martinez came up with an antimatter generator which he analyzed in detail in his paper. His generator first produces antimatter in a specially designed self-reflective chamber, then separates the electrons and positrons by the action of powerful rotational electromagnetic fields and, finally, converts them into electrical power.

It has also been proposed to use the principle of geothermal electricity to convert the antimatter annihilation energy into electricity. By using the energy to heat a fluid we can create a fluid similar to the geothermal fluid. Then we can utilize the thermal energy of the fluid in one of the many ways it is done in geothermal power generation. For example, the fluid will be heated to its boiling point and then the steam produced will travel directly to a turbine, which drives a generator that produces electricity. Another method for the same is on the basis of Binary cycle geothermal power plants. The heated fluid (Should be below 400°F or 204.44° C) is passed through a heat exchanger with a secondary fluid with a much lower boiling point that water. Heat from the geothermal fluid causes the secondary fluid to convert into vapor, which then rotates the turbines and generates electricity.

Another method which I can think of is by using the photoelectric effect. The result of the matter antimatter annihilation is a burst of photons and gamma rays. The key would be to somehow control the flow of these in some way that they can be directed towards a metal. That metal would then give out electrons based on the amount of energy that hits its surface. Currently, no such method exists that can effectively change the path of photons and gamma rays while creating a steady flow. But in the future if such a method comes up it can be used to create a steady flow of electricity.

1.2.6 Other Applications and future possibilities

One popular idea, that brought a lot of attention to antimatter, is its use as rocket fuel. Because of the astronomically high energy density of a matter antimatter annihilation, it has all the characteristics to be an excellent rocket fuel. The blast would propel the rocket faster than any other fuel source and estimates say that 10 grams of antimatter can enable us to reach Mars in one month. Proposed designs either directly use the annihilation products or use the heat and radiation produced to indirectly power the rocket. However, antimatter reactions produce high energy gamma rays which damage matter and break apart molecules in cells. This makes them extremely dangerous and prolonged contact with gamma rays can prove to be fatal. The NASA Institute for Advanced Concepts (NIAC) is working on a new design for an antimatter-powered spaceship that avoids this ill-effect by producing gamma rays with much lower energy. Currently, Fermilab is able to produce 2 nanograms of antimatter per year, but a new NASA NIAC plan by Gerald Jackson could increase this to a staggering 20 grams per year with a $670 million per year cost. This is a 10 billion times increase and would be a monumental feat. This also provides a possible solution for long-term antimatter storage. He thinks his novel method can get rocket propulsion up to 10% of light speed. Jackson's ideas, if true, will revolutionize all of science and will enable us to

1.2.7 Drawbacks

Gerald Jackson's ideas are only theoretical as of now and the main issue with antimatter is that it has to be artificially created as when its naturally created it gets annihilated instantly. This process is very time energy and resource consuming. In 1999, NASA gave a cost estimate of $62.5 trillion per gram of antihydrogen (equivalent to, approximately, $96 trillion today). So even though a matter-antimatter annihilation is the most energy dense reaction it is also one of the most inefficient. You get only a tenth of a billion (10-10) of the invested energy back.

Along with this, there is the costly storage of antimatter also. Antimatter particles such as positrons and antiprotons can't be held in regular containers as they annihilate on contact with matter. They are stored in devices called Penning traps and magnetic bottles. These aren't suitable for long term storage and even if they were they would be extremely costly, energy and money wise. Due to this limitation, antihydrogen has only been stored on earth for a maximum of 16 minutes. Another problem is the extraction of useful energy or momentum from the products of antimatter annihilation. Gamma rays and photons which are forms of extremely energetic radiation are difficult to convert into usable electricity or energy. Most of the mechanisms proposed to date haven't been tested thoroughly. Over this, gamma rays can also be extremely harmful for the body as they damage mater they contact. Finally, the stakes with antimatter energy generation would be much higher. Any leakage would be devastating with it annihilating some matter and then releasing a blast of photons, gamma rays, etc.

III. CONCLUSION

Presently, there is no energy efficient method for using antimatter as an energy source. Until we discover a ready source of antimatter on our planet or devise a method which significantly boosts antimatter production, antimatter isn't a viable energy source. Process of experimentation along these lines will be very costly but will pay for itself if an effective method is found. The energy produced can be converted into any form and will gave world changing implications in every field. This is a novel part of physics and there is much more to find about antimatter. Much like the advancements in clean energy, autonomous cars and space technology – the future will be here. According to experts, it will be here sooner than you think, it will take the

next few decades to make antimatter a feasible fuel. With innovative thinkers like Gerald Jackson, this could be even less, but until that day it remains to be an infeasible energy source.

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