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Antimatter Rockets

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Abstract

The superior energy density of antimatter annihilation has often been pointed to as the ultimate source of energy for propulsion. In our day to day life cost of fuel is being improved. So for launching satellite we need to spend more money for that, to avoid that we just planned to introduce advanced antimatter propulsion rockets. In propulsion power which is created using collision between electron & positron is used. It is a type of ion propulsion rocket. The important factor is availability of fuel, to avoid that we can use this type of rockets. Power produced by this propulsion is very higher than that the any other type of propulsion. In this paper Production and trapping of antiprotons for space propulsion applications are reviewed. Present and fore-seeable production rates at Fermi lab are discussed, and experiments on trapping, confinement and transport of large quantities of antiprotons, as well as synthesis of atomic anti-hydrogen, are outlined. Unfortunately, the limited capacity and very low efficiency of present-day antiproton production meth-ods suggest that antimatter may be too costly to consider for near-term propulsion applications.

Index terms: Antimatter, Antimatter Propulsion, Antimatter Annihilation, AIMSTAR Rocket, Antimatter Power Generation

1 INTRODUCTION

An antimatter rocket is a proposed class of rockets that uses antimatter as their power source. There are several designs that attempt to accomplish this goal. The advantage to this class of rocket is that a large fraction of the rest mass of a matter/antimatter mixture may be converted to energy, allowing antimatter rockets to have a far higher energy density and specific impulse than any other proposed class of rocket.

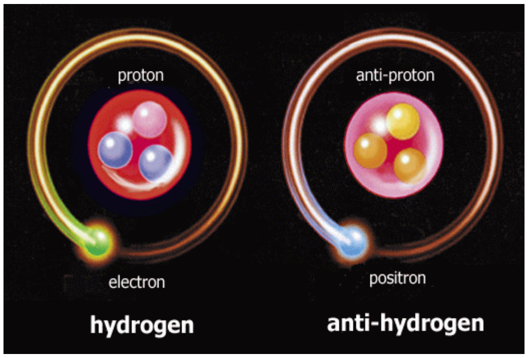
The annihilation of subatomic particles with their antimatter counterparts has the highest energy per unit mass of any reaction known in physics. The energy released from proton antiproton annihilation (4.3 x 1013 cal per gram of antiprotons) is 1010 times greater than oxygen hydrogen combustion and 100 times more energetic than fission or fusion. That is, one gram of anti hydrogen (i.e., a "mirror" atom composed of an

Antiproton and positron (anti electron)) reacted with the same amount of normal hydrogen produces a total energy equivalent to that delivered by 23 Shuttle External Tanks (ET).

Ever since 1953 when Eugene Sanger first proposed use of electron-positron annihilation to produce thrust, there have been many serious and not-so-serious attempts to identify ways of exploiting antimatter for propulsion. Practically all of these concepts involve applying the products from proton-antiproton annihilation either to create thrust directly or to energize a propellant through inter particle collisions or heating of an intermediate solid core. In addition, the scientific community, which until several decades ago had exhibited only casual curiosity about the subject, is now devoting more attention and resources to uses of antimatter. The best examples of this are the accelerators at Fermi National Accelerator Laboratory (FNAL) and The European Laboratory for Particle Physics (CERN), which routinely produce antiprotons to extend the energy range of particle collision experiments. Although the worldwide production capacity has been growing at a nearly geometric rate since the discovery of the antiproton in 1955, the current output rate of 1 to 10 nanograms(ng) per year is minuscule compared to that of other exotic materials. For this reason, some people have questioned the practicality of using antimatter for propulsion, at least within the next century or so

2. Antimatter

In particle physics, antimatter is material composed of antiparticles, which have the same mass as particles of ordinary matter but have opposite charge and quantum spin. Antiparticles bind with each other to form antimatter in the same way that normal particles bind to form normal matter. For example, a positron (the antiparticle of the electron, with symbol e+) and an antiproton (symbol p) can form an anti hydrogen atom. Furthermore, mixing matter and antimatter can lead to the annihilation of both, in the same way that mixing antiparticles and particles does, thus giving rise to high-energy photons (gamma rays) or other particle–antiparticle pairs. The result of antimatter meeting matter is an explosion.



There is no intrinsic difference between particles and antiparticles; they appear on essentially the same footing in all particle theories. This means that the laws of physics for antiparticles are almost identical to those for particles; any difference is a tiny effect. But there certainly is a dramatic difference in the numbers of these objects we find in the world around us; the entire world is made of matter. Any antimatter we produce in the laboratory soon disappears because it meets up with matching matter particles and annihilates.

The mass of any antiparticle is identical to that of the particle. All the rest of its properties are also closely related but with the signs of all charges reversed. For example, a proton has a positive electric charge, but an antiproton has a negative electric charge. The existence of antimatter partners for all matter particles is now a well-verified phenomenon, with both partners for hundreds of such pairings observed.
Any pair of matching particle and antiparticle can be produced anytime if there is sufficient energy available to provide the necessary mass-energy. Similarly, anytime a particle meets its matching antiparticle, the two can annihilate each another that is, they both disappear, leaving their energy transformed into some other form.

3. Antimatter Production

3.1Natural Production:

Antimatters are produced everywhere in the Universe where high-energy particle collisions take place. High-energy cosmic rays impacting Earth's atmosphere produce antimatter in the resulting particle, which is immediately destroyed by contact with nearby matter. Antimatters are produced in the centre of the Milky Way Galaxy and other galaxies, where very energetic celestial events occur. Antimatters are also produced in any environment with a sufficiently high temperature (Particle energy should be greater than the pair production threshold). During Big Bang, when the Universe was extremely hot and dense, matter and antimatter were created equally.

Positrons are produced naturally in β^+ decays of naturally occurring radioactive isotopes (for example, potassium-40) and in interactions of gamma quanta (emitted by radioactive nuclei) with matter. Antineutrinos are another kind of antiparticle created by natural radioactivity (β^- decay). Many different kinds of antiparticles are also produced by (and contained in) cosmic rays. Recent (as of January 2011) research by the American Astronomical Society has discovered antimatter (positrons) originating above thunderstorm clouds; positrons are produced in gamma-ray flashes created by electrons accelerated by strong electric fields in the clouds. Antiprotons have also been found to exist in the Van Allen Belts around the Earth by the PAMELA module.

High-energy galactic cosmic rays (GCR) continually bombard the upper atmosphere of the planets in our Solar System, as well as interacting with material in the interstellar medium. The result is 'pair production,' the creation of an elementary particle and its antiparticle. The kinetic energy of the GCR particle is converted into mass when it collides with another particle.

About a kilogram of antiprotons enters our Solar System every second, but only a few grams reach the vicinity of the Earth in a year. That would seem to make collecting naturally produced antimatter impossible save for one thing. Planets with strong magnetic fields create properties in nearby space that can create much larger fluxes as the particles interact with both the magnetic field and the atmosphere.

3.2Artificial Production:

An atom of antihydrogen is composed of a negatively-charged antiproton being orbited by a positively-charged positron. An antiproton, travelling at relativistic speeds and passing close to the nucleus of an atom, would have the potential to force the creation of an electron-positron pair. It was postulated that under this scenario the antiproton would have a small chance of pairing with the positron (ejecting the electron) to form an antihydrogen atom.

In 1995 CERN announced that it had successfully created nine antihydrogen atoms by implementing the SLAC/Fermilab concept during the PS210 experiment. The experiment was performed using the Low Energy Antiproton Ring (LEAR), and was led by Walter Oelert and Mario Macri. Fermilab soon confirmed the CERN findings by producing approximately 100 antihydrogen atoms at their facilities.
The antihydrogen atoms created during PS210, and subsequent experiments (at both CERN and Fermilab) were extremely energetic ("hot") and were not well suited to study. To resolve this hurdle, and to gain a better understanding of antihydrogen, two collaborations were formed in the late 1990s—ATHENA and ATRAP. The primary goal of these collaborations is the creation of less energetic ("cold") antihydrogen, better suited to study.

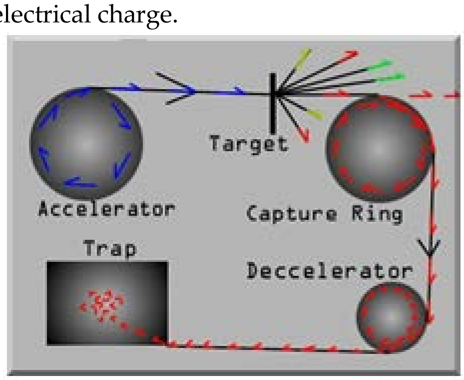
In early 2004 ATHENA researchers released data on a new method of creating low-energy antihydrogen. The technique involves slowing antiprotons using the Antiproton Decelerator, and injecting them into a Penning trap (specifically a

Penning-Malmberg trap). Once trapped the antiprotons are mixed with electrons that have been cooled to an energy potential significantly less than the antiprotons; the resulting Coulomb collisions cool the antiprotons while warming the electrons until the particles reach an equilibrium of approximately 4 K.

While the antiprotons are being cooled in the first trap, a small cloud of positron plasma is injected into a second trap (the mixing trap). Exciting the resonance of the mixing trap's confinement fields can control the temperature of the positron plasma; but the procedure is more effective when the plasma is in thermal equilibrium with the trap's environment. The positron plasma cloud is generated in a positron accumulator prior to injection; the source of the positrons is usually radioactive sodium.

Once the antiprotons are sufficiently cooled, the antiproton-electron mixture is transferred into the mixing trap (containing the positrons). The electrons are subsequently removed by a series of fast pulses in the mixing trap's electrical field. When the antiprotons reach the positron plasma further Coulomb collisions occur, resulting in further cooling of the antiprotons. When the positrons and antiprotons approach thermal equilibrium antihydrogen atoms begin to form. Being electrically neutral the antihydrogen atoms are not affected by the trap and can leave the confinement fields.

ATHENA and ATRAP are now seeking to further cool the antihydrogen atoms by subjecting them to an inhomogeneous field. While antihydrogen atoms are electrically neutral, their spin produces magnetic moments. These magnetic moments vary depending on the spin direction of the atom, and can be deflected by inhomogeneous fields regardless of electrical charge.



Production of Antimatter

4. Antimatter Propulsion

Antimatter propulsion is the Holy Grail of spaceflight. When matter and antimatter react, the energy produced is several billion times larger than the thermomechanical energy resulting from burning a kilogram of a hydrocarbon fuel.
Matter reacting with antimatter is the ultimate source of energy which might be available to power space travel beyond the Solar System. The energy released by the reaction of a gram each of antimatter and matter is about equal to that of a forty kiloton atomic bomb. As a result, numerous conceptual studies have examined antimatter as a fuel for extrasolar spacecraft. A full design effort is somewhat pointless at this stage, as at present we don't know how to manufacture, store, or manipulate large quantities of antimatter - the current cost of that gram of antimatter is roughly estimated at about a trillion US dollars.

One element of the system that can be studied with existing technology is the design and operation of a magnetic nozzle for a beamed core antimatter rocket engine. By causing moving charged particles to be directed into a beam, the magnetic nozzle generates propulsive thrust from the annihilating antimatter.
The beamed core antimatter rocket depends on a little-known fact about antimatter - the only particle-antiparticle annihilation that immediately converts 100 percent of the particle mass into energy is the reaction of an electron with an positron. In contrast, when protons and antiprotons react, they produce a variety of charged and uncharged pions, which are elementary particles. More interesting phenomena occur when antiprotons annihilate against a compound nucleus, such as copper or lead. Many of the electrically charged reaction products retain their identity as charged particles long enough that they can be focused into a unidirectional beam by a magnetic nozzle.
Past studies of such magnetic nozzles determined that magnet coils providing a magnetic field well in excess of 100 Tesla in strength were required. Such strong magnetic fields can only be produced in extremely short pulses using today's technology, so this early solution was not practical. These studies also suggested that the exhaust velocity of a beamed core antimatter engine would top out at about a third of the speed of light, which is rather marginal for interstellar missions.
To accelerate to a speed equal to that of the engine's exhaust velocity (0.33*c*) and then decelerate to a stop at your destination, 86 percent of the initial mass of the spacecraft would have to be fuel - half of that antimatter. One could in principle go faster, but reaching a speed of double the exhaust velocity (0.66 *c*) and then stopping at your destination would require that 98 percent of the spacecraft initial mass is fuel - a rather difficult build job, although use of multi-stage vehicles could improve the situation in the same way as is seen in chemical rockets.

The principle is simple: an equal mixture of matter and antimatter provides the highest energy density of any known propellant. Whereas the most efficient chemical reactions produce about 1 × 107 joules(J)/kg, nuclear fission 8 × 1013 J/kg, and nuclear fusion 3 × 1014J/kg, the complete annihilation of matter and antimatter, according to Einstein's mass-energy relationship (E = mc2), yields 9 × 1016 J/kg. In other words, kilogram for kilogram, matter-antimatter annihilation releases about ten billion times more energy than the hydro-

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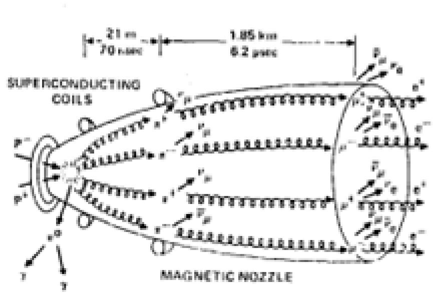
gen/oxygen mixture that powers the Space Shuttle Main Engines and 300 times more than the fusion reactions at the Sun's core.



5. Antimatter Rockets

An antimatter rocket is a proposed class of rockets that use antimatter as their power source. There are several designs that attempt to accomplish this goal. The advantage to this class of rocket is that a large fraction of the rest mass of a matter/antimatter mixture may be converted to energy, allowing antimatter rockets to have a far higher energy density and specific impulse than any other proposed class of rocket.

Antimatter rockets can be divided into three types: those that directly use the products of antimatter annihilation for propulsion, those that heat a working fluid which is then used for propulsion, and those that heat a working fluid to generate electricity for some form of electric spacecraft propulsion system.

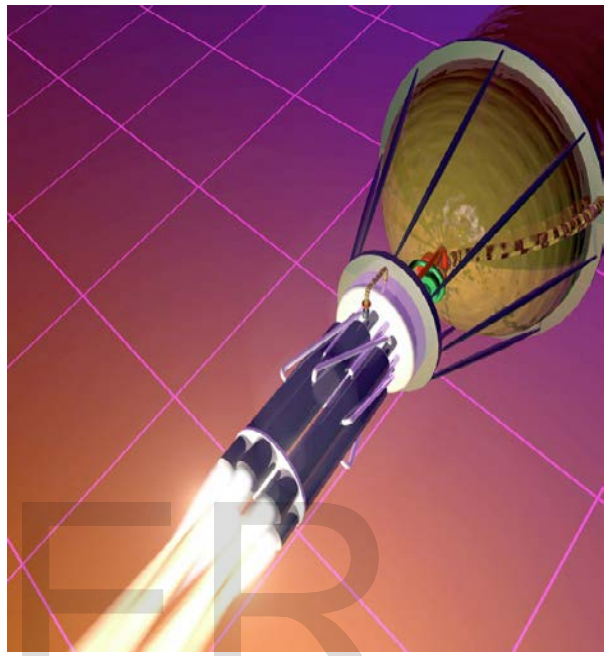
5.1 Direct use of reaction products

Antiproton annihilation reactions produce charged and uncharged mesons, in addition to gamma rays. The charged mesons can be channelled by a magnetic nozzle, producing thrust. This type of antimatter rocket is a beamed core configuration. It is not perfectly efficient; energy is lost as the rest mass of the charged and uncharged mesons, lost as the kinetic energy of the uncharged mesons (which can't be deflected for thrust), and lost as gamma rays.

Positron annihilation has also been proposed for rocketry. Annihilation of positrons produces only gamma rays.

The beam-core thruster employs a diverging magnetic field just upstream of the annihilation point between the antimatter and low-density hydrogen. The magnetic field then directly focuses the energetic charged pions as the exhausted propellant. Since the charged pions are traveling close to the speed of light, the specific impulse of the device could possibly range as high as 10 million seconds, but at very low thrust levels.

The beam core scheme has a matter/antimatter annihilation ratio of nearly 1:1 and would need metric tons of reaction mass for deep space missions. However, it has the fuel efficiency to be made into a true interstellar rocket, able to obtain up to 40% lightspeed. It could reach the nearby stars with an antimatter fuel requirement of a "mere" ten metric tons.



Beamed Core Antimatter Rocket

5.2 Antimatter heating of an exhaust fluid

Several methods for heating an exhaust fluid using the gamma rays produced by positron annihilation have been proposed.These methods resemble those proposed for nuclear thermal rockets. One proposed method is to use positron annihilation gamma rays to heat a solid engine core. Hydrogen gas is ducted through this core, heated, and expelled from a rocket nozzle. A second proposed engine type uses positron annihilation within a solid lead pellet or within compressed xenon gas to produce a cloud of hot gas, which heats a surrounding layer of gaseous hydrogen. Direct heating of the hydrogen by gamma rays was considered impractical, due to the difficulty of compressing enough of it within an engine of reasonable size to absorb the gamma rays. A third proposed engine type uses annihilation gamma rays to heat an ablative sail, with the ablated material providing thrust. As with nuclear thermal rockets, the specific impulse achievable by these methods is limited by materials considerations, typically being in the range of 1000–2000 seconds.

5.3 Antimatter power generation

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The idea of using antimatter to power an electric space drive has also been proposed. These proposed designs are typically similar to those suggested for nuclear electric rockets. Antimatter annihilations are used to directly or indirectly heat a working fluid, as in nuclear thermal rocket, but the fluid is used to generate electricity, which is then used to power some form of electric space propulsion system. The resulting system shares many of the characteristics of other electric propulsion proposals (typically high specific impulse and low thrust)

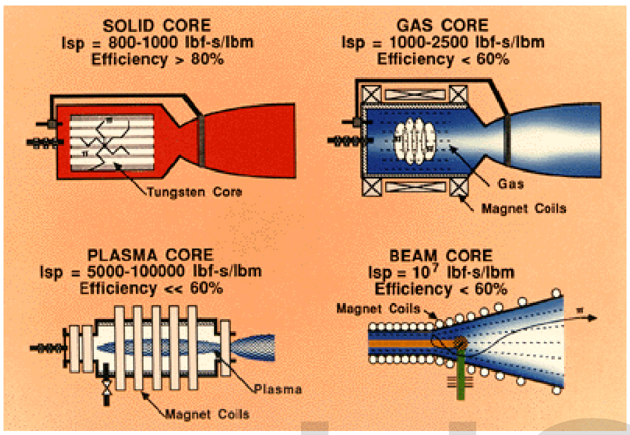

Image-Different Types of Antimatter Rockets

5.4 AIMSTAR ANTIMATTER ROCKET

The AIM in AIMSTAR stands for Antimatter Initiated Microfusion. The AIMStar is being developed by the Pennsylvania State University, specifically for an interstellar "precursor" mission that would carry a probe well beyond the heliopause to a distance of 10,000 AUs from the sun. Also the AIMStar engine tries to make use of existing or near-term antimatter technology, specifically penning traps, and apply it to space propulsion.

A penning trap is basically a powerful magnetic bottle with specific electrical fields used to hold anti-protons. Pellets of fission/fusion fuel (similar to the ICAN propellant pellets, above, but smaller) are "shot" through the trap, basically compressed onto the outer layer of the antiparticle mass in the trap as it passes through. The energy of the antimatter annihilations initiates a fission reaction, which in turn sparks a fusion burn in the compressed deuterium-tritium mix. This superheated plasma is then expelled for thrust.

After each such "burn" the antiprotons in the penning trap are allowed to reset back to their original configuration, minus about 0.5% of their original mass, which was used up in the burn cycle annihilations. After every 50 burns, new antiprotons are injected into the magnetic bottle to reload the trap. The AIMStar engine would fire at about 200 burns per second.

Fuels being considered for the AIMStar are a deuterium-tritium (DT) mix and a deuterium-helium-3 (DHe3) mix. The DT fuel provides much more energy and higher thrust, but the tritium for the DT mix is much harder to obtain than helium-3 and the reaction produces far more radiation than the DHe3 fuel.

The AIMStar engine would require about 28 micrograms of antimatter for the proposed 10,000 AU mission, and has an upper specific impulse of about 61,000 seconds.

6. Difficulties with Antimatter Rocket

The chief practical difficulties with antimatter rockets are the problems of creating antimatter and storing it. Creating antimatter requires input of vast amounts of energy, at least equivalent to the rest energy of the created particle/antiparticle pairs, and typically (for antiproton production) tens of thousands to millions of times more.Most proposed antimatter rocket designs require a large amount of antimatter (around 10 grams to reach Mars in one month).Most storage schemes proposed for interstellar craft require the production of frozen pellets of antihydrogen. This requires cooling of antiprotons, binding to positrons, and capture of the resulting antihydrogen atoms - tasks which have, as of 2010, been performed only for small numbers of individual atoms. Storage of antimatter is typically done by trapping electrically charged frozen antihydrogen pellets in Penning or Paul traps. There is no theoretical barrier to these tasks being performed on the scale required to fuel an antimatter rocket. However, they are expected to be extremely (and perhaps prohibitively) expensive due to current production abilities being only able to produce small numbers of atoms, a scale approximately 10^{23} times smaller than needed for a 10-gram trip to mars.

A secondary problem is the extraction of useful energy or momentum from the products of antimatter annihilation, which are primarily in the form of extremely energetic ionizing radiation. The antimatter mechanisms proposed to date have for the most part provided plausible mechanisms for harnessing energy from these annihilation products.

One technical challenge to making a positron spacecraft a reality is the cost to produce the positrons. Because of its spectacular effect on normal matter, there is not a lot of antimatter sitting around. In space, it is created in collisions of high-speed particles called cosmic rays. On Earth, it has to be created in particle accelerators, immense machines that smash atoms together. The machines are normally used to discover how the universe works on a deep, fundamental level, but they can be harnessed as antimatter factories.

A rough estimate to produce the 10 milligrams of positrons needed for a human Mars mission is about 250 million dollars using technology that is currently under development. This cost might seem high, but it has to be considered against the extra cost to launch a heavier chemical rocket (current launch costs are about $10,000 per pound) or the cost to fuel and make safe a nuclear reactor. Based on the experience with nuclear technology, it seems reasonable to expect positron production cost to go down with more research.

Another challenge is storing enough positrons in a small space. Because they annihilate normal matter, you can't just stuff them in a bottle. Instead, they have to be contained with electric and magnetic fields. "We feel confident that with a dedicated research and development program, these challenges can be overcome," said Smith.

If this is so, perhaps the first humans to reach Mars will arrive in spaceships powered by the same source that fired star ships across the universes of our science fiction dreams.

Though the antimatter rocket seems to be a very prospective way of space travelling the reality is somewhat different.
According to some experts it is not possible to use antimatter for the space travel until the next few decades or so.

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