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Antimatter and its Application

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Abstract:

The conjecture of Antimatter was first proposed by Schuster in 1889. In 1928, Dirac and others gave theoretical predictions in the equation. After four years, Anderson formally observed antiparticles through experiments. In this paper, we review the antimatter universe model, and sort out the origin of baryons and the matter-antimatter asymmetry. We also outline the main research directions in the field of antimatter, such as matter-antimatter symmetry violation and antimatter inside protons. For those unsolved issues, especially like the ratio of matter to antimatter in the universe, the baryon generation model, the gravitational behavior of antimatter is also summarized. In terms of practical applications, we have summarized some technologies related to antimatter, mainly applied as PET and CT (positron emission tomography and computer tomography), etc.

Keywords: Antimatter, CP-violation, related applications.

1. Introduction

Antimatter originated from the imagination of physicist Arthur Schuster in a spare moment, from positive and negative charges, south magnetic field and north magnetic field to positive matter and antimatter [1]. He believed that the encounter between positive and antimatter would excite amazing energy. In 1889, he wrote this imagination in a letter to the journal "Nature". Not long time later, in 1928, the physicist Dirac formulated the Dirac equation describing the behavior of fermions, and in this equation, he predicted the existence of antimatter [2]. Positrons, first observed by Dmitri Skobeltsyn in 1929, which behave like electrons but bend in the opposite direction in a magnetic field. At the same time, C.Y.Chao , who was still a graduate student, discovered a particle with an electron-like property but a positive charge in the abnormal absorption of γ-rays [3]. In 1932, Carl David Anderson published the experimental results of the discovery of positrons in the trajectory of the cloud chamber, which was in line with Dirac's predictions, and won the Nobel Prize in Physics in 1936 for this discovery [4].

With the advancement of science and technology, antimatter particles such as antiproton, antideuteron, $antihelium^3$, anti-hyper tritium and $antihelium^4$ have been discovered in experiments one after another [5]. Antimatter can now be detected by the Relativistic Heavy Ion Collision Facility. In 2011, scientists at Conseil Européen pour la Recherche Nucléaire (CERN) were able to keep antihydrogen around for about 17 minutes [6]. The record for stored antiparticles is currently held by CERN's TRAP experiment: antiprotons were kept in the Penning trap for 405 days [7]. People have discovered some anomalous properties of antimatter in research, which are not as predicted in advance. For example, antimatter and matter are not asymmetric, and regions with a large amount of antimatter have not yet been found in the universe. What is even more strange is that although matter and antimatter will annihilate when collision, but there is a repulsive force between them. On the contrary, the interior of the antimatter attracts each other; in the study of the interior of the proton, the antiquark also appeared on the stage, subverting the proton from up-down quarks and gluons model. These studies, while uncovering the mystery of antimatter, have brought more doubts to people.

From a macroscopic perspective, in the early days of the universe, matter and antimatter were created at the same time and annihilated each other. If this is the case, how do we create it? What kind of existence allows matter to escape under the engulfment of antimatter? From a microscopic perspective, baryons are very small remnants of matter-antimatter asymmetry in the early universe. How are baryons generated? What functional distribution does its ratio to antibaryons fit? From the perspective of gravity, what kind of interactions exist between matter and antimatter, and within antimatter? These are not only major problems to be explored in the field of antimatter, but also major problems that have not been resolved in physics. They are very important for us to study the evolution process of the early universe and understand how human beings can exist. The force phenomenon of antimatter is more likely to provide new discoveries for the current four major forces.

Although the truth is always confusing, according to the properties that people have discovered, antimatter has begun to be gradually applied in real life. Positrons are created when the energy inside atoms is excited, which can be detected by special instruments because positrons collide with electrons that annihilate and produce high-energy gamma rays. Based on this principle, medical PET scanners are manufactured for clinical diagnosis. Others speculate that if the energy generated during the annihilation of matter and antimatter is used reasonably, it may also create more powerful energy sources or weapons, but this is still only at the theoretical level. In this paper, we will discuss the model of antimatter universe, antimatter observation methods, antimatter applications and summarize some unsolved problems in the field of antimatter.

2. The cosmological model of antimatter

2.1 . *Antimatter based on theoretical predictions*

Does matter have an opposite side to it? It's obviously a bit philosophical and sci-fi. In recent years, some authors have written their imaginations about antimatter into their novels. Going back to the source, Schuster first proposed this idea. He wrote in a letter to the journal Nature: Since there are north-south magnetic fields and positive and negative charges, is it possible that matter also has the opposite side, that is, antimatter [8]? This idea is the beginning of abstract fantasy being corroborated by reality. In 1928, physicist Dirac described the mathematical equations for the motion of electrons in a paper "The quantum theory of the electron"[9]. It not only has the characteristics of quantum mechanics, but also satisfies the special theory of relativity, and contains some artificial factors that were originally added to quantum mechanics for the sake of experimental results, and finally presented to people in a concise and beautiful form. This equation is famous all over the world, but it posed a problem: just as the equation $x^2 = 4$ can have two possible solutions (x=2 or x=-2), so Dirac's equation could have two solutions, one for an electron with positive energy, and one for an electron with negative energy. But classical physics (and common sense) dictated that the energy of a particle must always be a positive number (remind that the electron has a negative charge, but its total energy is positive, which value is about $5\times10^5 ev$). The explanation of the negative energy was far beyond the understanding of people at the time, and everyone did not know how to explain it. On the one hand, electrons with negative total energy were never found. On the other hand, this would lead to a conclusion that is very different from the real world in the theory of quantum mechanics. In order to solve this distressing problem, in 1930, Dirac put forward a bold hypothesis: negative energy electrons exist, and the number is large enough [10]. The "sea" ("Dirac Sea" model) of these negative-energy electrons is what we call a vacuum. According to the theory of quantum mechanics, negative energy electrons can easily transition into positive energy electrons. If this is true, the vacuum will have a hole due to the generation of positive energy electrons, which is equivalent to a particle with positive energy and a positive charge. Dirac guessed that there should be particles in the universe with the same mass as electrons. At the beginning, he also made a mistake and judged it to be a proton. It was only after the subsequent calculations and dialectics of several physicists that he gradually came up with the speculation of "antiparticles". In a real sense, 1931 is the birth year of antimatter.

2.2 . *Antimatter based on experimental observations*

Scientists observe antiparticles in the lab just as bumpy. In fact, long before the theoretical prediction, there were already signs of antiparticles in the laboratory, but due to the background of the times, people did not dare to easily define new particles, so this phenomenon was ignored. After the "Dirac Sea" model was proposed, the phenomenon of antiparticles in the laboratory gradually attracted the attention of physicists. They have successively observed a particle path like electrons but with opposite trajectories in the cloud chamber, such as the research on the Blackett cosmic ray by the British physicist [11], the anomalous absorption effect of gamma rays by the Chinese physicist, C.Y. Chao, etc., but there is no direct evidence for the existence of antiparticles. The one who finally reached the definitive conclusion was Anderson, a classmate who was at Caltech with Chao at the time.

Anderson discussed with his mentor, Robert Andrews Millikan, after discovering the unusual particle trajectories. At first, Millikan also misjudged it as a proton because of its reverse deflection, but because the proton is a heavy particle, it is very far-fetched to use it to explain the deflection trajectory of this anomalous particle, and this explanation was quickly rejected. Anderson then offered another explanation, which he suggested could be caused by electrons moving in the opposite direction, but that explanation was also problematic. His experiments were based on cosmic rays, which cannot move in the opposite direction. To detect the particle more accurately, Anderson inserted a thin lead plate into the cloud chamber to slow the particle's motion. In this way, Anderson confirmed that the particle did not move in the opposite direction, and the only explanation was that it came from a new positively charged particle far lighter than the proton. Immediately after the results of this experiment were published, Blackett, who had already made this discovery, added a new conclusion that new particles and electrons were created in pairs. After these results were published one after another, the anti-electron was renamed today's "positron".

2.3 . *The evolution of the cosmological model of antimatter*

The discovery of antimatter is a double success of theory and experiment, and it also means that physicists have taken another crucial step in the exploration of the origin of the universe. As mentioned earlier, matter and antimatter have the same characteristics, opposite charged properties, and are produced in pairs. However, in fact, so far, we have not found a large amount of antimatter in the universe, and we have only produced extremely small amounts of antimatter particles in the laboratory and have a short storage time. So, how did matter-antimatter evolve in the early universe? Where has antimatter gone? In recent decades, with the continuous advancement of science and technology, the cosmological model of antimatter has gradually changed.

Initially, when antimatter was just confirmed, people once regarded it as a "mirror particle of matter", in line with the CPT symmetry principle, that is, under the conjugation of parity (P), charge (C), and time (T) reversal, all phenomena observed in nature are constant. So far, many popular science books have been stuck in describing antimatter as a mirror-image particle of matter. But later, this claim was overturned.

In the process of observing antiparticles, scientists discovered the phenomenon that matter-antimatter collisions annihilate each other and release high-energy gamma rays. If matter-antimatter conforms to the charge-conjugation parity-reversal (CP) symmetry principle, then in the early universe, when particles and antiparticles were created in pairs, they collided and annihilated, and our real world today would not exist. Based on this phenomenon, people give priority to the theoretical point of view, that is, because the real world exists, matter-antimatter must be asymmetric, and baryons are just the remnants of this asymmetry. The mechanism by which more particles than antiparticles were dynamically created in the early universe, proposed by Sakharov in 1967, is now considered one of the cornerstones of modern cosmology [12]. The three necessary conditions for the generation of baryons proposed by him are: (1) baryonic charge is not conserved, (2) the symmetry between particle and antiparticle is broken, (3) deviation of thermal equilibrium in the original plasma.

In today's cosmological research, the baryon generation model is still an unsolved problem. CERN recently published a study on neutrino oscillations, giving some experimental evidence for CP destruction, but theoretical physics has yet to give a clear conclusion. The existing views mainly include: (1) Heavy particle decay, (2) Weak electric baryon generation, (3) Baryon synthesis by leptons, (4) Black hole evaporation theory, (5) Spontaneous baryon generation, (6) Supersymmetry (SUSY) condensed baryon generation [13].

3. The important and latest research in Antimatter

3.1 . *Matter-antimatter symmetry breaking*

The current laws of physics do not provide an explanation for the matter-antimatter imbalance in the universe. One reason given by Sakharov is the breaking of the charge conjugation parity (CP) inversion symmetry between matter and antimatter. The only CP violation observed so far occurs in the weak interaction of quarks, but it is too small to explain cosmic phenomena.

In 2017, scientists found the first evidence of CP violation in the baryon sector for the first time at the Large Hadron Collider. The researchers search for CP violations in the decay angle distributions of Λ_b^0 baryons decaying to p $\pi^-\pi^+\pi^-$ and p $\pi^-K^+K^-$ final states. This is the first observation of these decay patterns. Asymmetry measurements across the phase space did not reveal any evidence of violations of P or CP. Searching for local P or CP violations by measuring asymmetries in different regions of phase space, the results are consistent with the CP symmetry for Λ_b^0 to p $\pi^-K^+K^-$ decays, but evidence for CP violation at the 3.3 standard deviations level is found in Λ_b^0 to p $\pi^-\pi^+\pi^-$ decays. No obvious P violations were found. This represents the first evidence of a CP violation in the baryonic sector and suggests an asymmetry between baryonic matter and antimatter [14].

In 2020, CERN discovered the phenomenon of CP violation in the lepton sector, which is also the latest research on CP violation so far. It is found experimentally that CP violation in the lepton sector can generate matter-antimatter differences through the process of lepton generation. Quantum mixing of neutrinos (neutrino-leptons in the Standard Model) provides a potential source of CP violation via complex-phase δ_{CP}, which can occur in μ -to-electron-neutrino oscillations and related anti- neutrino oscillations that can be experimented with beams produced by the accelerator established at the Tokai-to-Kamioka (T2K) [15].

CP violation still needs more experimental evidence support, and its source is also a topic of endless debate. Whether such a destruction mechanism is manifest or spontaneous, the evolution process of the early universe corresponding to different source theories is also quite sundry.

3.2 . *Antimatter inside protons*

How are protons made up? Most science books or textbooks introduce that a proton is composed of two up quarks with a charge of $+2/3$, a down quark with a charge of $-1/3$, and many gluons. It charges $+1$ as a whole. This is a simplified model that does not provide further explanations for the properties of quarks and gluons.

According to quantum chromodynamics, the strong energy carried by gluons allows the gluons inside the proton to freely generate, expand, and form quark-antiquark pairs. These oppositely charged antiquarks and quarks contribute zero to the charge of the proton, do not affect the total charge, and are difficult to detect because of their ephemeral existence.

Decades ago, theorists predicted that protons might contain a uniform distribution of different types of antimatter, with more down antiquarks than up antiquarks. In 2021, an experiment called SeaQuest published in the journal “Nature” found that in the quark-antiquark model produced by the strong force, the probability distribution of the upper and lower antimatter quarks according to the momentum function should be almost the same. Over a wide range of momentums, there are on average 1.4 down antiquarks per up antiquark [16].

The latest experimental data supplements some information to the above simplified model, the number of antiquarks is surplus, and there is asymmetry inside the proton. Proton is a type of baryon, and the asymmetry of baryon generation has also become one of the important research topics of antimatter.

3.3 . *The force of Antimatter*

To fix the contradiction between the dynamic space-time geometry of general relativity and the fixed-background approach of quantum, also to introduce gravity properly into the Standard Model, some scientists actively pursue the unification of gravity with other interactions, a Theory of Everything.

In field theory, interactions are mediated by exchanging particles. The spin and charge properties of these exchange bosons determine whether they attract or repel each other. Even-spin particles create an attractive force between all types of charges, while the exchange of odd-spin particles results in a repulsive force between like charges. Ordinary “Newtonian” gravity is related to the massless tensor exchanging bosons because the force has infinite range and is always attractive. In addition to tensor parts, gravity can also have scalar and vector components. Unlike tensor and scalar components, vector components cause repulsive forces between like charges. This force would therefore influence antimatter particles in Earth’s gravitational field, violating the weak equivalence principle (also known as the universality of free fall).

The problem of gravitational interaction of antimatter is completely independent of the matter-antimatter symmetry (CPT) problem, because the CPT invariance only determines the equality of the inertial masses of particle and antiparticle pairs but has no restrictions on the gravitational mass.

Using the STAR Collaboration. experimental data on the Relativistic Heavy Ion Collider ($RHIC$)^3, the researchers accurately constructed the antiproton-antiproton correlation function, and combined with the quantum multi-particle correlation theory, quantitatively extracted two basic parameters of the interaction: the scattering length and the effective range of interaction. The study shows that, within experimental precision, the interaction between antiprotons remains consistent with that of positive protons. The strong interaction between antiprotons and antiprotons is attractive, and they can overcome the Coulomb repulsion between antiprotons of the same sign (negative charge) and antiprotons to combine into antimatter nuclei [17].

4. Unresolved issues

4.1 . *The ratio between matter and antimatter in the universe*

The ratio of matter to antimatter in the universe is expressed by this formula: $\beta = \frac{N_B - N_{\bar{B}}}{N_\gamma}$ where the N_B is the CMBR baryon universe number density , $N_{\bar{B}}$ is the CMBR antibaryon universe number density, and the N_γ is the CMBR photon universe number density, CMBR refers to the microwave background radiation. Currently measured CMBR photon universe number the density is $412/cm^3$, and the cosmic number density of baryons is far greater than that of antibaryons. The current mainstream view is that in the high-temperature (Temperature greater than 100MeV) early universe, the number density of antibaryons and baryons in the quark state are almost equal, and the relative precision is on the order of β [18].

According to the baryon model pioneered by Sakharov in 1967, the asymmetry of baryon is homogeneous, that is, β has nothing to do with the point in space, and the total charge of baryon in the universe is not zero[19]. Described in mathematical language, the triple integral of β with respect to x≠0, that is, B_{tot}≠0 Pending issues:

1. Is β a constant or a function of points in space, i.e., $\beta = \beta(x)$?
2. If $\beta = \beta(x)$, what is its variable characteristic scale L_B? Is it possible that L_B is smaller than the current horizon L_{hor} ~ 3Gpc?
3. If β is variable, in some astronomical scale regions, β<0, does it mean that some part of the universe is dominated by antimatter?
4. If β<0 exists, what is the global baryon charge of the universe? If $B_{tot} \neq 0$ then the universe will have global charge asymmetry; if $B_{tot} = 0$ then the universe will have global charge symmetry.

There was no density contrast at the beginning of the Big Bang, and the energy densities of the baryon and antibaryon domains, as well as the baryon sparse boundary between them, were the same. When baryons become non-relativistic, the energy density of regions with more baryon (or antibaryon) numbers also becomes greater than that of baryon-sparse regions. Since non-relativistic matter cools faster, the photon temperature in the (anti-) baryon-sparse region will be higher than in the (anti-) baryon-rich region. Higher photon temperatures cause excessive pressure, which separates baryons and antibaryons, reducing the likelihood of annihilation. This could bring the antibaryon domain closer to us than the predicted Gpa scale, especially if the universe is not baryonic symmetric and the amount of antimatter in the universe is significantly smaller than the amount of matter. However, there is no definitive conclusion yet [18].

4.2 . *Baryon generation model*

The mechanism of baryon generation is a key factor in unraveling the mystery of matter and antimatter. Currently there are roughly the following models:

1. Decay of heavy particles: the first model of baryon generation, which later gained a strong theoretical basis based on the GUTs (Grand Unified Theory) [20]. The following is the mechanism: if the GUT heavy bosons X is not in the thermal equilibrium, then, i.e., decays $X \to 2q$ and $\bar{X} \to 2\bar{q}$ where q is a quark, the decay probabilities may be different for C(CP) destruction, such that Baryons outnumber antibaryons.
2.Electroweak baryon generation: Standard electroweak (EW) theory has all the features necessary for baryon generation: non-conservation of baryon charge, symmetry breaking between particles and antiparticles, and possibly even severe thermal equilibrium deviations. The balance disruption by particle mass is very weak, but the cosmic phase transition from unbroken EW to broken EW is likely to be of first order, then, thermal equilibrium may be strongly disrupted.
3. Baryons are synthesized via leptons: This theory combines ideas from the two theories above. First, the lepton asymmetry arises in the decay of the heavy Majorana neutrino ν_M for a mass of about $m_M \sim 10^{10}$ GeV. Electroweak processes that preserve the difference in baryon and lepton charge (B - L) will equilibrate them.
4. Black hole evaporation theory: The evaporation of low-mass black holes may produce more baryons than antibaryons. The temperature $T_{BH} = \frac{m_{pl}^2}{8\pi M_{BH}}$ [18]. It can be produced in the process of evaporating all particles with a mass less than the black hole. Massive mesons in the gravitational field of a black hole may decay into light baryons and heavy antibaryons and vice versa, but the decay probabilities may differ due to C(CP) destruction [21]. Since the reverse capture of heavy particles by black holes is more likely than light particles, this process could lead to a net flux of baryonic charges into outer space, with equal anti-baryonic charges hidden inside the vanishing black hole. If the ratio of the black hole energy density to the total cosmological energy density was close to 1 in the early universe, this mechanism could explain the observations of cosmic baryon asymmetry.

5. The common (and potential) applications of anti-matter

5.1 . *To trigger nuclear fusion*

We can use antiprotons to trigger nuclear fusion as follows [22].

$$D + T \to {}_{2}^{4}He + 17.59MeV + n \tag{1}$$

$$D + D \to P + T + 4.03MeV \tag{2}$$

$$D + D \to {}_{2}^{3}He + 3.27MeV + n \tag{3}$$

$${}_{3}^{6}Li + n \to {}_{2}^{4}He + 4.28MeV + T \tag{4}$$

These reactions are impossible at room temperature and pressure, because the energy of deuterium-tritium nuclei is very low at room temperature and pressure. Insufficient to overcome the effect of Coulomb potential, fusion reaction cannot occur. When the energy (kinetic energy) of the deuterium-tritium nucleus is large enough (about 0.5MeV), the effect of the Coulomb potential can be overcome, and the fusion reaction can take place. To make the deuterium-tritium nucleus reach 0.5MeV, a high level of energy is required. If the energy of the deuterium-tritium nucleus is all provided by thermal energy, it needs to have a high temperature of several billion degrees, so the explosion of a hydrogen bomb requires an atomic bomb to detonate. The hydrogen bomb generally has two levels, and the primary is generally a fusion-enhanced atomic bomb. The secondary is composed of fusion materials such as deuterium tritium and lithium deuterium, and is the main body of hydrogen bomb energy. After the primary explosion. The resulting high-energy x-rays cause the secondary shell to form a high-temperature, high-density plasma, compressing the secondary fusion material. In order to achieve fusion ignition conditions. The shock wave that occupies most of the explosion energy cannot be used to generate fusion reactions, because it can disperse the secondary, so only a small part of the primary energy is used to generate the reaction of the secondary fusion reaction. When protons react with protons, a charged meson can be produced, which quickly decays into a meson. The mass of this meson is more than 200 times that of an electron, and it can replace electrons in atoms. The atomic radius is reduced by more than 200 times, the effect of the Coulomb potential between atoms can be greatly reduced, and the conditions required for the fusion reaction are greatly reduced (this fusion is also called cold fusion). Studies have shown that a single meson can trigger 200-300 times of deuterium-tritium fusion, and, about 100 t TNT equivalent hydrogen bomb can be ignited by about ling antiproton or antihydrogen. Since it does not need an atomic bomb to detonate, the volume of the hydrogen bomb can be greatly reduced, which is different from the hydrogen bomb that is detonated by an atomic bomb. It does not need to occur step by step, resulting in low explosion efficiency, too large equipment and limited energy. Antimatter detonating a hydrogen bomb is a one-time process. In this process, the utilization efficiency of fusion materials is very high, almost all fusion. Most of the energy is produced in the last few fusions, and the detonation time is much shorter than that of ordinary hydrogen bombs. The explosion efficiency is very high. This property of antiprotons can not only be used to miniaturize hydrogen bombs, but also make it possible to manufacture ultra-high-yield hydrogen bombs. Technically, this application requires far fewer antiprotons. And there is no need to control the technology of antimatter annihilation reactions, the biggest obstacle comes from the storage of antiprotons.

5.2 . *PET and CT (positron emission tomography and computer tomography)*

PET and CT are very efficient physical examination technologies. They have high imaging, high accuracy, non-invasive, effective, safety and other technologies. The main characteristics are:

1.Identify whether the lump is a benign tumor or a malignant tumor.

2.It can quickly locate the location area of malignant tumors in the body and quickly find the tumor.

3.Before the tumor forms a lump, you can still be in a cell state to identify whether it is a malignant tumor.

4.It can be used as an indicator for post-treatment of malignant tumors.

When fluoro-18 is introduced into a glucose or drug molecule and injected into the body, it reaches its target and decays in the body to produce antimatter electrons that emit gamma rays:

$$ {}^{18}F \to {}^{18}O + \nu + e^{+} \ldots(5) $$

We can use positron emitter-labeled glucose, amino acids and other substances as tracers to display tissue lesions, tissue cell functions, cell proliferation and other information at the molecular scale, to provide more clinical basis for physiological and pathological diagnosis.

5.3 . *Used as a power source for rockets*

We can use antimatter to power rocket engines, and according to the relevant data, matter-antimatter provides a higher energy density than any known propellant can provide, according to the Einstein's mass-energy relationship ($E = mc^2$), the annihilation of antimatter and matter yields has the energy that can be produced per 1 kilogram of $9 \cdot 10^{16} J$, which is about 10 billion times the energy density that can be provided by a hydrogen-oxygen mixture propellant, produced by nuclear fusion reactions in the core of the sun More than 300 times the energy density, and the matter-antimatter annihilation reaction can proceed spontaneously, so large-scale or complex reactor systems are not required. The matter-antimatter annihilation reaction is an ideal source of rocket energy. However, before we can use the matter-antimatter annihilation reaction as a source of energy for rockets, we need to face the following problems:

1.There is not numerous antimatters in nature. Currently, antimatter is only made through energetic collisions in giant particle accelerators. The process of making antimatter is to accelerate protons to near the speed of light and let them crash into a target made of tungsten or another material with better penetration resistance. The fast-moving protons are decelerated by collisions with the nuclei of the matter in the target. Or stop, and the kinetic energy of the proton is converted into matter in the form of various subatomic particles, including antiprotons. But so far, the production of antiprotons around the world is far from enough to use them in industry, and the efficiency of generating antiprotons is extremely low.

2. Antimatter cannot be stored in a normal container because it will undergo an annihilation reaction with the container. There is currently a device that can store antiprotons, and that is the Penning Trap, an extremely low temperature, evacuated electromagnetic bottle in which charged particles of antimatter can be suspended, so antiprotons can be stored instead [23].

When applying antimatter to rocket propulsion, annihilation between antiproton and proton is more feasible than annihilation between antielectron and electron because the products of proton-antiproton annihilation are charged particles and they can be oriented and confined by magnetic fields, compared to, electron-anti-electron annihilation can only produce gamma rays, which is not easy to preserve, and cannot guide gamma rays to generate effective thrust. The products of proton-antiproton annihilation reactions include neutral muons (π_0) and charged muons (π_+, π_-). Charged muons can be trapped by magnetic fields and generate directional thrust, and are easy to store. But these products also have rest mass, so not all energy is produced in the proton-antiproton annihilation reaction [24].

5.4 . *Application in biology*

Low-energy positron beams have now been used for a range of topics related to atom/molecule interactions with positrons. At the macromolecular scale, positron annihilation reactions can be used to produce ions for mass spectrometry experiments. This technique may provide structural information on biomolecules [25].

6. Conclusion

Antimatter has been mentioned since the 19th century, and its development time is close to the modern cosmological theories, all of which are still in the early stage. The dual discovery of antimatter from theory to experiment is a gratifying research result, but it is particularly important to note that the asymmetry of matter-antimatter, the model of baryon generation, and the gravitational effect of antimatter are still unresolved. It plays a very important role in the early cosmos evolution process and will also help humans explain the mystery of existence more scientifically. Physical science research will always bring essential changes to people's real life. Based on the matter-antimatter annihilation reaction, scientists have also successfully applied antimatter to medical treatment and achieved some remarkable results. In the future, antimatter may also play a role in the military and aviation fields, such as antimatter rockets and antimatter weapons.

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All authors contributed equally to this work and should be considered co-first authors.

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