

The Gravitational Segregation of Matter and Antimatter

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If matter and antimatter appeared in equal amounts at the creation of the universe, where is the antimatter? I offer a new hypothesis for the segregation of matter and antimatter based on the assumptions that matter has positive mass, antimatter has negative mass, and that the gravitational mass is equal to the inertial mass. This hypothesis, based on CPM (charge-parity-mass) symmetry, predicts that matter would attract both itself and antimatter, while antimatter would repel both itself and matter. The overall effect would be for matter to accumulate and for antimatter to surround it in some kind of dispersed state with an equilibrium between attraction to matter and repulsion from itself. If antimatter acts as an absorber when its temperature is greater than that of the background and is nonluminous, as predicted by CPM symmetry, then antimatter, defined by having a negative mass, has the correct gravitation and radiant properties to be a contender for the title of the missing hidden matter known as dark matter.

1. Introduction

According to Goldhaber [1], symmetry argues that matter and antimatter were created in equal amounts in the big bang and that neither matter nor antimatter can have a preferred position in the universe. However, if matter and antimatter were co-localized, they would annihilate each other transforming their co-localized masses into radiation. As a result there would be neither an observable universe nor any observers. However, mechanisms that could segregate matter and antimatter through a “*gravitational force of repulsion between atoms and anti-atoms—in short, by anti-gravity, as opposed to the gravitational attraction that operates between atom and atom of antimatter*” were discounted because they appeared to contradict the Theory of General Relativity [2]. Burbidge and Hoyle [2] wrote, “*It is upon this rock that anti-matter ideas have foundered. For the idea of anti-gravity cannot be accepted without destroying basic principles of the general theory of relativity.*” A gravitational separation mechanism is possible however if one considers antimatter to have a negative mass [3]. Hermann Bondi has shown that negative mass is consistent with the Theory of General Relativity [4].

In order to explain the asymmetry in the visibility of matter and antimatter in the universe without the possibility of macroscopic separation, Andrei Sakharov suggested that there may be an

inherent asymmetry in the creation or decay of matter and antimatter. Such a suspension of the symmetry in the conservation laws would result in a dearth of antimatter [5]. However, the observed preponderance of matter and a paucity of antimatter in the visible universe may only be apparent.

Predictions of equal amounts of visible matter and anti-matter are based upon the assumption that “*anti-matter should look exactly like ordinary matter*” [2]. But what if this assumption is false? Is it possible that the asymmetry between matter and antimatter is not a result of an asymmetry due to the inexactness in the laws of nature proposed by Sakharov, but is a result of an asymmetry in the luminosity of matter and antimatter as opposed to an asymmetry in its presence?

Symmetry holds an important place in the laws of physics for describing and explaining the natural world [6,7]. The standard model of physics (SMP) is based on CPT (charge-parity-time) symmetry, which assumes that matter and antimatter have positive masses, and that antimatter behaves like matter going backwards in time [8,9]. I have proposed a discrete symmetry called CPM (charge-parity-mass) symmetry that defines matter as having positive mass and antimatter as having negative mass—both classes of mass participating in processes that proceed forward in time [10]. Using CPM symmetry, I have generalized the Second Law of Thermodynamics to describe and predict the order of events in time that take place in reversible thermodynamic systems [11]. I have also applied CPM symmetry to model the photon [12]

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and to describe irreversible radiation systems characterized by the Stefan-Boltzmann law, Planck's blackbody radiation law, and Einstein's law of specific heat [13].

Deficiencies in the ability of the SMP to explain the observed matter-antimatter asymmetry in the universe, dark matter, and other phenomena [14] have led to the proposal of supersymmetries [15] for the new physics that go beyond the standard model (BSM). An alternative to the proposals of supersymmetries, is the proposal to question the veracity of the fundamental symmetries upon which the root of the SMP is founded. This is the route I have taken.

CPT symmetry would hold that at a given temperature greater than that of the cosmic microwave background radiation (CMBR), hot blackbodies made of matter would act as emitters forward in time and hot blackbodies made of antimatter would act as emitters backwards in time. Using CPM symmetry, I concluded that at a given temperature greater than that of the cosmic microwave background radiation (CMBR), hot blackbodies made of matter act as emitters and hot blackbodies made of antimatter would act as absorbers [13]. Such absorbers would appear as nonluminous substances commonly known as dark matter. While the thermodynamic predictions of CPT and CPM symmetry are identical, CPM symmetry helps to frame the problem with observations that take place forward in time.

The best characterized property of dark matter is its ability to interact gravitationally with matter [16]. According to Feng [17], "*all solid evidence for dark matter is gravitational*". Given that CPM symmetry predicts that antimatter characterized as having negative mass will appear nonluminous [13], it is vital to ask, what are the gravitational properties of antimatter predicted by CPM symmetry?

2. Results and Discussion

There is no question that the inertial mass and the gravitational mass of matter are both positive and equal to each other. The equality of the gravitational and inertial mass is known as the equivalence principle and it is known to be accurate to less than one part in 10^{12} [18]. There is an attractive gravitational force ($F_g > 0$) parallel to the unit distance vector ($\hat{r}$) between a material test mass and the earth as given in the following equation:

$$F_g = G \frac{M_e m_g}{r^2} \hat{r} > 0 \quad (1)$$

Where, $M_e (> 0)$ is the mass of the earth, $m_g (> 0)$ is the mass of the test body made of matter, G is the gravitational constant, r is the distance between the earth and the test mass, and $\hat{r}$ be the unit distance vector pointing from the test mass to the earth. The acceleration (g) of the test mass is obtained by equating the gravitational force with the inertial force given by Newton's Second Law:

$$F_g = F_i = m_i g \quad (2)$$

Since F_g is positive, F_i is positive and since m_i is positive, g must be positive and the test mass, whether an apple or the moon, accelerates toward the earth parallel to the unit distance vector [19].

There is a question as to the signs of the masses of antimatter [2,9,20,21]. It is possible that the inertial mass of antimatter is positive but the gravitational mass is negative [9,22], consistent with the original definition of "anti-gravity" [23]; or that the inertial and the gravitational masses of antimatter are both negative [24], consistent with the equivalence principle. The answer to this question is forthcoming as the ratio of the gravitational mass to the inertial mass of antihydrogen is now being tested [25]. The result is far from conclusive, but it is more consistent with the proposal that the gravitational and inertial masses have the same sign than the proposal that they have opposite signs. If the gravitational mass of antimatter were negative, there would be a repulsive force ($F_g < 0$) between an antimaterial test mass and the earth as given in the following equation:

$$F_g = G \frac{M_e m_g}{r^2} \hat{r} < 0 \quad (3)$$

Where, $M_e (> 0)$ is the gravitational mass of the earth and $m_g (< 0)$ is the gravitational mass of the test body made of antimatter. If the inertial mass ($m_i > 0$) were positive, the acceleration (g) of the antimaterial test mass would be given by:

$$F_g = F_i = m_i g < 0 \quad (4)$$

Since F_g is negative, F_i is negative and since m_i is positive, g must be negative and the test mass would accelerate away from the earth antiparallel to the unit distance vector. This is the characteristic of antigravity, where opposites move away from each other and like substances move toward each other [23,26,27].

On the other hand, if the inertial mass ($m_i < 0$) were negative, the acceleration ($\mathbf{g}$) of the test mass would be given by:

$$\mathbf{F}_g = \mathbf{F}_i = m_i \mathbf{g} < 0 \quad (5)$$

Since $\mathbf{F}_g$ is negative, $\mathbf{F}_i$ is negative and since m_i is negative, $\mathbf{g}$ must be positive and the test mass would accelerate towards the earth parallel to the unit distance vector. Thus overall, antimatter would behave just like matter even though it has negative gravitational and inertial masses which means that the details of the gravitational interaction differ. That is, matter falls because the force of gravity is attractive and positive mass accelerates in the direction of the attractive force while the antimatter falls because the gravitational force is repulsive, and since the test body has a negative mass, it accelerates in the direction antiparallel to the repulsive force. The definition of antimatter as having negative gravitational and inertial masses consistent with the equivalence principle has been productive in the formation of a model of the photon and in explaining the importance of the gravitational force in propelling the photon [12]. Because of this explanatory power, I consider this definition to be the correct one.

In order to complete the symmetry, let's assume that there is an "antibody" such as an "antistar" or "antiearth" with a negative mass ($M_e < 0$). The gravitational force between an antiearth and a negative test mass ($m_g < 0$) will be attractive ($\mathbf{F}_g > 0$) as given in the following equation:

$$\mathbf{F}_g = G \frac{M_e m_g}{r^2} \hat{\mathbf{r}} > 0 \quad (6)$$

The acceleration ($\mathbf{g}$) of the negative test mass ($m_i < 0$) is obtained by equating the gravitational force with the inertial force given by Newton's Second Law:

$$\mathbf{F}_g = \mathbf{F}_i = m_i \mathbf{g} > 0 \quad (7)$$

Since $\mathbf{F}_g$ is positive, $\mathbf{F}_i$ is positive and since m_i is negative, $\mathbf{g}$ must be negative and the test body with negative mass, accelerates away from the antiearth antiparallel to the unit distance vector.

Continuing with the assumption of an "antibody" such as an "antistar" or "antiearth" with a negative mass ($M_e < 0$), there will be a repulsive force ($\mathbf{F}_g < 0$) between a material test body with a positive mass ($m_g > 0$) and the antiearth as given in the following equation:

$$\mathbf{F}_g = G \frac{M_e m_g}{r^2} \hat{\mathbf{r}} < 0 \quad (8)$$

The acceleration ($\mathbf{g}$) of the positive test mass ($m_i < 0$) is obtained by equating the gravitational force with the inertial force given by Newton's Second Law:

$$\mathbf{F}_g = \mathbf{F}_i = m_i \mathbf{g} < 0 \quad (9)$$

Since $\mathbf{F}_g$ is negative, $\mathbf{F}_i$ is negative and since m_i is positive, $\mathbf{g}$ must be negative and the test body with positive mass, accelerates away from the antiearth antiparallel to the unit distance vector.

Considering all possible gravitational interactions between matter with positive gravitational and inertial masses ($m_g = m_i > 0$) and antimatter with negative gravitational and inertial masses ($m_g = m_i < 0$), I predict that the matter would tend to aggregate or clump as a result of its gravitational interaction with other matter while antimatter would tend to disgregate or disperse as a result of its gravitational interaction with other antimatter. Gravitational bodies composed of matter would also attract nearby antimatter, although this antimatter and the matter it touches will annihilate upon contact. The larger material bodies that would be minimally affected by annihilation would be selected over the smaller material bodies that may be annihilated by the antimatter. The radiation pressure caused by annihilation would tend to separate the remaining matter and antimatter. As a result of gravitational interactions, the condensation of material bodies made of positive mass would tend to increase over time. On the other hand, as a result of gravitational interactions, the condensation of antimatter would tend to decrease over time. As a result of gravitational interactions, matter would condense and solidify and antimatter would disperse and gasify. The gravitational condensation of matter and the gravitational dispersal of antimatter would be mitigated by the thermal expansion of matter and the thermal condensation of antimatter [11].

If matter and antimatter exist within the same universe or the same galaxy, why do they not totally annihilate each other? The likely answer to this question is that they are too far apart. It is well known that the amount of material in the universe is sparse as highlighted by Olber's paradox [28]. Indeed, the average separation of clusters of galaxies is of order 10,000,000 parsecs, the average separation between galaxies in a cluster is several millions of parsecs, and the average separation between mutually-gravitating stars in a galaxy like

our own that has a diameter of order 100,000 parsecs is a little greater than a parsec, where $1 \text{ parsec} = 3.26 \text{ light years} = 3.08 \times 10^{16} \text{ m}$. That is, matter with a positive mass and antimatter with a negative mass can be partially segregated by gravity.

Additional segregation of ionized matter and antimatter by electromagnetic fields could have resulted because of the differing charge-to-mass ratios of the constituent particles and antiparticles as described by Hannes Alfvén and others [29-35]. An electron, has a charge-to-mass ratio of $-1.76 \times 10^{11} \text{ C/kg}$, a proton has a charge-to-mass ratio of $+9.58 \times 10^7 \text{ C/kg}$, a positron or antielectron has a charge-to-mass ratio of $+1.76 \times 10^{11} \text{ C/kg}$ and an antiproton [36] has a charge-to-mass ratio of $-9.58 \times 10^7 \text{ C/kg}$. With CPM symmetry, the positron or antielectron is considered to have a negative charge ($\approx q$) and a negative mass (m), which gives the observed positive charge-to-mass ratio, and the antiproton is considered to have a positive charge and a negative mass, which gives the observed negative charge-to-mass ratio [10].

Antimatter defined to have a negative mass has the ability to interact gravitationally with matter. Since “*all solid evidence for dark matter is gravitational*” [17], it is reasonable to include antimatter defined to have a negative mass as a contender substance for dark matter.

The above scenarios will occur even when the matter and antimatter are at thermal equilibrium with the background radiation and the gravitational interactions dominate over radiation effects, including light pressure [37,38]. However, according to the generalization of Planck's blackbody radiation law [13], the temperature difference between the background radiation and matter or antimatter determines where the substance will act as an emitter or as an absorber. Matter with a positive mass will act as an emitter when its temperature is greater than the temperature of the background and as an absorber when its temperature is less than the temperature of the background. By contrast, antimatter with a negative mass will act as an emitter when its temperature is less than the temperature of the background and as an absorber when its temperature is greater than the background. Currently, when the background radiation has a temperature of about 2.7 K [39], matter with a positive mass, including brown dwarfs [40], act as emitters and appear luminous, antimatter with a negative mass is predicted to act as absorbers and appear dark [13].

The signs of the mass and energy of a photon depend on the sign of the mass of the absorber [13]. The effective mass and energy of the photon is positive when measured with positive mass detectors, negative when measured with negative mass detectors, and zero when measured equally with symmetrical detectors composed of matter or antimatter [13]. Matter with a positive mass is known to bend the trajectory of photons towards itself and act as a converging lens [41]. Antimatter defined as having a negative mass is predicted to bend the trajectory of photons away from itself and act as a diverging lens.

Antimatter defined as having a negative mass interacts gravitationally with light and matter and it is possible that some of the dark matter is synonymous with antimatter considered to have a negative mass. In the SMP based on CPT symmetry, antimatter is predicted to behave like matter going backwards in time. Perhaps it would be more perspicacious and insightful to consider the order of events of all interactions going forward in time.

The analysis presented here is based on CPM symmetry, which was developed upon the laws of thermodynamics, and interprets matter and antimatter to travel forward in time (FIT). The predictions differ from those given by CPT symmetry, which was developed upon the Special Theory of Relativity. There are two versions of CPT symmetry. The standard interpretation states that matter travels forward in time and antimatter travels backwards in time (BIT) [42]. Recami and coworkers [43-47] have developed an alternative CPT symmetry using the principle of reinterpretation (RIP) to extend the Special Theory of Relativity. They consider matter to have a positive rest mass that travels forward in time and antimatter to have a negative rest mass that travels backwards in time. However, due to their principle of reinterpretation (RIP), which asserts that physical signals are transported only by objects that appear with positive energy travelling forward in time, two negatives make a positive and antimatter is experienced as positive mass traveling forward in time. To my knowledge, CPT symmetry based on extended or non-restricted special relativity has not been applied to gravitational phenomena.

3. Conclusions

Experiments on the response of antimatter to gravity are underway [25,48]. The direction of movement of antimatter in space and/or time has been thought-provoking since the discovery of the

antielectron [positron] in cosmic rays by Carl Anderson [49], who wondered if the tracks he observed in the cloud chamber showed “ordinary electrons (of negative charge) moving upward, or some unknown lightweight particles of positive charge moving downward. In the spirit of scientific conservatism, I [Carl Anderson] tended at first toward the former interpretation, namely, that these particles were upward-moving negative electrons. This led to frequent discussions between the Chief [Robert Millikan] and myself, in which he repeatedly pointed out that cosmic ray particles travel downward”. This quote emphasizes that predictions concerning the appearance of antimatter in space and time are model-dependent.

Burbidge and Hoyle [2] state that “symmetry arguments demand that if anti-matter exists both matter and anti-matter must be created in equal amounts. The evolutionary theory would require that the original nucleus from which the universe expanded must have contained both kinds of matter in equal parts”. The fact that quantities of antimatter equivalent to the quantities of matter in the universe have not been seen has not been adequately explained. On the other hand, the existence of dark matter in the universe has been widely accepted. According to Rubin et al. [16], “The conclusion is inescapable that non-luminous matter exists beyond the optical galaxy.” This non-luminous matter is known as dark matter, but it is possible that the dark matter is just known antimatter considered to have a negative mass?

While most cosmologists consider the universe to be devoid of antimatter as a result of an asymmetry in the laws of physics [50], Gary Steigman [51] suggested that the “failure to construct consistent, symmetric cosmologies may indicate either a lack of antimatter or a lack of imagination.” It is possible that the lack of consistent symmetric cosmologies can be traced back to the assumption that antimatter has a positive mass—an assumption that is based on Dirac’s interpretation of the vacuum [52], which posits that the vacuum has an infinite number of occupied negative energy states, which oddly enough give the vacuum many characteristics of the historical aether. According to Dirac [52], “The above theory does provide a way out from the negative-energy difficulty, but it is not altogether satisfactory. The infinite number of electrons that it involves requires one to deal with wave functions of very great complexity and leads to such complicated mathematics that one cannot solve even the simplest problems accurately, but must resort to crude and unreliable approximations.

Such a theory is a most inconvenient one to have to work with, and on philosophical grounds one feels that it must be wrong.” With a like mind Pauli [53] wrote, “a correct theory should neither lead to infinite zero-point energies nor to infinite zero charges, that it should not use mathematical tricks to subtract infinities or singularities, nor should it invent a ‘hypothetical world’ which is only a mathematical fiction before it is able to formulate the correct interpretation of the actual world of physics.”

In resolving the negative energy difficulty in finding a correct theory, one can make the mathematically-equivalent assumption that time itself can flow in the positive or the negative direction or that mass can be either positive or negative [10]. CPT symmetry assumes the former and CPM symmetry assumes the latter. The predictions made in this paper assuming the validity of CPM symmetry are at odds with the predictions made assuming the validity of CPT symmetry. CPT symmetry predicts that matter and antimatter are both self-attractive while matter and antimatter repel each other [9,42,54,55]. CPM symmetry has been useful in understanding entropy and the nature of the photon [12,13] as well as the vacuum, which is predicted to be devoid of virtual particles [10]. I have recently suggested that radiation friction due to real photons is equivalent to the apparent mass given to a massless particle by the Higgs field [56] and that dark energy that results in the acceleration of the expansion of the universe is equivalent to a decrease in radiation friction [57]. CPM symmetry may provide a way of explaining some of the mysteries of the natural world in terms of substances that are already known.

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