Turk J Phys
36 (2012) , 165 – 177.

doi:10.3906/fiz-1103-16

Symmetry and the order of events in time. A proposed identity of negative mass with antimatter

Randy WAYNE
Laboratory of Natural Philosophy, Department of Plant Biology, Cornell University, Ithaca, NY 14853 USA
e-mail: row1@cornell.edu

Received: 16.03.2011

Abstract

In another paper in this series, we developed a symmetrical theory of mass which describes how systems of positive mass and negative mass will respond to an input of thermal energy. A system composed of positive mass or negative mass will respond to an input of thermal energy in opposite ways. For example, if a system composed of positive mass expands in response to radiation from a hot body, a system composed of negative mass will contract. Likewise, if the system composed of positive mass contracts when brought in communication with a cold body, a system composed of negative mass will expand. In addition, when a system of positive or negative mass is brought into contact with radiation from a thermal reservoir either hotter or colder than the system, thermal processes are induced such that the sign of the change of entropy of a system composed of positive mass is opposite of that of a system composed of negative mass. That is, in response to thermal energy, a system of negative mass behaves as if it is a system of positive mass going backwards in time. This is reminiscent of Feynman's definition of antimatter as matter going backwards in time.

Negative mass is consistent with the negative energy solutions to the equations of the Special Theory of Relativity when combined with quantum mechanics. Formally, the total energy of a particle can be either positive or negative, which means that the mass of that particle can be either positive or negative. Dirac eliminated the negative mass solution by giving certain complex properties to the vacuum. Pauli used only the positive mass solutions to build the theory of spin and statistics. On the other hand, we interpret both the positive and negative energy solutions to be real solutions that represent substances with positive mass and negative mass, respectively.

Thermal energy is only one part of the spectrum of electromagnetic radiation. It is well known that matter and antimatter respond to electromagnetic radiation in opposite ways. For example, if an electron moves one way in an electromagnetic field, a positron will move in the opposite way. We apply our theory of positive and negative mass to matter and antimatter and suggest that it productive to consider matter as having a positive mass and antimatter as having a negative mass. The equations presented here, which treat matter as having a positive mass and antimatter as having a negative mass, can account for the experimental observations of matter and antimatter in electromagnetic fields. Our treatment allows the symmetry between matter and antimatter to be treated in a more causal manner.

Key Words: Antimatter, entropy, negative mass, reversibility, Second Law of Thermodynamics, symmetry, time direction.

1. Introduction

One distinguishing feature of Einstein's approach to physics was to assume that the proper form of the Laws of Nature would be formally symmetrical and that problems in physics could be recognized and solved by discovering formal asymmetries in fundamental theories and finding a way to make them symmetrical [1, 2]. In other papers of this series, we identified an asymmetry in the Second Law of Thermodynamics, and then mended the asymmetry by introducing a discrete symmetry for mass [3, 4]. That is, a reversible thermal energy converter composed of positive mass, converted thermal energy into mechanical work by moving through a prescribed sequence of quasi-static states in the time domain with a concomitant flow of entropy from the hotter reservoir to the colder reservoir. By contrast, a reversible thermal energy converter composed of negative mass, converted thermal energy into mechanical work by moving through the opposite sequence of quasi-static states in the time domain with a concomitant flow of entropy from the colder to the hotter reservoir. Here we show that negative mass, which has been postulated to exist by others [5, 6, 7, 8, 9, 10], is not a fictional characteristic, but a realistic way of looking at antimatter.

2. Results and discussion

Consider a closed system composed of an ideal gas made of positive mass. When the gas is in communication with radiation from a reservoir hotter than the gas, the gas expands isothermally and the thermal energy is converted into pressure-volume work. As the volume is increased quasi-statically, the gas molecules move into the minute newly-created space which results in the gas molecules moving along an isothermal concentration gradient. As the volume expands, the particles reflecting off the boundary would lose kinetic energy if there were no thermal input. Thus the kinetic energy that would be lost by expansion is exactly balanced by the kinetic energy increase due to the thermal energy input. As long as there is a thermal input, the gas will continue to expand and the kinetic energy will remain constant. Under isothermal conditions, the thermal energy ($\aleph TdS$, where $\aleph$ is a coefficient that represents the relative atomic mass standard, T is the absolute temperature and dS is the change of the entropy of the system) is equal to the pressure-volume work ($\aleph PdV$, where P is the pressure and dV is the change in volume of the system):

$$\aleph TdS = \aleph PdV. \tag{1}$$

By definition, $\aleph TdS$ is positive when a gas is in communication with a radiant energy reservoir hotter than the system ($T_{\text{reservoir}} > T_{\text{gas}}$) [4]. By equation (1), $\aleph PdV$ must also be positive. Since $\aleph$ and P are positive by definition [4] for positive mass, dV must be positive, and the positive mass gas expands. By contrast, if the gas were composed of negative mass, where $\aleph$ is defined to be negative and P is defined to be positive, by equation 1, dV would be negative and the gas would contract (i.e. concentrate instead of diffuse).

By definition, if a positive mass or negative mass gas is in communication with a radiant energy reservoir that is colder than the gas ($T_{\text{reservoir}} < T_{\text{gas}}$), then $\aleph TdS$ would be negative. In the case of positive mass, where $\aleph$ and P are positive, dV must be negative and the gas would contract (i.e. concentrate instead of diffuse). By contrast, if the gas were composed of negative mass, where $\aleph$ is defined to be negative and P is defined to be positive, by equation 1, dV would be positive and the gas would expand (i.e. diffuse instead of concentrate).

When a system of positive mass or negative mass is brought into communication with a thermal radiant energy reservoir either hotter or colder than the system, thermal processes are induced, and for a given input,

the sign of the change of entropy of a system composed of positive mass would be opposite of that of a system composed of negative mass:

$$dS_{(+\text{mass})} = -dS_{(-\text{mass})}. \tag{2}$$

Thermodynamically, a system made of negative mass behaves as if it were a system made of positive mass going backwards in time. This is reminiscent of Feynman's [11] theory of matter and antimatter, in which "*the electron moving backward in time would look like a positron moving forward in time.*" In isolated systems or under adiabatic conditions [4], where there is no flow of thermal energy into or out of the system, positive mass and negative mass systems would behave identically. By contrast, the differential responses of systems composed of positive mass and negative mass are seen when the thermodynamic input (e.g. thermal energy) can be described as an electromagnetic wave.

The possibility of positive mass and negative mass is formally consistent with the positive and negative solutions to the equations of the Special Theory of Relativity when combined with quantum mechanics [12]. In Dirac's resulting quantum electrodynamic theory, the energy ($E_{\text{relativistic}}$) of a moving body, in the absence of any potential energy field is given by:

$$E_{\text{relativistic}} = \pm\sqrt{p^2c^2 + m_\circ^2c^4}. \tag{3}$$

In equation 3, p is the relativistic momentum and $m_\circ$ is the invariant mass. There are two solutions to equation 3; a positive solution ($E_{\text{relativistic}} = +\sqrt{p^2c^2 + m_\circ^2c^4}$) and a negative solution ($E_{\text{relativistic}} = -\sqrt{p^2c^2 + m_\circ^2c^4}$). Dirac [13] described these as the "wanted" and "unwanted" solutions, respectively. The "negative energy difficulty" arises in quantum mechanics, because in quantum mechanics unlike classical mechanics which assumes continuity, a perturbation could cause a positive energy electron to move into a negative energy state, and if there are an infinite number of negative energy states, over time, the positive energy electrons would end up in the negative energy states. Dirac denied the existence of negative energy electrons by introducing the vacuum. That is, he removed the "negative energy difficulty" by postulating "*that in the world as we know it, nearly all the states of negative energy are occupied, with just one electron in each state, and that a uniform filling of all the negative-energy states is completely unobservable to us*" [14]. In the development of spin and statistics, which Pauli [15] considered to be "*one of the most important applications of the special relativity theory,*" Pauli also asserted that only the positive energy solutions had meaning. By contrast, here we interpret both the positive and negative energy solutions to be real solutions that represent substances with positive mass and negative mass, respectively.

Antimatter was first detected by observing the tracks left by positive electrons or positrons in cloud chambers. These tracks seemed to be caused by the movement of particles with an apparent charge-to-mass ratio ($e/m_\circ$) that was opposite in sign to that of electrons [16, 17, 18]. As we will show below, the positron could also be described as a negative mass, negatively-charged electron[1]. Since the positron has been and is defined as having a positive charge, we will retain the designation of the positive charge and define a positron using our equations that include the atomic mass standard coefficient $\aleph$ [4], as a particle that has mass and charge equal in magnitude but opposite in sign to that of an electron. Below we will show how $\aleph$ can be introduced into the equations of electricity and magnetism as we present some of the experiments that have contributed significantly to the understanding of the nature of charged particles.

[1]Algebraically and experimentally, $e/m_\circ$ can not be used to distinguish between a positively charged, positive mass particle and a negatively charged, negative mass particle.

The ability to ionize gases with x-rays led to the idea that the neutral atom was not an elementary and uncuttable particle as its name implies but a complex structure composed of negative and positive charges. From that point on, work began on discovering and characterizing the constituents of atoms [19]. The study of cathode rays and canal rays provided the means to quantify the physical properties of the sub-atomic charged particles that made up atoms [20, 21, 22, 23, 24, 25, 26, 27].

The masses of particles and antiparticles can be determined by the way they are deflected by an electromagnetic field relative to the way a hydrogen ion is deflected. The angles, θ_{e} and θ_{m}, which particles or antiparticles are deflected by electric and magnetic fields, respectively, are given by the following formulas:

$$\theta_{\mathrm{e}} = (e\mathbf{E}/m_{\circ})(l/v^2) \tag{4}$$

and

$$\theta_{\mathrm{m}} = (e\mathbf{v}\mathbf{B}/m_{\circ})(l/v^2), \tag{5}$$

where $\mathbf{E}$ and $\mathbf{B}$ are the strengths of the electric and magnetic fields of length l, respectively. $\mathbf{E}$ and $\mathbf{B}$ are defined as positive when they emanate from a positive charge or a north pole, respectively, e is the charge of the particle, and $\mathbf{v}$ is the velocity of the moving particle. Since $\mathbf{v} = (\theta_{\mathrm{m}}/\theta_{\mathrm{e}})\mathbf{E}/\mathbf{B}$, $\mathbf{B}$ is adjusted during the experiment so that $\theta_{\mathrm{m}} = \theta_{\mathrm{e}}$. When $\theta_{\mathrm{m}} = \theta_{\mathrm{e}}$, the velocity of the charge is equal to $\mathbf{E}/\mathbf{B}$. Substituting E^2/B^2 for v^2 into equation 4, we get

$$\theta_{\mathrm{e}} = (e\mathbf{E}/m_{\circ})(lB^2/E^2). \tag{6}$$

Solving for $e/m_{\circ}$, we get:

$$e/m_{\circ} = (\mathbf{E}/lB^2)\theta_{\mathrm{e}}. \tag{7}$$

Since the length of the electric plates, the strength of the electric field, the strength of the magnetic field, and the angle of deflection, were known, J. J. Thomson [22] determined the value of $e/m_{\circ}$ by varying the strength of the magnetic field and measuring the angle θ_{e}. Both the sign and the magnitude of e and $m_{\circ}$ depend on the relative atomic mass standard.

Historically, the charge of the electron was considered to be negative. Given the fact that atoms are electrically neutral, it was postulated that the charge of an electron was equal in magnitude but opposite in sign to the charge of a hydrogen ion or any other univalent cation [28]. Since a hydrogen ion was assigned a relative mass of 1 and a charge of about 10^{-10} electrostatic units, the charge of the electron was assigned to be approximately -10^{-10} electrostatic units. Its mass was obtained by dividing the $e/m_{\circ}$ of an hydrogen ion by the $e/m_{\circ}$ of an electron. In this way, the mass of the electron was estimated to be approximately 1/1836 of the mass of a proton. The $e/m_{\circ}$ ratio for a hydrogen ion had previously been determined by Michael Faraday with his Volta-electrometer by measuring how much current (C/s) was needed to produce 1 gram of hydrogen gas from an aqueous solution in a given time.

The ratio $e/m_{\circ}$ of hydrogen ions was determined electrochemically by making use of the charge-to-mass ratio we now know as the Faraday (9.65×10^4 C/mol) [29, 30, 31]. Similar values of the charge-to-mass ratio were determined by Wien [23, 24] for the most deflectable canal rays, which were composed of hydrogen ions. Thus the value of e depended on the value assigned to $m_{\circ}$, which in turn depended on the value assigned to H^+, which depended on the relative atomic mass standard. This is even true of Millikan's [19] oil drop experiment when one takes into consideration the possibility that the charge on the falling droplet could formally have either a positive or negative mass. Since e also depends on the relative atomic mass standard, we introduce the

coefficient $\aleph$ into any equation that contains the elementary charge (e) or the Faraday (F) for the same reason that we introduced $\aleph$ into any equation that contained either Boltzmann's Constant (k) or the Universal Gas Constant (R) [4]. Thus:

$$\aleph e/m_\circ = (\mathbf{E}/lB^2)\theta_\mathrm{e} \tag{8}$$

This form of the equation allows for positive and negative masses. For an electron, $\aleph$ and $m_\circ$ are positive and e is negative, and consequently θ_e is negative. By contrast, for a positron, $\aleph$ and $m_\circ$ are negative while e is positive, and consequently θ_e is positive. These are the same results as those obtained using the standard theory. Thus it is equally likely that the ratio $\aleph e/m_\circ$ was being measured in experiments aimed at determining $e/m_\circ$. Thus the certainty that antimatter has a positive mass cannot be deduced from these electrodynamic experiments, and the possibility that antimatter has a negative mass cannot be excluded by the same experiments.

Since the magnitude and sign of the charge of a particle depends on the calibration of its relative mass, the charge per particle (e) and the charge per mole (F) should always be associated with the coefficient $\aleph$ to reflect this dependence. This applies to particles analyzed with mass spectrometers [32, 33], energy spectrometers [34] and accelerators [35, 36, 37]. In order to generalize the description of the behavior of positive and negative mass in an electromagnetic field, we have rewritten the Lorentz [38] force equation and Newton's Second Law to allow for negative mass by including the coefficient $\aleph$.

$$\mathbf{F} = \aleph e(\mathbf{E} + \mathbf{v} \times \mathbf{B}) = m_\circ \mathbf{a}, \tag{9}$$

where $\mathbf{a}$ is the acceleration of the charged particle in response to the Lorentz force. We have also rewritten Coulomb's Law and Newton's Second Law to describe the polarity of an electrostatic field and the nonrelativistic dynamic behavior of charged particles with positive or negative mass in an electrostatic field:

$$\mathbf{F} = \aleph_{e_\mathrm{t}} e_\mathrm{t} \mathbf{E} = \frac{1}{4\pi\epsilon_\circ} \frac{\aleph_{e_\mathrm{s}} e_\mathrm{s} \aleph_{e_\mathrm{t}} e_\mathrm{t}}{r^2} = m_\circ \mathbf{a}, \tag{10}$$

where $\aleph_{e_\mathrm{t}} e_\mathrm{t}$ represents the test charge, $\aleph_{e_\mathrm{s}} e_\mathrm{s}$ represents the source charge, $m_\circ$ represents the mass of the test charge and $\epsilon_\circ$ is the electrical permittivity of the vacuum. A negative electrostatic force is defined as an attractive force and a positive electrostatic force is defined as a repulsive force. The acceleration vector of a test particle made of positive mass is parallel to the electrostatic force vector. The acceleration vector of a test particle made of negative mass is antiparallel to the electrostatic force vector. This means that a positive test mass accelerates towards the source of an attractive force and away from the source of a repulsive force while a negative test mass accelerates towards the source of a repulsive force and away from the source of an attractive force. Again, one can consider the response of a negative test mass to an electrostatic force as equivalent to a positive test mass going backwards in time.

In the equations that include the atomic mass standard coefficient $\aleph$, a proton is an example of a particle with positive mass and positive charge; an antiproton is an example of a particle that can be considered to have a negative mass and a negative charge; an electron is an example of a particle with positive mass and negative charge; and a positron is an example of a particle that can be considered to have a negative mass and a positive charge.

In order to explore the consequences of equation 10, we first consider the situation where the electric fields are caused by substances with positive mass as they are under laboratory conditions (see Table 1). Consider the source to have a positive charge and assume that an electric field ($\mathbf{E}$) is directed away from the positive source

Table 1. Coulomb's Law for positive masses.

$\aleph_{e_t}$	e_t	$\aleph_{e_s}$	e_s	=	**F**	=	m_o	**a**	direction of movement relative to charge that produces the field
+	-	+	+		-		+	-	toward
+	-	+	-		+		+	+	away
+	+	+	+		+		+	+	away
+	+	+	-		-		+	-	toward

charge (see Figure 1). A positive test charge placed in the electric field will experience an electrostatic force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$. Since $\aleph_{e_s}$, $\aleph_{e_t}$ e_s and e_t are positive, the electrostatic force will be positive and thus repulsive. A positive test charge with a positive mass will then accelerate parallel to the electric field (i.e. away from the positive charge creating the field). A negative test charge placed in the electric field will experience a force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$. In this case, the electrostatic force is negative and attractive. Consequently, a negative test charge with a positive mass will accelerate antiparallel to the electric field (i.e. towards the positive charge creating the field).

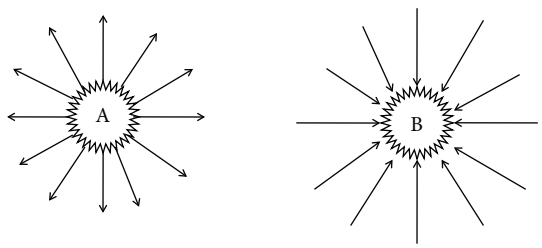

Figure 1. A shows the electric field lines of a particle with positive mass and positive charge and a particle with negative mass and negative charge. B shows the electric field lines of a particle with positive mass and negative charge and a particle with negative mass and positive charge.

Now consider the situation where the electric fields are caused by substances with positive mass and a negative charge (see Table 1) Assume that the electric field (**E**) is directed towards the negative source charge (see Figure 1). A positive test charge placed in the electric field will experience an electrostatic force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$. Since $\aleph_{e_s}$, $\aleph_{e_t}$ and e_t are positive and e_s is negative, the electrostatic force will be negative and thus attractive. A positive test charge with a positive mass will then accelerate parallel to the electric field (i.e. towards the negative charge creating the field). A negative test charge placed in the electric field will experience a force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$. In this case, the electrostatic force is positive and repulsive. Consequently, a negative test charge with a positive mass will accelerate antiparallel to the electric field (i.e. away from the negative charge creating the field).

Now consider how a test charge will behave if it is composed of negative mass and positive charge (Table 2). Further assume that an electric field (**E**) is directed towards a positive source charge with negative mass (Figure 1). A positive test charge placed in the electric field will experience an electrostatic force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$. Since e_t and e_s are positive but $\aleph_{e_t}$ and $\aleph_{e_s}$ are negative, the electrostatic force will be positive and thus repulsive. A positive test charge with a negative mass will then accelerate parallel to the electric field

Table 2. Coulomb's Law for negative masses.

$\aleph_{e_t}$	e_t	$\aleph_{e_s}$	e_s	=	**F**	=	m_o	**a**	direction of movement relative to charge that produces the field
-	-	-	+		-		-	+	away
-	-	-	-		+		-	-	toward
-	+	-	+		+		-	-	toward
-	+	-	-		-		-	+	away

(i.e. towards the positive charge creating the field). A negative test charge with a negative mass placed in the electric field will experience a force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$. In this case, the electrostatic force is negative and attractive. Consequently, a negative test charge with a negative mass will accelerate antiparallel to the electric field (i.e. away from the positive charge creating the field).

Further assume that an electric field (**E**) is directed away from a negative source charge with negative mass (see Figure 1). A positive test charge placed in the electric field will experience an electrostatic force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$. Since e_t is positive but $\aleph_{e_t}$ and $\aleph_{e_s}$ and e_s are negative, the electrostatic force will be negative and thus attractive. A positive test charge with a negative mass will then accelerate parallel to the electric field (i.e. away from the negative charge creating the field). A negative test charge with a negative mass placed in the electric field will experience a force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$. In this case, the electrostatic force is positive and repulsive. Consequently, a negative test charge with a negative mass will accelerate antiparallel to the electric field (i.e. towards the negative charge creating the field).

Now consider a field produced by a positive mass with a positive charge and we will explore how a test charge will behave if it is composed of negative mass (see Table 3). Further assume that the electric field (**E**) is directed away from the positive source charge with positive mass (Figure 1). A positive test charge with a negative mass placed in the electric field produced by the positive source charge will experience an attractive force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$ and will accelerate parallel to the electric field (i.e. away from the positive charge creating the field). A negative test charge with a negative mass placed in the electric field produced by the positive source charge will experience a repulsive force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$ and will accelerate antiparallel to the electric field (i.e. towards the positive charge creating the field).

Now consider a field produced by a positive mass with a negative charge and we will explore how a test charge will behave if it is composed of negative mass (Table 3). Further assume that the electric field (**E**) is directed towards the negative source charge with positive mass (Figure 1). A positive test charge with a negative mass placed in the electric field produced by the negative source charge will experience a repulsive force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$ and will accelerate parallel to the electric field (i.e. towards the negative charge creating the field). A negative test charge with a negative mass placed in the electric field produced by the negative source charge will experience an attractive force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$ and will accelerate antiparallel to the electric field (i.e. away from the negative charge creating the field).

Now consider a field produced by a negative mass with a negative charge and we will explore how a test charge will behave if it is composed of positive mass (Table 4). Further assume that the electric field (**E**) is directed away from the negative source charge with negative mass (Figure 1). A positive test charge with a positive mass placed in the electric field produced by the negative source charge will experience a repulsive

Table 3. Coulomb's Law for source charge with positive mass and test charge with negative mass.

$\aleph_{e_t}$	e_t	$\aleph_{e_s}$	e_s	=	**F**	=	m_o	**a**	direction of movement relative to charge that produces the field
-	-	+	+		+		-	-	toward
-	-	+	-		-		-	+	away
-	+	+	+		-		-	+	away
-	+	+	-		+		-	-	toward

Table 4. Coulomb's Law for source charge with negative mass and test charge with positive mass.

$\aleph_{e_t}$	e_t	$\aleph_{e_s}$	e_s	=	**F**	=	m_o	**a**	direction of movement relative to charge that produces the field
+	-	-	+		+		+	+	away
+	-	-	-		-		+	-	toward
+	+	-	+		-		+	-	toward
+	+	-	-		+		+	+	away

force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$ and will accelerate parallel to the electric field (i.e. away from the negative charge creating the field). A negative test charge with a positive mass placed in the electric field produced by the negative source charge will experience an attractive force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$ and will accelerate antiparallel to the electric field (i.e. towards the negative charge creating the field).

Now consider a field produced by a negative mass with a positive charge and we will explore how a test charge will behave if it is composed of positive mass (Table 4). Further assume that the electric field (**E**) is directed towards the positive source charge with negative mass (Figure 1). A positive test charge with a positive mass placed in the electric field produced by the positive source charge will experience an attractive force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$ and will accelerate parallel to the electric field (i.e. towards the positive charge creating the field). A negative test charge with a positive mass placed in the electric field produced by the positive source charge will experience a repulsive force equal to $\frac{1}{4\pi\epsilon_o}\frac{\aleph_{e_s}e_s\aleph_{e_t}e_t}{r^2}$ and will accelerate antiparallel to the electric field (i.e. away from the positive charge creating the field).

Although they are based on unconventional assumptions, the above equations and descriptions are consistent with the observed behavior of real charged particles, including electrons, protons, positrons and antiprotons. In all cases, one must distinguish the causal electrostatic force from the responding inertial force. When the causal electrostatic force is attractive, a positive mass particle will accelerate towards the source of the electrostatic force and a negative mass particle will accelerate away from the source of the electrostatic force. When the causal electrostatic force is repulsive, a positive mass particle will accelerate away from the source of the electrostatic force and a negative mass particle will accelerate towards the source of the electrostatic force. For positive test masses, the force and acceleration vectors are parallel and for negative test masses, the force and acceleration vectors are antiparallel. Again, a negative mass particle responds to an electrostatic force like a positive mass particle going backwards in time.

Consider a Cartesian coordinate system in which a charged particle is traveling in the $+x$ direction through a magnetic field that points in the $+y$ direction. The magnetic force will be pointing in either the $+z$ or the -z direction, depending on the sign of the product of $\aleph$ and e_t. When the product is positive, the force will bend the trajectory of the particle to the left from the perspective of an observer looking in the direction from which the particle originated. When the product is negative, the force will bend the trajectory

Table 5. Magnetic Force on charged particles made of positive or negative mass.

$\aleph_{e_t}$	e_t	$\mathbf{v} \times \mathbf{B}$	=	$\mathbf{F}$	=	$m_\circ$	$\mathbf{a}$	direction of movement relative to $\mathbf{v} \times \mathbf{B}$
+	+	+		+		+	+	left (positive z)
+	-	+		-		+	-	right (negative z)
-	+	+		-		-	+	left (positive z)
-	-	+		+		-	-	right (negative z)

of the particle to the right from the perspective of an observer looking in the direction from which the particle originated. The causal force is given by $\mathbf{F} = \aleph e_t(\mathbf{v} \times \mathbf{B})$ and the response force is given by $\mathbf{F} = m_\circ \mathbf{a}$. The magnetic force and the influence of that force on the nonrelativistic motion of a charged particle or antiparticle in the uniform magnetic field found in spectrometers and accelerators is given by the following forms of the Lorentz Force Law and Newton's Second Law:

$$\mathbf{F} = \aleph e_t(\mathbf{v} \times \mathbf{B}) = m_\circ \mathbf{a}. \tag{11}$$

Assume that the velocity vector and the magnetic field vector are oriented in space so that $\mathbf{v} \times \mathbf{B}$ is positive. A positive test charge with a positive mass placed in the magnetic field will experience a magnetic force equal to $\aleph e_t(\mathbf{v} \times \mathbf{B})$. Since $\aleph$, e_t and $(\mathbf{v} \times \mathbf{B})$ are positive, the magnetic force will be positive. A negative test charge with a positive mass placed in the magnetic field will experience a magnetic force equal to $\aleph e_t(\mathbf{v} \times \mathbf{B})$. Since $\aleph$, and $(\mathbf{v} \times \mathbf{B})$ are positive, but e_t is negative, the force will be negative and directed antiparallel to the force exerted on a positive charge. Thus a positive mass particle with a positive charge and a positive mass particle with a negative charge will be accelerated by a magnetic field in opposite directions (Table 5).

Now consider how a test charge will behave if it is composed of negative mass. A positive test charge with negative mass placed in the magnetic field will experience a magnetic force equal to $\aleph e_t(\mathbf{v} \times \mathbf{B})$. Since e_t and $(\mathbf{v} \times \mathbf{B})$ are positive, but $\aleph$ is negative, the magnetic force will be negative and directed orthogonal to the velocity of the charge and the magnetic field. A negative test charge with negative mass placed in the magnetic field will experience a magnetic force equal to $\aleph e_t(\mathbf{v} \times \mathbf{B})$. Since $(\mathbf{v} \times \mathbf{B})$ is positive, but $\aleph$ and e_t are negative, the magnetic force will be positive and the force will be directed antiparallel to the force exerted on a positive charge. Thus a negative mass particle with a positive charge and a negative mass particle with a negative charge will be accelerated by a magnetic field in opposite directions. According to equation 12,

$$\mathbf{a} = \frac{\aleph}{m_\circ} e_t(\mathbf{v} \times \mathbf{B}) \tag{12}$$

where the sign of the atomic mass standard $\aleph$ and the sign of the mass cancel each other, and consistent with observation where electrons and positrons spiral in opposite directions in a uniform magnetic field, the direction of acceleration in a uniform magnetic field will depend only on the sign of the charge.

While in the book entitled, *Concepts of Mass in Contemporary Physics and Philosophy*, Max Jammer [39] stated that the type of antimatter predicted by Dirac [13, 14] and observed by others [16, 17, 18, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49] has a positive and not a negative mass, we emphasize that this assertion is based on the fact that heretofore the assumption of positive mass was already embedded in the equations used to predict the behavior of antimatter. By assuming that all masses were positive, the "unwanted" properties were first eliminated by introducing the Dirac Sea of negative energy states and later accounted for by introducing the complex quantum electrodynamic vacuum inhabited by fluctuations that give rise to virtual particle-antiparticle pairs [50, 51].

A discrete symmetry already exists between positive and negative charges and north and south magnetic poles. Taking into consideration the possibility of negative mass, we have shown that we can describe the observed behavior of antimatter in response to electromagnetic fields by assuming that it has a negative mass. Moreover, we have shown, using equations that do not exclude negative mass, that an ideal gas with positive mass heated under isothermal conditions expands and behaves as a "source," whereas an ideal gas with negative mass heated under isothermal conditions would contract and behave as a "sink." Substances that behave as sinks instead of sources were first postulated by Karl Pearson [52] in 1891, and given the name, negative matter. Arthur Schuster [53] independently postulated a type of substance that acted as a sink instead of a source and called it antimatter. Using the equations that do not exclude negative mass, we have shown that the "Dirac-type" antimatter and the substances with negative mass that act like sinks, upon an input of thermal energy, instead of sources, are synonymous. When one considers matter to have positive mass and antimatter to have negative mass, there is complete discrete symmetry between matter and antimatter. Moreover, in the absence of matter and antimatter, the vacuum can be considered to have a net mass of zero.

Fermi and Yang [54] considered the possibility that massive particles may not be elementary, and wrote, "*It is by no means certain that nucleons, mesons, electrons, neutrinos are all elementary particles and it could be that at least some of the failures of the present theories may be due to disregarding the possibility that some of them may have a complex structure.*" Given that particles and antiparticles respond oppositely to an input of various forms of electromagnetic energy, we considered the possibility that the photon, which is a massless particle that serves as the carrier of electromagnetic energy including thermal energy, may be a composite structure in which the sum of the masses equal zero. While Bragg [55, 56], de Broglie [57] Born [58], and others [59] have modeled the photon as a binary structure, we [60] have extended their model by considering the possibility that the massless photon is composed of a positive mass particle and its conjugate negative mass antiparticle, both of which move from the emitter to the absorber forward in time. Pair production and annihilation represent photon splitting and photon creation, respectively. In our model, the photon is propelled by the gravitational force between the two particles and its speed is set by the electrical permittivity of the vacuum, the magnetic permeability of the vacuum and the electromagnetic force. Using this model as a basis, we have shown that light itself prevents charged particles from going faster than the speed of light without the need of introducing the relativity of time as postulated by the Special Theory of Relativity [61, 62]. Furthermore, we have shown that there is also no need to postulate the relativity of time in order to understand the relativity of simultaneity [63] and the optics of moving bodies [64]. Taking into consideration this challenge to the concept of relative time, particularly the relativity of the direction of time introduced by Richard Feynman to describe antimatter [65, 66, 67, 68], we now suggest a more causal symmetry between matter and antimatter. That is, instead of using CPT symmetry [69], where matter is antisymmetrical with antimatter in terms of its charge (C), parity (P) and direction in time (T), we suggest that matter is antisymmetrical with antimatter in terms of its charge, parity and mass.

$$CPM_{\text{particle}} = -CPM_{\text{conjugate antiparticle}} \tag{13}$$

Dirac [70] wrote that, "*Physicists have been very clever in finding ways of turning a blind eye to terms they prefer not to see in an equation.*" We find it worthwhile to include the possibility of negative mass in the equations of physics because it provides a new discrete symmetry related to the order of events in time. While there are currently other discrete symmetries that do not involve negative mass being proposed [71, 72], the new symmetry presented here, which preserves the temporal sequences observed for matter and antimatter, may prove to be useful theoretically and experimentally. Moreover, such a discrete mass symmetry may provide a

new way of organizing a large number of isolated facts, give new insight into their connections with each other and allow us to predict new facts.

References

[1] M. J. Klein, *The Natural Philosopher*, **3**, (1964), 1.

[2] A. Einstein, The collected papers of Albert Einstein, vol. 2 (Princeton University Press, Princeton. 1989) p. 357.

[3] B.-Z. Ginzburg and R. Wayne, Symmetry and the order of events in time. I. The asymmetrical order of events in time in a reversible energy converter. (in press)

[4] R. Wayne, Symmetry and the order of events in time. The description of a reversible thermal energy converter composed of negative mass. (submitted)

[5] H. Bondi, *Rev. Mod. Phys.*, **29**, (1957), 423.

[6] B. Hoffmann, *Science Journal,* **1**, (1965), 74.

[7] L. Brillouin, Relativity reexamined, (Academic Press, New York. 1970).

[8] R. Forward, *New Scientist*, **125**, (1990), 54.

[9] R. H. Price, *Amer. J. Physics*, **61**, (1993), 216.

[10] M. Jammer, Concepts of mass in contemporary physics and philosophy, (Princeton University Press, Princeton, NJ. 2000).

[11] R. P. Feynman, Quantum electrodynamics, (W. A. Benjamin, Inc., New York. 1962).

[12] P. A. M. Dirac, *Proc. Roy. Soc. Lond.,* **A118**, (1928), 351.

[13] P. A. M. Dirac, *Proc. Roy. Soc.*, **A126**, (1930), 360.

[14] P. A. M. Dirac, Theory of electrons and positrons, Nobel Lecture, December 12, 1933.

[15] W. Pauli, *Phys. Rev.*, **58**, (1940), 716.

[16] C. D. Anderson, *Science*, **76**, (1932), 238.

[17] C. D. Anderson, *Phys. Rev.*, **43**, (1933), 491.

[18] C. D. Anderson, The discovery of antimatter, (World Scientific, Singapore. 1999).

[19] R. A. Millikan, Electrons (+ and -), protons, photons, neutrons, mesotrons, and cosmic rays, Revised edition, (Univ. of Chicago. Chicago. 1947).

[20] G. J. Stoney, *Phil. Mag. 5th Series*, **38**, (1894), 418.

[21] J. Perrin, *Nature*, **53**, (1896), 298.

[22] J. J. Thomson, *Phil. Mag.*, **44**, (1897), 293.

[23] W. Wien, *Wied. Ann. der Phys.*, **65**, (1898), 449.

[24] W. Wien, *Ann. der Phys.*, **8**, (1902), 244.

[25] P. A. von Lenard, On cathode rays, Nobel Lecture, May 28, 1906.

[26] J. J. Thomson, Carriers of negative electricity, Nobel Lecture, December 11, 1906.

[27] E. Goldstein, Canalstrahlen, (Ostwald's Klassiker der Exakten Wissenschaften. Akademische Verlagsgesellschaft, Leipzig, 1930).

[28] M. Faraday, Experimental researches in electricity, (Great Books Series, Encyclopdia Britannica, Chicago, 1952).

[29] W. Ostwald, Electrochemistry. History and theory, vol. 1 (Amerind Publishing Co., New Delhi, India, 1980).

[30] S. Arrhenius, Text-book of electrochemistry, (Longmans, Green, and Co., London, 1902).

[31] W. Nernst, Theoretical chemistry, (Macmillan and Co., London, 1923).

[32] F. W. Aston, Mass spectra and isotopes, Nobel Lecture, December 12, 1922.

[33] F. W. Aston, Mass-Spectra and Isotopes, (Longmans, Green & Co., New York. 1933).

[34] K. Siegbahn, Beta- and gamma-ray spectroscopy, (Interscience Publishers Inc., New York, 1955).

[35] E. O. Lawrence, The evolution of the cyclotron, Nobel Lecture, December 11, 1939.

[36] J. D. Cockcroft, Experiments on the interaction of high-speed nucleons with atomic nuclei, Nobel Lecture, December 11, 1951.

[37] E. T. S. Walton, The artificial production of fast particles, Nobel Lecture, December 11, 1951.

[38] H. A. Lorentz, The theory of electrons, (Dover Publications, New York, 1952).

[39] M. Jammer, Concepts of mass in contemporary physics and philosophy, (Princeton University Press, Princeton, 2000).

[40] P. M. S. Blackett and G. P. S. Occhialini, *Proc. Roy. Soc. Lond.*, **139**, (1933), 699.

[41] P. M. S. Blackett, *Nature*, **132**, (1933), 917.

[42] J. Chadwick, P. M. S. Blackett and G. Occhialini, *Nature*, **131**, (1931), 473.

[43] J. Chadwick, P. M. S. Blackett and G. P. S. Occhialini, *Proc. Roy. Soc. Lond.*, **144**, (1934), 235.

[44] O. Chamberlain, E. Segré, C. Wiegand and T. Ypsilantis, *Nature*, **100**, (1955), 947.

[45] B. Cork, G. R. Lambertson, O. Piccioni and W. A. Wenzel, *Nature*, **104**, (1956), 1193.

[46] E. Segré and C. E. Wiegand, *Scientific Amer.*, **194**, (1956), 37.

[47] G. Baur, G. Boero, S. Brauksiepe, A. Buzzo, W. Eyrich, R. Geyer, D. Grzonka, J. Hauffe, K. Kilian, M. LoVetere, M. Macri, M. Moosburger, R. Nellen, W. Oelert, S. Passaggio, A. Pozzo, K. Röhrich, K. Sachs, G. Schepers, T. Sefzick, R. S. Simon, R. Stratmann, FD. Stinzing and M. Wolke, *Phys. Lett. B*, **368**, (1996), 251.

[48] D. Blanford, D. C. Christian, K. Gollwitzer, M. Mandelkern, C. T. Munger, J. Schultz and G. Zioulas, *Phys. Rev. Lett.*, **80**, (1998), 3037.

[49] J. Eades and F. J. Hartmann, *Rev. Mod. Phys.*, **71**, (1999), 373.

[50] T. D. Lee, Symmetries, asymmetries, and the world of particles, (Univ. of Washington Press, Seattle, WA, 1988).

[51] H. Genz, Nothingness. The science of empty space, (Perseus Books, Reading, MA, 1999).

[52] K. Pearson, *Amer. J. Math.*, **13**, (1891), 309.

[53] A. Schuster, *Nature*, **58**, 367, (1898), 618.

[54] E. Fermi and C. N. Yang, *Phys. Rev.*, **76**, (1949), 1739.

[55] W. H. Bragg, *Trans. and Proc. and Rep. of the Royal Soc. of South Australia*, **31**, (1907), 79,94.

[56] W. H. Bragg, *Phil. Mag. Series 6*, **14**, (1907), 429.

[57] L. de Broglie, *Phil. Mag. Series 6*, **47**, (1924), 446.

[58] M. Born and N. S. Nagendra Nath, *Proc. Indian Acad. Sci.*, **3**, (1936), 318.

[59] V. V. Dvoeglazov, *Annales de la Fondation Louis de Broglie*, **24**, (1999), 111.

[60] R. Wayne, Light and video microscopy, (Elsevier Academic Press, Amsterdam, 2009) p. 277.

[61] R. Wayne, *Acta Physica Polonica B*, **41**, (2010), 2297.

[62] R. Wayne, Plant cell biology: From astronomy to zoology, (Elsevier Academic Press, Amsterdam, 2009) p.363.

[63] R. Wayne, *African Physical Review*, **4**, (2010), 43.

[64] A. F. Maers and R. Wayne, *African Physical Review*, **5**, (2011), 7.

[65] G. Fraser, Antimatter. The ultimate mirror, (Cambridge University Press, Cambridge. 2000) p. 90.

[66] C. Itzykson and J.-B. Zuber, Quantum field theory, (McGraw-Hill, New York. 1980).

[67] J. J. Brehm and W. J. Mullin, Introduction to the structure of matter, (John Wiley & Sons. 1989).

[68] R. A. Serway, C. J. Moses and C. A. Moyer, Modern physics, Third Edition, (Brooks/Cole, Australia. 2005).

[69] R. F. Streater and A. S. Wightman, PCT, spin and statistics, and all that, (W. A. Benjamin, New York. 1964).

[70] P. A. M. Dirac, Albert Einstein. Historical and cultural perspectives, eds. G. Holton and Y. Elkana, (Princeton University Press, Princeton. 1982) p. 85.

[71] A. K. Mamedov, *Eur. J. Sci. Res.*, **36**, (2009), 570.

[72] A. K. Mamedov, *Eur. J. Sci. Res.*, **42**, (2010), 359.