Derivation of the Inertial Mass $m = E_o / c^2$ of an Electron Composed of a Circling Spin-½ Charged Photon

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Using Newton's second law of motion $\Sigma \bar{F} = d\bar{p} / dt = m\bar{a}$, the inertial mass $m = E_o / c^2$ is derived for a resting electron proposed to be composed of a circling spin-½ charged photon of energy E_o and circling momentum $p_o = E_o / c$. In this view, the inertia of a particle is not due to "vis inertiae" or an "inertial force" within matter that resists acceleration, as Newton proposed. Rather, the inertial mass of an elementary particle of matter is due to the momentum of a circling photon-like object composing the particle. The particle's inertial mass is calculated as the time rate of change of the momentum vector of a circling photon-like object composing the particle, divided by the associated centripetal acceleration of the circling photon-like object. A transluminal energy quantum model of the proposed spin-½ charged photon is introduced.

Keywords: Inertia, Mass, Inertial Mass, Energy, Momentum, Electron, Photon, Model, Transluminal, Newton's 2nd Law

1. Introduction

Matter has the interesting (and mysterious) physical property of inertia – the resistance to a change in its state of motion. The term "inertia" (Latin: lazy, idle) was first used in a physics context by Kepler in the sense taught by the Greek philosopher and naturalist Aristotle -- that there are certain natural (unforced) motions and certain forced motions of physical objects. For Kepler, inertia was the presumed tendency of an object such as a planet in its elliptical orbit to be motionless unless it is moved in its orbit by an applied force. Galileo, a contemporary of Kepler, used the word "inertia" in a more modern sense. For Galileo, inertia was the tendency of an object like a ship or a polished metal ball on a horizontal surface to either remain motionless or to move horizontally with a constant speed in one direction unless acted on by an outside force such as friction or gravity. This tendency of matter as described by Galileo came to be called Galileo's "law of inertia".

Galileo's law of inertia was developed by Descartes and was later included in Newton's three laws of motion. In his *Principia*, Newton's[1] first law of motion states: "Every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by forces impressed." In modern terminology, Newton's first law has become: Unless acted upon by a net unbalanced force, an object will maintain a constant velocity.

No "vis insita" (inherent force) or as Newton also called it, "vis inertiae" (inertial force), was ever discovered to explain this inertial property of matter. In modern physics the unexplained inertial property of matter has been supplemented by the quantitative term "inertial mass". This is defined as the amount of resistance of an object to a change in its velocity, and is calculated with Newton's second law of motion: "A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed." In modern terms this has become $\Sigma \bar{F} = d\bar{p} / dt = m\bar{a}$. $\Sigma \bar{F}$ is the sum of forces (or net force) acting on an object, $d\bar{p} / dt$ is the time rate of change of the momentum $\bar{p}$ of the object, m is the inertial mass of the object and $\bar{a}$ is the acceleration of the object. Newton's second law states that the net force on an object is equal to the time rate of change of the object's momentum, which equals the inertial mass of the object times the acceleration of the object.

Newton originally defined the "quantity of matter" (or the mass) of an object as "a measure of matter that arises from its density and volume jointly." But since density is mass per unit volume, this definition of mass has been criticized as being circular. The mass of an

object can be measured, relative to another object of some standard mass, by a) weighing the object compared to the standard mass object, b) physically colliding or interacting the object with the standard mass object and comparing the change of motions of the two objects during the collision or interaction, or c) comparing the accelerations of the two objects with the forces acting on them. The first method makes use of the fact that the masses of two objects are proportional to their weights (when the objects are weighed in the same physical location). The second and third methods make use of Newton's second law of motion. The second method also makes use of Newton's third law of motion: "To any action there is always an opposite and equal reaction." This means that when two objects interact, the change of momentum of the first object is equal and opposite to the change in momentum of the second object.

2. Some Background about the Electron

Newton did not know about electrons, which are very small particles of electrically charged matter discovered in 1897. Electrons have mass and inertia. The mass m of an electron is 9.11×10^{-31} kilograms. Electrons also carry a negative electric charge $-e = -1.602 \times 10^{-19}$ Coulombs. Electrons have a characteristic spin component $S_z = \frac{1}{2}\hbar$ where $\hbar = h / 2\pi$ and h is Planck's constant and equals 6.626×10^{-34} Joule seconds. This value of the spin component S_z is $S_z = 5.26 \times 10^{-35}$ Js for an electron. The electron's resting energy is $E_o = 0.511$ MeV, where MeV is one million electron volts, and one electron volt is equal to 1.602×10^{-19} Joules of energy. If a photon has the same energy $E_o = mc^2 = h\nu = hc / \lambda$ as a resting electron, this photon's wavelength λ is called the Compton wavelength $\lambda_{Compton}$ and is given by $\lambda_{Compton} = h / mc = 2.43 \times 10^{-12}$ meters. An electron also acts like a little magnet and has a property called its magnetic moment μ, which has been measured extremely precisely experimentally. This experimental value has also been predicted theoretically extremely precisely by the theory of quantum electrodynamics (QED).

3. $E_o = mc^2$ and Einstein's Theory of Relativity

It is commonly written in physics books for the general public and in some textbooks, and even by some well-known physicists, that the mass of an object increases with the object's speed as this speed approaches the speed of light. But this is not how mass is generally understood today by physicists. Nowadays the mass m

of an object is defined as the object's invariant mass – the object's mass when it is at rest. This invariant mass m of an object is independent of the velocity of the object. An object having a mass m of one kilogram has the same invariant mass of one kilogram when it is moving at half the speed of light as when it is at rest. In Einstein's special theory of relativity, an object of invariant mass m has an associated energy $E_o = mc^2$ when the object is at rest. E_o is called the rest energy of the object. In the case of a resting electron, its inertial mass m is equal to the invariant mass $m = E_o / c^2$ of the electron.

The relation $E_o = mc^2$ for a stationary object of mass m indicates that this object contains energy $E_o = mc^2$. Under appropriate circumstances all or a portion of this energy can be released in the form of photons or other forms of energy such as kinetic energy. For example, an electron and its antiparticle the positron can mutually annihilate to create two or three photons whose total energy is equal to c^2 times the total mass of the electron and the positron before this annihilation. The idea that the loss of energy ΔE from an object is accompanied by a loss of mass $\Delta m = \Delta E / c^2$ by the object was introduced by Einstein[2] as a consequence of his special theory of relativity. Many attempts to theoretically derive $E_o = mc^2$ were made by Einstein and others. Though this mathematical formula is now well established experimentally, the road to its theoretical proof has been rocky, as described by Ohanian[3]. Okun[4,5] discusses the history, derivations and usage of the equation $E_o = mc^2$ as well as the more commonly known equation $E = mc^2$. This latter equation implies that the mass of an object is proportional to the object's total energy. Theoretical derivations of $E_o = mc^2$ for a particle have not explained the origin or nature of the inertial property of the mass m of the particle.

4. Justifications for Modeling Elementary Particles by a Circulating Photon-like Object

Several researchers such as Hestenes[6], Gauthier[7], Williamson and van der Mark[8], and Rivas[9] have modeled an electron as a circulating light-speed object moving in a circle or a helix. It may be argued that since photons don't move in a circle, how can a particle like an electron be composed of a circling photon? Also, since a photon has spin of $1\hbar$, or spin 1 in units of $\hbar$, how can a photon circulate to form an electron that has spin of $\hbar / 2$, or spin ½ in units of $\hbar$? And how can a photon, which is uncharged, move in a circle to form an electrically charged electron?

One answer to these questions may be that there exists a previously unobserved variety of photon that is electrically charged and can circle in a double-loop to form a spin-½ electron or another electrically charged elementary particle. If this is the case, why have physicists never observed this variety of photon? It may be because a spin-½ charged photon is generally curled up and called an electron, or another name if it is another related particle.

A model of a relativistic electron composed of a spin-½ helically-moving charged photon was proposed by Gauthier[10], while a model of a relativistic electron composed of a helically-moving charged photon was earlier proposed by Gauthier[11]. The charged photon in both of these models would move in a circle in a resting electron. It is shown below that a model of a resting electron consisting of a circling charged photon-like object generates the electron's inertial mass.

One indirect source of support for the proposal of a spin-½ charged photon composing an electron comes from Dirac[12]. In his Nobel Prize lecture Dirac said in reference to the Dirac equation: "It is found that an electron which seems to us to be moving slowly, must actually have a very high frequency oscillatory motion of small amplitude superposed on the regular motion which appears to us. As a result of this oscillatory motion, the velocity of the electron at any time equals the velocity of light. This is a prediction that cannot be directly verified by experiment, since the frequency of the oscillatory motion is so high and its amplitude is so small. But one must believe in this consequence of the theory, since other consequences of the theory which are inseparably bound up with this one, such as the law of scattering of light by an electron, are confirmed by experiment."

Dirac did not propose that the electron is a circling spin-½ charged photon. But the light-speed spin-½ electron that he describes as a solution to the Dirac equation sounds very much like the proposed circulating spin-½ charged-photon electron model. The spin-½ charged-photon electron model has, besides internal light-speed, three other properties of Dirac electron as mentioned in Barut and Bracken[13]: its internal small amplitude of oscillation $R_o = \hbar/2mc$, its internal high frequency $v_{zitt} = 2mc^2/h$ called the *zitterbewegung* frequency, and its spin $\frac{1}{2}\hbar$. The electron model also has one-half of the Dirac electron's magnetic moment $e\hbar/2m$. The electron model generates the relativistic electron's de Broglie wavelength $\lambda_{deBroglie} = h/\gamma mv$ for a moving electron.

It was recently found by Ballentine[14] that in certain experimental conditions involving two-dimensional motion, a photon can have spin ½ instead of the normal spin 1. Though this spin-½ photon is uncharged, it is still a surprising discovery about photons. It suggests that other surprising varieties of photon such as the spin-½ charged photon may also be discovered.

5. Derivation of the Resting Electron's Inertial Mass $m = E_o/c^2$

Let us first make a simple model of a resting elementary particle as composed of a circling photon-like object of energy E_o, momentum $p_o = E_o/c$ and speed c. The photon-like object moves in a circle of radius R with an angular velocity $\omega = c/R$, since $c = \omega R$. Newton's second law defines a force $\bar{F}$ as $\bar{F} = d\bar{p}/dt$, the time rate of change of the momentum of an object. For this photon-like object of momentum $\bar{p}_o$ moving in a circular orbit of radius R, the time rate of change of the photon-like object's momentum is given by $\bar{F} = d\bar{p}_o/dt = \omega p_o \hat{r}$ where $\hat{r}$ is a unit vector pointing towards the center of the circle. This force $\bar{F}$ on the circling photon-like object continually points towards the center of the circle as the photon-like object moves around the circle. There is also a centripetal acceleration $\bar{a}_c$ of the circling photon-like object, of magnitude $a_c = c^2/R = \omega^2 R$ since $c = \omega R$ for circular light speed motion. In vector terms, $\bar{a}_c = \omega^2 R \hat{r}$.

Starting with Newton's second law $\bar{F} = d\bar{p}/dt = m\bar{a}$, where m is the inertial mass of the circulating photon-like object that composes the particle and $\bar{a} = \bar{a}_c$ is the centripetal acceleration of the circulating photon-like object, we have

$$
\begin{aligned}
m &= \bar{F}/\bar{a}_c \\
&= (d\bar{p}_o/dt)/(\omega^2 R\hat{r}) \\
&= (\omega p_o \hat{r})/(\omega^2 R\hat{r}) \\
&= p_o/\omega R \\
&= p_o/c \\
&= (E_o/c)/c \\
&= E_o/c^2
\end{aligned}
\tag{1}
$$

This $m = E_o/c^2$ is the derived inertial mass of the circling photon-like object. Since the particle is proposed to be composed of this circling photon-like object, m is also the inertial mass of the particle. The above derivation of a particle's inertial mass applies to any particle composed of a circling photon-like object having a resting energy E_o (different for different types of particles) and momentum $p_o = E_o/c$.

While a circular orbit of the photon-like object was used for simplicity in the above inertial mass calculation, other smoothly curving trajectories of a photon-like object of energy E_o and momentum $p_o = E_o / c$ forming a resting particle would lead to the same result $m = E_o / c^2$. This is because at any point on the photon-like object's trajectory, there would be an instantaneous value of the angular velocity ω of the photon and an instantaneous value of R for the radius of curvature of the photon's curving trajectory, such that ωR equals c, the speed of the photon. This leads to the same result as above: the resting particle's inertial mass is $m = E_o / c^2$.

The above derivation doesn't require the trajectory of the elementary particle modeled by a circling photon-like object of energy E_o to have a particular radius. However, if an elementary particle such as an electron is to be modeled, the properties of the electron have to be taken into consideration in the modeling process, such as the electric charge, the spin and the magnetic moment of the electron. Gauthier[10] proposed a new variety of photon that carries the electron's negative electric charge –e and its spin $\frac{1}{2}\,\hbar$. Like uncharged spin-1 photons, this proposed spin-½ charged photon has energy $E = h\nu$ and momentum $p = E / c = h\nu / c$. If a resting electron of mass $m = 9.11 \times 10^{-31}$ kg is modeled by a circling spin-½ electrically-charged photon of rest energy $E_o = 0.511 MeV$, then the light frequency ν of the circling charged photon is found from $E_o = h\nu = mc^2$. Applying the light wave formula $c = \nu\lambda$, the circling spin-½ charged photon's wavelength λ is then found from $E_o = h\nu = hc / \lambda = mc^2$. This gives $\lambda = h / mc$, the Compton wavelength that equals 2.43×10^{-12} m. To get the correct spin-½ for the electron model, the spin-½ charged photon is formed into a double loop of total length one Compton wavelength. This gives the radius R_o of the double-looped spin-½ charged photon model of the electron to be $R_o = \hbar / 2mc = 1.93 \times 10^{-13}$ m.

6. The Calculated Magnitudes of the Internal Angular Frequency, Internal Momentum, Internal Centripetal Acceleration, and Internal Radial Force in the Spin-½ Charged-Photon Model of a Resting Electron

We have derived the inertial mass $m = E_o / c^2$ of a resting electron, modeled as a circling spin-½ charged photon-like object, without mentioning the magnitudes of a) the internal angular frequency ω of rotation, b) the circulating internal momentum $p_o = mc$, c) the internal centripetal acceleration $a_c = \omega^2 R_o$, and d) the internal force $\bar{F} = d\bar{p}_o / dt = \omega p_o \hat{r}$ required to rotate the internal momentum $p_o = mc$ of the charged photon at this internal angular frequency ω. These quantities are calculated below.

6.1 *The Internal Angular Frequency*

The internal *zitterbewegung* ("jittery motion") angular frequency $\omega = \omega_{zitt}$ in the resting electron model is given by $\hbar\omega_{zitt} = 2mc^2$, or $\omega_{zitt} = 2mc^2 / \hbar$. The *zitterbewegung* angular frequency corresponds to the *zitterbewegung* frequency $\nu_{zitt} = 2mc^2 / h$ found for the internal frequency of the Dirac electron. So

$$\omega_{zitt} = 2mc^2 / \hbar$$
$$= 2 \times (9.11 \times 10^{-31})(3.00 \times 10^8)^2 / (6.63 \times 10^{-34} / 2\pi)$$
$$= 1.55 \times 10^{21}\,\text{rad/s} \qquad (2)$$

6.2 *The Internal Momentum*

The value of $p_o = mc$ is given by

$$p_o = mc = 9.11 \times 10^{-31}\,\text{kg} \times 3.00 \times 10^8\,\text{m/s}$$
$$= 2.73 \times 10^{-22}\,\text{kg m/s} \qquad (3)$$

6.3 *The Internal Centripetal Acceleration*

This is given by

$$a_c = \omega_{zitt}^2 R_o$$
$$= (2mc^2 / \hbar)^2 \times (\hbar / 2mc)$$
$$= 2mc^3 / \hbar$$
$$= 2 \times (9.11 \times 10^{-31}) \times (3.00 \times 10^8)^3 / (6.63 \times 10^{-34} / 2\pi)$$
$$= 4.66 \times 10^{29}\,\text{m/s}^2 \qquad (4)$$

where $R_o = \hbar / 2mc = 1.93 \times 10^{-13}$ m is the radius of the double-looping charged-photon model of the electron.

6.4 *The Internal Radial Force*

This is given by

$$\bar{F} = d\bar{p}_o / dt = \omega_{zitt} p_o \hat{r}$$
$$= (1.55 \times 10^{21}\,\text{rad/s})(2.73 \times 10^{-22}\,\text{kg m/s})\,\hat{r} \qquad (5)$$
$$= 0.424\text{N}\,\hat{r}$$

The source of this remarkably large force $F = 0.424$N and correspondingly large centripetal acceleration $a_c = 4.66 \times 10^{29}\,\text{m/s}^2$ within the spin-½ charged photon model of the electron model is unknown. An accelerated electric charge normally loses energy through radiation, according to standard electromagnetic theory. But the circulating spin-½ charged photon apparently does not lose energy due to this large centripetal acceleration. In quantum mechanics, an electron in the ground state of the hydrogen atom does not radiate energy in spite of its internal motion. Something similar may be going on with the proposed centripetally-accelerated charged photon-like object within an individual electron.

7. The Equations for the Transluminal Energy Quantum Spin-1 and Spin-½ Photon Models

The proposal here is that a circling spin-½ charged photon may compose an electron. The equations for a proposed transluminal energy quantum spin-½ charged photon are presented below. First the equations proposed by Gauthier[15] for a translumial energy quantum model of a spin-1 photon are presented for comparison. It is shown below also that the z-component of the spin of the spin-1 and spin-½ photons are calculated to be $\hbar$ and $\hbar / 2$ respectively. The speed of the helically moving transluminal energy quantum is calculated for both models to be $c\sqrt{2}$. The forward helical angle of the helical trajectory of the transluminal energy quantum is found to be 45 degrees in both of these models. The spin-1 photon transluminal energy quantum's helical trajectory makes one full helical turn per longitudinal photon wavelength λ and has a helical radius of $\lambda / 2\pi$. The spin-½ charged photon transluminal energy quantum's helical trajectory makes two full helical turns per longitudinal photon wavelength λ and has a helical radius of $\lambda / 4\pi$.

For a right-handed spin-1 photon model traveling in the $+z$ direction with energy $E = \hbar\omega$, angular frequency ω and wavelength $\lambda = c / v = 2\pi c / \omega$, the equations for the trajectory of the transluminal energy quantum (neglecting a possible phase factor) are:

$$x(t) = \frac{\lambda}{2\pi}\cos(\omega t),$$

$$y(t) = \frac{\lambda}{2\pi}\sin(\omega t), \qquad (6)$$

$$z(t) = ct$$

for the components of the circulating transluminal energy quantum's position with time, and

$$p_x(t) = -\frac{h}{\lambda}\sin(\omega t),$$

$$p_y(t) = \frac{h}{\lambda}\cos(\omega t), \qquad (7)$$

$$p_z(t) = \frac{h}{\lambda}$$

for the components of the circulating transluminal quantum's momentum with time.

The z-component of spin of the spin-1 model above is calculated from its equations as

$$S_z = (\bar{R} \times \bar{p})_z = x(t) \times p_y(t) - y(t) p_x(t)$$

$$= \frac{\lambda}{2\pi} \times \frac{h}{\lambda}[\cos^2(\omega t) + \sin^2(\omega t)] \qquad (8)$$

$$= \frac{h}{2\pi} = \hbar$$

which is the spin of a spin-1 photon.

The speed $v(t)$ of the transluminal energy quantum for the spin-1 model is calculated from the velocity components of the transluminal energy quantum, which are derived by differentiating the position components for the spin-1 model in the equations above as

$$v_x(t) = dx(t) / dt = -\frac{\lambda\omega}{2\pi}\sin(\omega t)$$

$$v_y(t) = dy(t) / dt = \frac{\lambda\omega}{2\pi}\cos(\omega t) \qquad (9)$$

$$v_z(t) = dz(t) / dt = c$$

and

$$v(t)^2 = v_x(t)^2 + v_y(t)^2 + v_z(t)^2$$

$$= [-\frac{\lambda\omega}{2\pi}\sin(\omega t)]^2 + [\frac{\lambda\omega}{2\pi}\cos(\omega t)]^2 + c^2$$

$$= c^2[\sin^2(\omega t) + \cos^2(\omega t)] + c^2 \qquad (10)$$

$$= c^2 + c^2$$

$$= 2c^2$$

As a result, $v(t) = \sqrt{2c^2} = c\sqrt{2}$ for the speed of the transluminal energy quantum of the spin-1 photon model.

For a right-handed spin-½ charged photon with energy $E = \hbar\omega$, angular frequency ω and wavelength $\lambda = 2\pi c / \omega$, traveling in the $+z$ direction, the equations for the trajectory of the transluminal quantum (again neglecting a possible phase factor) that makes two helical turns per photon wavelength λ are:

$$x(t) = \frac{\lambda}{4\pi}\cos(2\omega t),$$

$$y(t) = \frac{\lambda}{4\pi}\sin(2\omega t), \qquad (11)$$

$$z(t) = ct$$

for the components of the circulating transluminal energy quantum's position with time, and

$$p_x(t) = -\frac{h}{\lambda}\sin(2\omega t),$$

$$p_y(t) = \frac{h}{\lambda}\cos(2\omega t), \qquad (12)$$

$$p_z(t) = \frac{h}{\lambda}$$

for the components of the circulating transluminal energy quantum's momentum with time.

The z-component of spin of the spin-½ charged photon model above is calculated from its equations as

$$S_z = (\vec{R} \times \vec{p})_z = x(t) \times p_y(t) - y(t)p_x(t)$$

$$= \frac{\lambda}{4\pi} \times \frac{h}{\lambda}[\cos^2(2\omega t) + \sin^2(2\omega t)] \qquad (13)$$

$$= \frac{h}{4\pi} = \hbar / 2$$

which is the spin of a spin-½ photon.

The corresponding calculation for the speed of the transluminal energy quantum of the spin-½ charged photon model also gives $v(t) = c\sqrt{2}$.

8. Discussion

The proposal here is that the inertial mass m of a resting electron is derived from the circling momentum $p_o = E_o / c$ of a circling spin-½ charged-photon of energy E_o that is proposed to compose the resting electron. This short derivation was discovered after Gauthier[9] developed a model of the relativistic electron as composed of a spin-½ charged-photon. This relativistic electron model was developed from an internally superluminal model of a resting electron developed earlier by Gauthier[13].

The formula $E_o = mc^2$, relating the energy E_o of a resting particle to its inertial mass m is well-grounded in experimental evidence. What is being proposed here is that an elementary particle does not get its inertial mass directly from its resting energy E_o. Rather, an elementary particle derives its inertial mass from the circling momentum E_o / c of a photon-like object proposed to compose this elementary particle.

One can object that, although the derivation of a particle's inertial mass m from the circulating momentum of a photon or photon-like object using Newton's 2nd law may be correct, there is no experimental evidence that a photon or photon-like object can actually move in a circle or helix to form an elementary particle such as an electron. A normal spin-1 uncharged photon is not known to be able to move in a circle small enough to form an elementary particle.

The same may not be true for a hypothesized new variety of photon that *can* move in a circle to form a resting electron and in a helical trajectory to form a relativistic electron. An electron has spin-½ and carries a negative electrical charge. Gauthier[9] proposed an electron model that is composed of a spin-½ negatively charged photon that moves along a circular trajectory (for a stationary electron) or along a helical trajectory (for a moving electron). In this model the proposed spin-½ charged photon composing the electron moves along its circular or helical trajectory at the speed of light, and moves in the forward or longitudinal direction at the electron's observed speed, which is less than the speed of light.

So far, no one to my knowledge has shown that this proposed spin-½ charged photon cannot exist or cannot move in a circular or helical trajectory to form an electron. In fact the electric charge of the proposed spin-½ charged photon may be what causes the charged photon to move in a circular or helical trajectory. It remains for experiment to test this spin-½ charged photon hypothesis. If a spin-½ charged photon does exist, it may not have been recognized yet partly because it has already been named an electron or some other known particle with mass, and therefore has not been looked for experimentally as a spin-½ charged photon.

It can also be objected that even if such a spin-½ charged photon does exist and composes an electron, it is not really a photon because it does not have spin 1 and has electric charge, unlike a normal photon. However, the proposed spin-½ charged photon has other properties of a photon. It obeys the well-known wave formula $\lambda \nu = c$ (where λ is the charged photon's wavelength and ν is its frequency). It also

obeys the well-known formulas for a photon's energy $E = h\nu$ (where h is Planck's constant) and momentum $p = h\nu / c$. The author prefers to call this proposed spin-½ charged light-speed object a new variety of photon rather than giving it a completely different particle name.

Another possible objection to a circling-photon-like-object model of a fundamental particle is that a single photon-like object would seem to violate the law of conservation of momentum by traveling in a circular trajectory instead of a straight trajectory. However, the proposed spin-½ charged-photon model assumes that the circling spin-½ charged photon composing a resting electron is acted on by a central force $\bar{F} = d\bar{p}_o / dt$, which changes the momentum $p_o = E_o / c$ of the spin-½ charged photon so that it moves in a circle instead of a straight line. This central force $\bar{F}$, when divided by the circling charged photon's centripetal acceleration $a_c = \omega^2 R_o$ as described above, yields the inertial mass m of the circling spin-½ charged photon and therefore the inertial mass m of the particle composed of the circling spin-½ charged photon.

The nature of this central force proposed to act on the circling photon-like object composing an elementary particle is currently unknown. Still, its value can be easily calculated for any particular circling-photon-like-object model of a particle. For example, in the spin-½ charged-photon model of the electron, the value of the central force $\bar{F}$ acting on the double-looping circling charged photon is calculated above to be 0.424 N, or 0.095 pounds. This is a remarkably strong, presumably non-nuclear force that is proposed to be related to a single electron.

The spin or angular momentum of an elementary particle is currently unexplained. Spin is considered to be an "intrinsic" property of an elementary particle like an electron. The spin of a particle like an electron can be explained by the internal circulation of a single photon-like object composing the electron, but not without the circling charged photon appearing to violate the law of conservation of momentum. In the spin-½ charged-photon model of an electron, the electron model's spin component S_z is calculated by multiplying the circling charged photon's momentum $p_o = E_o / c = mc$ by the double-looping circle's radius $R_o = h / 4\pi mc$, giving $S_z = h / 4\pi = \hbar / 2$. This is the exact experimental value of the spin of an electron. If the spin-½ charged photon did not appear to violate the conservation of linear momentum, it could not move in a double-looping circular trajectory to give the electron particle model the experimentally correct electron spin.

More generally, other non-light-speed fundamental particles with inertial mass such as quarks, neutrinos, W particles, Z particles, the Higgs boson and even some proposed dark matter particles, may each be composed of an internally-circulating light-speed photon-like object. These other particles could also derive their inertial masses from their circulating internal momenta. In this view, the inertia of a particle is not a property of matter due to an "inherent force" or "inertial force" in matter that resists acceleration, as Newton proposed but never explained. Rather, the inertial mass of an elementary particle of matter is calculated from the rate of change of the circling momentum vector of a photon-like object composing the particle. When this rate of change of circling momentum is combined with Newton's 2nd law of motion $F = ma$ and the circulating particle's centripetal acceleration, the result is the property of matter called inertial mass $m = E_o / c^2$. This analysis of a particle's inertial mass m supports the idea that ordinary spin-1 photons carry inertial mass $m = E / c^2 = h\nu / c^2$. But it is only when the energy and momentum of a photon becomes localized in a particle with mass by circulating, as in the case of the proposed spin-½ charged photon, that a photon's inertial mass becomes a particle's rest mass or invariant mass.

Usually Einstein's formula is written $E = mc^2$. This better-known formula is less precise than $E_o = mc^2$, because the total energy E of a moving particle increases with the particle's speed, while the moving particle's "invariant mass" or "rest mass" m is independent of the particle's speed and is always proportional to E_o. But why should the term c^2 even occur in the formula for the energy contained in a particle at rest like an electron that has inertial mass m? The simplest answer is that there is something moving at light speed c inside the particle or composing the particle.

As mentioned above, several researchers have proposed that the electron is composed of something moving internally at light speed c. To the author's knowledge a derivation of a particle's inertial mass $m = E_o / c^2$ using Newton's second law of motion $\Sigma\bar{F} = d\bar{p} / dt = m\bar{a}$ on the rotating momentum vector $p_o = E_o / c$ of a circling photon-like object of resting energy E_o proposed to compose the particle, along with the centripetal acceleration a_c of the circling photon-like object, has not previously been presented by another researcher.

9. Conclusions

A model of a resting elementary particle composed of a circling photon-like object of resting energy E_o and

circling momentum $p_o = E_o / c$ is used to provide a short, non-relativistic derivation of the particle's inertial mass $m = E_o / c^2$, or $E_o = mc^2$. To obtain this result, Newton's second law $\Sigma \bar{F} = d\bar{p} / dt = m\bar{a}$, or $m = (d\bar{p}/dt)/\bar{a}$, which defines inertial mass m, is applied to the circulating photon-like object's changing vector momentum $\bar{p}_o$ and its centripetal acceleration $a_c = c^2 / R$. Spin-1 photons are uncharged and do not move in a circular trajectory. An internally-transluminal spin-½ charged-photon model is proposed that can move in a double-looping circular trajectory to give the resting electron model a spin of ½. At highly relativistic velocities, as shown in Gauthier[10], the spin-½ charged photon model of the electron internally moves along a helical trajectory at light speed to give the sub-light-speed electron model a spin of ½ as well.

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