The Electron Is a Charged Photon

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Abstract

A charged photon and its light-speed helical trajectory form a surprising new solution to the relativistic electron's energy-momentum equation $E^2 = p^2c^2 + m^2c^4$. This charged photon is a new model for the electron, and quantitatively resembles the light-speed electron described by Dirac. His relativistic quantum mechanical equation for the electron was derived from the above energy-momentum equation. While the electron's energy is $E = \gamma mc^2$, the charged photon's energy is $E = \gamma mc^2 = h\nu$. The electron's relativistic momentum $p = \gamma mv$ is the longitudinal component of the charged photon's helically circulating momentum $p_{total} = \gamma mc$. At any electron speed, the charged photon has an internally circulating transverse momentum $p_{trans} = mc$, which at the helical radius $R_o = \lambda_{Compton} / 4\pi = 1.93\times10^{-13}\text{m}$ for a resting electron produces the z-component $\hbar/2$ of the electron's spin. The right and left turning directions of the charged photon's helical trajectory correspond to a spin up ($s_z = \hbar/2$) and spin down ($s_z = -\hbar/2$) electron. The negative and positive possible charges of the charged photon correspond to the electron and the positron. The circulating charged photon at the helical radius R_o produces one-half of the electron's pre-QED magnetic moment $\mu = -\mu_{Bohr}$ predicted by the Dirac equation. There is a relativistic variation with the electron's speed v of the charged photon's helical radius $R = R_o/\gamma^2$ and its helical pitch $P = (2\pi v/\gamma c)R_o$. The pitch has a maximum value $P_{\max} = \pi R_o$ when the electron's speed is $v = c/\sqrt{2}$. The decreasing charged photon's helical radius $R = R_o/\gamma^2$ with the electron's increasing speed v quantitatively explains why the electron appears so small ($<10^{-18}\,\text{m}$) in high-energy electron scattering experiments, even though the characteristic radius of the circulating charged photon model for the electron is R_o.

Introduction

In his Nobel Prize lecture Paul Dirac (1933) said: "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 which 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."

One surprising result of the Dirac equation was that the electron moves at the speed of light and has a characteristic associated length $R_o = \hbar / 2mc = 1.93 \times 10^{-13}$ m , where $\hbar = h / 2\pi$ and h / mc is the Compton wavelength $L_{compton} = 2.426 \times 10^{-12}$ m . A second and related surprise was that the electron has a "trembling motion" or zitterbewegung in addition to its normal linear motion. Dirac's finding of light-speed for the electron is particularly problematical because electrons are experimentally measured to travel at less than the speed of light. Dirac did not offer a spatially extended model of the electron to correspond to these results, though his results did contain a characteristic length R_o.

Various researchers such as Hestenes (1990), Williamson and van der Mark (1997), Rivas (2008), Hu (2004), and Gauthier (2007,2013) have suggested spatially-extended electron models where the internal energy of the electron circulates at light speed with the characteristic Dirac radius $R_o = \hbar / 2mc$. Both the Dirac equation's light-speed motion and its zitterbewegung are reflected in these models.

Hestenes and Rivas independently analyzed the Dirac equation for spatial and dynamical characteristics of the electron's motion. Based on these analyses, they independently proposed that the trajectory of a moving free electron is a helix along which the electron's charge moves at light-speed. When the linear speed and momentum of the electron are zero, the helix becomes a circle of radius $R_o = \hbar / 2mc$. Neither author associates this circulating light-speed electric charge with a photon.

Modeling the moving electron as a charged photon

I propose that Hestenes' and Rivas' light-speed helical trajectory of an electron's charge is better described as the helical trajectory of a charged photon. This charged photon has the energy, momentum, speed, wavelength and frequency relationships of a normal photon, but carries the point-like electron's charge with it at the speed of light along the charged photon's helical trajectory.

I found an infinite set of relativistic equations for the helical motion of a charged photon with energy $E = \gamma mc^2 = \gamma h\nu$ and momentum $p = \gamma mc = \gamma h\nu / c$ that satisfy the electron's relativistic energy-momentum equation $E^2 = p^2c^2 + m^2c^4$ and for which the charged photon's velocity component v in the helix's longitudinal direction equals the velocity of the electron. But only one of this infinite set of helical equations is consistent with both the charged photon model of the electron and with Hestene's and Rivas' light-speed helical trajectory of the electron's charge, which has a helical radius R_o and a z-component of electron spin equal to $s_z = \pm \hbar / 2$.

The parametric equations for the full set of these relativistic helical light-speed trajectories are:

$$x(t) = (\lambda_{Compton} / 2\pi n\gamma^2)\ \cos(2\pi n\gamma ct / \lambda_{Compton})$$
$$y(t) = \pm(\lambda_{Compton} / 2\pi n\gamma^2)\ \sin(2\pi n\gamma ct / \lambda_{Compton})$$
$$z(t) = vt$$

where $n = 1,2,3...$ are the positive integers. The "$\pm$" corresponds to a right and left-turning helix respectively. The meaning of n is the number of complete turns of the helical trajectory corresponding to a length along the helical trajectory of exactly one wavelength $\lambda_{Compton}$. The one formula for the charged photon's relativistic trajectory that corresponds to the electron's relativistic energy/momentum equation and Hestenes' and Rivas' helically circulating charge models has $n = 2$. The light-speed along all of the above helical trajectories can be seen by differentiating $x(t)$, $y(t)$ and $z(t)$ with respect to time, and combining the resulting $v_x(t)$, $v_y(t)$ and $v_z(t)$ to give $v_{total} = c$:

$$v_x(t) = -c / \gamma\ \sin(2\pi n\gamma ct/\lambda_{Compton})$$
$$v_y(t) = \pm c / \gamma\ \cos(2\pi n\gamma ct/\lambda_{Compton})$$
$$v_z(t) = v$$

This gives v_{total} of the electron's helically circulating charge as

$$\begin{aligned} v_{total} &= \sqrt{v_x(t)^2 + v_y(t)^2 + v_z(t)^2} \\ &= \sqrt{(c^2/\gamma^2)[\sin^2(2\pi n\gamma ct/\lambda_{Compton}) + \cos^2(2\pi n\gamma ct/\lambda_{Compton})] + v^2} \\ &= \sqrt{(c^2/\gamma^2)[1] + v^2} \\ &= \sqrt{c^2(1 - v^2/c^2) + v^2} \\ &= \sqrt{c^2 - v^2 + v^2} \\ &= \sqrt{c^2} \\ v_{total} &= c \end{aligned}$$

For $n = 2$ the above parametric equation reduces to

$$x(t) = (\lambda_{Compton} / 4\pi\gamma^2)\ \cos(4\pi\gamma ct / \lambda_{Compton})$$
$$y(t) = \pm(\lambda_{Compton} / 4\pi\gamma^2)\ \sin(4\pi\gamma ct / \lambda_{Compton})$$
$$z(t) = vt$$

which, since $R_o = \lambda_{Compton} / 4\pi$, becomes

$$x(t) = (R_o / \gamma^2)\ \cos(\gamma ct / R_o)$$
$$y(t) = \pm(R_o / \gamma^2)\ \sin(\gamma ct / R_o)$$
$$z(t) = vt$$

The radius of the light-speed helix is $R = Ro / \gamma^2$ and its angular frequency is $\omega = \gamma c / R_o$ which for $\gamma \to 1$ becomes $\omega_{zitt} = 2\pi\nu_{zitt} = c / R_o$ where the frequency $\nu_{zitt} = c / 2\pi Ro = 2mc^2 / h$ is the well-known *zitterbewegung* frequency that characterizes the Dirac electron. These results for the helical radius R and helical frequency v_{zitt} for the helically circulating charged photon model of the electron will be derived below.

Dynamical properties of the charged photon model of the electron

Let us look closely at the energy and momentum characteristics of the charged photon model of a moving electron. The charged photon carries the electron's charge and moves helically at the speed c with the normal energy-frequency relationship $E = h\nu$ of a photon. Further, the total relativistic energy $E = \gamma mc^2$ of a moving free electron with longitudinal speed v and longitudinal momentum $p = \gamma mv$ is proposed to equal the helically circulating charged photon's energy $E = \gamma mc^2 = h\nu$. When the longitudinal component of the charged photon's velocity is identified with the electron's velocity, the electron's momentum $p = \gamma mv$ will then be found to equal the longitudinal component of the helically moving charged photon's total momentum $p_{total} = \gamma mc$. In summary, a helically-moving charged photon with energy $E = h\nu = \gamma mc^2$ and helically-directed momentum $p_{total} = E / c = (\gamma mc^2) / c = \gamma mc$ is the model for a moving electron that has energy E and momentum p that are related by $E^2 = p^2c^2 + m^2c^4$.

Relations of the charged photon's dynamics to the moving electron's dynamics

Let us assume that both the z-axis of the helix of the circulating electron charge above and therefore the electron's forward linear velocity $v_z = v$ are directed to the right. The helical trajectory given above makes an angle θ with the electron's forward velocity v. The light speed velocity c has a component velocity v in the forward direction, such that $v = c\cos(\theta)$ or $\cos(\theta) = v / c$. That forward component v of the charged photon is proposed to be identical to the forward speed v of the electron. The ratio of the electron's momentum $p = \gamma mv$ to the charged photon's total momentum $ptotal = \gamma mc$ is seen to be

$$\begin{aligned} p / p_{total} &= \gamma mv / \gamma mc \\ &= v / c \\ &= \cos(\theta) \end{aligned}$$

So the momentum p of the electron is seen to be equal to the longitudinal or z-component of the total momentum of the circulating charged photon.

Summarizing: $p = p_{total}\cos(\theta)$, $v = c\cos(\theta)$, and $\theta = \cos^{-1}(v/c)$

For example, if $v = c/2$, then $\theta = \cos^{-1}(1/2) = 60^{o}$. θ decreases as the electron's speed v increases towards c. But $v < c$ always, as is found experimentally for an electron moving in a vacuum.

The charged photon's transverse momentum component and electron spin

The helically directed total momentum p_{total} of the charged photon makes an angle $\theta < 90^{o}$ with the electron's momentum p, which is the longitudinal momentum component of p_{total}. There is therefore also a transverse momentum component p_{trans} of the charged photon's p_{total}, that is perpendicular to the longitudinal momentum p of the electron. This p_{trans} completes a right triangle with a forward angle θ, having p_{total} as the hypotenuse:

$$
\begin{aligned}
p_{trans}^{\ \ 2} + p^2 &= p_{total}^{\ \ 2} \\
p_{trans}^{\ \ 2} &= p_{total}^{\ \ 2} - p^2 \\
&= (\gamma mc)^2 - (\gamma mv)^2 \\
&= (\gamma mc)^2 (1 - v^2/c^2) \\
&= (\gamma mc)^2 / \gamma^2 \\
&= (mc)^2 \\
p_{\text{trans}} &= \sqrt{(mc)^2} \\
&= mc
\end{aligned}
$$

So there is a circulating transverse component $p_{trans} = mc$ of the helically-circulating charged photon's total momentum p_{total}, perpendicular to the momentum $p = \gamma mv$ of the electron. Since the charged photon's total momentum circulates along the helix, the value of the transverse momentum $p_{trans} = mc$ can be associated with an internally circulating momentum of the charged quantum, or the electron that is modeled by the charged quantum. This internally circulating momentum rotates at the same frequency $\nu = \gamma mc^2/h$ as the charged photon along its helical trajectory. If the electron has no longitudinal momentum, the direction of the transverse momentum will not be clearly defined, and there will be no clearly defined circle of rotation of the transverse momentum $p_{trans} = mc$. When the electron has a small external longitudinal momentum along the z-axis, the internal transverse momentum $p_{trans} = mc$ moves in the xy plane along a circle of radius R_o that is also transverse to the z-axis. Depending on whether the rotation of this momentum mc is positive or negative, this gives the charged photon model a z-component of its angular momentum or spin of

$$s_z = R_o \times p_{trans} = \pm(\hbar/2mc)(mc) = \pm\hbar/2$$

which is the experimental z-component of the spin of an electron. The "+" corresponds to a spin-up electron while the "-" corresponds to a spin-down electron. The charged-photon only has these two states for its spin. This corresponds to the quantum description of an electron's spin states, and could be the origin of these spin states of the electron.

Because the radius R_o of the charged photon's open helix corresponds for small electron speeds to a circumference of $2\pi R_o = 0.5\lambda_{compton}$, the circulating frequency of the charged photon's internal transverse momentum $p_t = mc$ and its light-speed electric charge would actually be

$$\begin{aligned} \nu_{zitt} &= c / circumference \\ &= c / 0.5\lambda_{Compton} \\ &= c / (0.5h / mc) \\ &= 2mc^2 / h \\ &= 2\nu_o \end{aligned}$$

This ν_{zitt} is the zitterbewegung frequency described for the Dirac electron.

The charged photon's magnetic moment

When the internal momentum $p_t = mc$ with the resting energy $E = mc^2$ of the circling, charged photon are combined with the radius (when the electron's speed $v = 0$) of the Hestenes and Rivas helix of $Ro = \hbar / 2mc$ (Dirac's characteristic electron distance), the result is a model of the electron as a double-looping charged photon whose closed double-looped length is $1\lambda_{Compton} = h / mc$. When this length $\lambda_{Compton}$ is double-looped to correspond to the charged photon making a double loop in a resting electron, this double-looped circle has a circumference of $\lambda_{Compton} / 2 = h / 2mc$, and a radius $Ro = (\lambda_{Compton} / 2) / 2\pi = \hbar / 2mc$.

The z-component of the magnetic moment of the charged photon is calculated using the classical method of $Mz = IA$, where I is the effective electric current $I = -e / T$ produced by the circulating electric charge $-e$ in a time T at light speed in a circular loop of radius R_o, and A is the area of the loop. The result is

$$
\begin{aligned}
M_z &= IA \\
&= (-e/T)(\pi R_o{}^2) \\
&= (-e/(2\pi R_o/c)(\pi R_o{}^2) \\
&= (-ec/2)R_o \\
&= (-ec/2)(\hbar/2mc) \\
&= -0.5e\hbar/2m \\
&= -0.5\mu_{Bohr}
\end{aligned}
$$

where $\mu_{Bohr} = e\hbar/2m$ is the Bohr magneton. The Dirac equation predicts the magnitude of the electron's magnetic moment's z-component to be $Mz = -1\mu_{Bohr}$.

How the pitch of the charged photon's helix depends on the electron's speed

We have seen that $\cos(\theta) = v/c$ where θ is the angle the charged photon's total momentum $p_{total} = \gamma mv$ makes with the longitudinal direction. A simple calculation leads to $\tan(\theta) = (\sqrt{c^2 - v^2})/v = (c/v)\sqrt{1 - v^2/c^2} = c/\gamma v$. Similarly, $\sin(\theta) = \cos(\theta)\tan(\theta) = (c/\gamma v)(v/c) = 1/\gamma$.

For an electron moving with speed v, the wavelength λ of the charged photon moving along the open helix is found from $E = \gamma mc^2 = h\nu = hc/\lambda$. That is, $\lambda = hc/\gamma mc^2 = h/\gamma mc = \lambda_{Compton}/\gamma$. This length λ along the helical trajectory corresponds to two turns of the helix or a longitudinal distance $2P$ where the helical pitch P is the longitudinal distance for one full helix rotation.

$$
\begin{aligned}
2P &= \lambda\cos(\theta) \\
2P &= (\lambda_{Compton}/\gamma)(v/c) \\
P &= (v/2c)(\lambda_{Compton}/\gamma) \\
P &= (v/2c)(4\pi R_o/\gamma) \\
P &= \left(2\pi\ v/c\gamma\right)\ R_o
\end{aligned}
$$

For example: if $v = 0.01c$, $P = 0.063\ R_o$. If $v = 0.5\ c$, $P = 2.72\ R_o$. If $v = 0.999c$, $P = 0.28\ R_o$.

The pitch has a maximum value P_{max} for one particular value of the electron's speed v. Calculation of this maximum pitch gives $P_{max} = \pi R_o$ when $v = (\sqrt{2}/2)$. At this value of v, the value of θ is $\theta = cos^{-1}(v/c) = cos^{-1}(\sqrt{2}/2) = 45^\circ$ exactly. The value of γ gamma for $v = (\sqrt{2}/2)\ c$ is $\gamma = \sqrt{2}$. The value of the charged photon's wavelength λ for this γ gamma is $\lambda = \lambda_{Compton}/\gamma = \lambda_{Compton}/\sqrt{2} = (\sqrt{2}/2)\ \lambda_{Compton}$.

How the radius of the charged photon's helix depends on the electron's speed

The radius R of the charged photon's helix varies with the electron's speed v. When two turns or a longitudinal length $2P$ of the helix are "unrolled" flat, a right triangle is formed having one angle θ as previously seen, where the charged photon's wavelength $\lambda = \lambda_{Compton} / \gamma$ is the hypotenuse, the vertical side of the triangle has length two helical circumferences or $4\pi R$, and the horizontal side of the triangle has length $2P = \lambda \cos(\theta) = (v/c)\lambda$. Using $\sin(\theta) = 1/\gamma$, the value of R can be calculated:

$$vertical\ side = hypotenuse \times \sin(\theta)$$
$$(4\pi R) = (\lambda_{Compton} / \gamma) \times (1/\gamma)$$
$$R = (\lambda_{Compton} / 4pi)(1/\gamma^2)$$
$$R = R_o / \gamma^2$$
$$R = R_o(1 - v^2/c^2)$$

where $R_o = \lambda_{Compton} / 4\pi = \hbar / 2mc$, the characteristic Dirac distance. This $R = R_o / \gamma^2$ is the radius of the helical trajectory for the charged photon given in the three parametric equations earlier in this article.

For example, when the electron's speed $v = 0.1c$, then $R = 0.99R_o$. For $v = 0.5c$, $R = 0.75R_o$. For $v = 0.9c$, $R = 0.19R_o$, and for $v = 0.999c$, $R = 0.002R_o$. The corresponding values of θ, where $\theta = \cos^{-1}(v/c)$, are 84°, 60°, 26° and 2.6°.

How the frequency of rotation of the charged photon depends on the electron's speed

In the parametric equation for the circulating charged photon, the argument of the sine and cosine functions is $\gamma ct / R_o$. Where does this come from? For an electron of speed v, the energy of the charged photon is $E = \gamma mc^2 = h\nu$, where ν is the frequency of the charged photon along its helical path. In the time that the charged photon has traveled one wavelength $L_{Compton}$ along its helical trajectory, the trajectory has looped twice around its axis. This double-looping of the trajectory in each cycle of the helical photon produces a cycling frequency around the helical axis of

$$\nu_{zitt} = 2\nu$$
$$= 2\gamma mc^2 / h$$
$$= 2\gamma c / \lambda_{Compton}$$
$$= 2\gamma c / (4\pi R_o)$$
$$= \gamma c / 2\pi R_o$$

The corresponding angular frequency for the charged photon around its longitudinal axis is

$$\begin{aligned}\omega_{zitt} &= 2\pi\nu_{zitt} \\ &= 2\pi(\gamma c/2\pi R_o) \\ &= \gamma c/R_o\end{aligned}$$

and the argument of the sine and cosine functions in the parametric equation for the charged helix is

$$\omega_{zitt} t = \gamma ct/R_o$$

The apparent upper-limit size of the electron as found from high-energy electron scattering experiments

Bender et al (1984) found from high-energy electron scattering experiments at 29 GeV (one GeV equals one thousand million electron volts) that the upper limit of the size of the electron is around $10^{-18}\,\text{m}$. This result has been difficult to reconcile with spatially extended models of the electron having a radius approximating $R_o = \lambda_{Compton}/4\pi = 1.93\times10^{-13}\,\text{m}$. But for a scattering experiment with electrons having energies of $E = 29GeV$, corresponding to $\gamma = E/(mc^2) = 29\times10^9 eV/0.51\times10^6 eV = 5.69\times10^4$, the value of the radius R for the charged photon's helix would be

$$\begin{aligned}R &= R_o/\gamma^2 \\ &= 1.93\times10^{-13}\,\text{m}/(5.69\times10^4)^2\,. \\ &= 6.0\times10^{-23}\,\text{m}\end{aligned}$$

This is well below the upper limit found in such high-energy scattering experiments.

Testing the charged photon model of the electron—the electron-clock experiment

The way to test the charged photon hypothesis is to see what new predictions the hypothesis leads to and to test these predictions experimentally to see if they are supported or not. Currently there is ongoing experimental research by Gouanère et al (2005) to test the idea that an electron behaves as if it has an internal "clock" based on the frequency ν_o found in the Einstein-de Broglie equation for the electron $h\nu_o = mc^2$ for a resting electron. If there were such a clock in the electron, special relativity predicts that the rate of ticking of that clock would be slower in a moving electron, as measured in a stationary laboratory. According to Gouanère et al, the slowing down of this "clock" with electron speed might be detectable by observing the variable scattering or absorption of electrons when passing with a range of energies through certain crystals at specific angles. The *zitterbewegung* frequency $\nu_{zitt} = 2\nu_o$ might also be observed by using this "clock model".

But according to the charged photon model of the electron, the electron does not behave like a clock whose frequency of ticking would slow down as the electron moved faster. Rather, the frequency ν of the charged photon modeling the electron increases with speed as $\nu = \gamma\nu_o$ since the energy of the circulating charged photon increases as $E = \gamma mc^2 = \gamma h\nu_o = h\nu$. The electron-frequency "clock" would beat faster rather than slower with increased electron speed. So the charged photon model predicts a negative result for Gouanère-type electron-clock experiments.

A continuing negative result of Gouanère-type electron-clock experiments would of course not be direct support for the charged photon hypothesis, since there could also be technical reasons for a negative result even if the electron-clock hypothesis were correct. But a confirmed positive result for these electron-clock experiments would disprove the charged photon hypothesis of the electron. So the model is falsifiable, an important property of a scientific hypothesis.

Dirac claimed in his Nobel lecture that the speed-of-light velocity of the electron could not be directly verified by experiment because of the high frequency of the oscillatory motion of the electron and its small amplitude of motion. But what was not feasible in 1933 might be feasible in 2014 or later, particularly since conceiving of the Dirac speed-of-light electron as a charged photon may introduce new thinking about directly or indirectly testing this hypothesis.

The charged photon model and the origin of the electron's spin

The electron (and positron) with a z-component of spin $\pm\hbar/2$ corresponds to the solution of the light-speed circulating charged photon for the value $n = 2$ in the general parametric equation for solutions to the relativistic energy-momentum equation $E^2 = p^2c^2 + m^2c^4$ presented above. The solutions to this equation are quantized in the sense that only integer values of n are permitted by the charged photon model. The model predicts that spin could be quantized differently, depending on the value of n, which is the number of times that a single wavelength $\lambda_{Compton}/\gamma$ of a charged photon corresponding to an electron with speed v turns around its helical axis during one period $T = 1/\nu = h/\gamma mc^2$ of a charged photon. Mathematically, there are also solutions to the energy-momentum equation corresponding to $n = 1,3,4,5,6...$. The value of the transverse component of momentum $p_{trans} = mc$ for a hypothetical particle with mass m composed of a circulating charged photon does not depend on the value of n, but on the radius of the helix formed, which is inversely proportional to n. This leads to other predictions of possible particles with spin $s_z = \pm\hbar$, $\pm\hbar/3$, $\pm\hbar/4$ and in general $\pm\hbar/n$. The value $n = 1$ corresponds to a charged boson, possibly the W^+ and W^- particles of the weak interaction. $n = 2$ corresponds to the electron, which is a fermion, to the muon and tau particles of the electron family which are also fermions, to the six types of quark, which also are fermions, and to all their fermion antiparticles. Higher values of n would correspond to smaller spin but also do not correspond to any known physical particles.

All of these charged-photon particles are mathematical solutions of the relativistic energy-momentum equation. It is interesting that the Dirac equation only gives solutions to the energy-momentum equation for $n = 2$, describing the electron and positron and the spin-up and spin-down values of the z-component of their spins. The charged photon model predicts that there should be equations similar to the Dirac equation that provide mathematical solutions for charged photon particles corresponding to $n = 1,3,4,5...$ of the energy-momentum equation, with corresponding $s_z = \pm\hbar,\ \pm\hbar/3,\ \pm\hbar/4,\ \pm\hbar/5$ and so on.

Conclusions

The charged photon model of the electron represents a new approach to modeling the electron in a way that may provide new insights into the quantum nature of the electron, and the origin of its spin and magnetic moment. The model includes a geometrical way that charged photon model of the electron can be spin-quantized. It is in terms of the integer number n of loops that one wavelength $\lambda = \lambda_{Compton}/\gamma$ of the charged photon makes around its helical axis during one period of its frequency $v = \gamma mc^2/h$ for a moving or stationary electron. Spin is quantized in terms of the newly-discerned Lorentz-invariant rotating transverse momentum $p_{trans} = mc$ of the charged photon for an electron moving at any speed $v < c$, along with the geometrically-defined integer n described above.

The Dirac equation, which is based on the relativistic energy-momentum equation for an electron, may have given only the spin values $s_z = \pm\hbar/2$ because of the way it was formulated for $n = 2$. Future and more general formulations of the Dirac equation, equally valid mathematically and consistent with the energy-momentum equation, could give spin solutions for particles of different values of n besides $n = 2$ for the electron.

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