

Quantum-entangled superluminal double-helix photon produces a relativistic superluminal quantum-vortex *zitterbewegung* electron and positron

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Abstract. Two oppositely-charged quantum-entangled superluminal open-helix spin- $\frac{1}{2}$ half-photons compose a double-helix photon model. During electron-positron pair production these charged half-photons curl up their single-helical trajectories to form geometrically-compatible *zitterbewegung*-frequency superluminal quantum-vortex electron and positron models. The superluminal energy quantum composing the electron and positron models moves on a mathematical toroidal surface that decreases in size and becomes more spherical with increasingly relativistic velocities.

1. Introduction

“All these fifty years of conscious brooding have brought me no nearer to the answer to the question, 'What are light quanta?' Nowadays every Tom, Dick and Harry thinks he knows it, but he is mistaken.” Einstein¹

There has been a continuing interest in the possibility of a composite model of the photon since de Broglie² proposed a composite-photon hypothesis. Below is a two-paragraph excerpt.

“From these general remarks, we concluded that in order to set up a theory of the photon it was necessary above all to use a relativistic form of wave mechanics having elements of symmetry like polarization and, secondly, to introduce *something more* in order to differentiate the photon from other corpuscles. The first part of this program is immediately realized by having recourse to Dirac's theory of the magnetic electron that we previously discussed. We know as a matter of fact that Dirac's theory is relativistic and that it has elements of symmetry that present a marked relationship with those of the polarization of light. Nevertheless it is not enough to suppose that the photon is a corpuscle of negligible mass obeying the equations of Dirac's theory, for the model of the photon thus obtained would have, as you might say, only half the symmetry of the actual photon; in addition, it would obey, it would seem, the Fermi statistics, as the electron does and would not be capable of being annihilated in the photoelectric effect. Something more is very much needed.”

“And this something more we have tried to introduce by supposing that the photon is made up not by one Dirac corpuscle, but by two. It can then be ascertained that these two corpuscles or demi-photons must be complementary to each other in the same sense that the positive electron is complementary to the negative electron in Dirac's theory of holes. Such a couple of complementary corpuscles can annihilate themselves on contact with matter by giving up all their energy, and this accounts completely for the characteristics of the photoelectric effect. In addition, the photon being thus made up of two corpuscles, each with a spin of $\hbar/2$ for a total of $1\hbar$ should obey the Bose-Einstein statistics, as the exactness of Planck's law of black body radiation demands. Finally, this model of the photon permits us to define an electromagnetic field connected with the probability of

annihilation of the photon, a field which obeys the Maxwell equations and possesses all the characters of the electromagnetic light wave. Although it would still be premature to make a definitive pronouncement on the value of this attempt, it is indisputable that it leads to interesting results and that it strongly focuses attention on the symmetry properties of the complementary corpuscles whose existence, suggested by Dirac's theory, has been verified by the discovery of the positive electron."

In another book, de Broglie³ gave a more extended discussion of his half-photon hypothesis, and the rationale behind it. He also suggested that the two half-photons might be two neutrinos.

Most of the quantitative research about de Broglie's spin- $\frac{1}{2}$ half-photon hypothesis of a composite photon has followed up de Broglie's suggestion that the two particles could be neutrinos, which at that time were hypothetical particles considered to be uncharged and massless. Now neutrinos are known to have very small but so far undetermined non-zero masses. Levitt⁴ proposed that a photon consists of double-helix pair of neutrinos, with undefined charge, that equally share the spin of a photon. Perkins⁵ reviewed various criticisms of de Broglie's two-neutrino suggestion and found that some of these criticisms are not valid, but that problems remain with the two-neutrino model. Múnera⁶ describes a 4-dimensional hydrodynamic model of the photon as a source-sink dipole consisting of an electron-positron pair. You⁷ proposes two ways to construct a composite photon: from an unbonded massless and uncharged fermion-antifermion pair, and from a bonded electron-positron pair.

Several charged electric-dipole double-helix photon models have been proposed. Boland⁸ proposes a superluminal double-helix electric-dipole composite photon model very similar to the present one, supported by microwave resonant cavity experiments. His charged-dipole composite photon model includes linear and elliptically polarized photons as well as the circularly polarized photon in the present model. Gauthier⁹ independently proposed a superluminal double-helix oppositely-charged-dipole composite photon model, with the same quantitative features as the Boland⁸ spin-1 photon model and the present double-helix photon model, before learning of de Broglie's spin- $\frac{1}{2}$ half-photon hypothesis. Caroppo¹⁰ independently proposes the identical superluminal double-helical charged-dipole composite photon model, with the same quantitative features as the Gauthier⁹ photon model. The present superluminal double-helical composite photon model updates the Gauthier⁹ photon model in light of de Broglie's spin- $\frac{1}{2}$ half-photon hypothesis while providing additional quantitative analysis of the Gauthier⁹ model. Giertz¹¹ proposes a double-helix photon model composed of two oppositely charged particles. In his model, the positive and negative charges rotate in opposite directions, unlike in the Boland⁸, Gauthier⁹ and Caroppo¹⁰ double-helix models above where the two opposite charges of magnitude $Q = 16.6 e$ rotate in the same direction.

The production of electron-positron pairs from single photons was first observed in 1933 by Blackett¹² soon after the discovery of the predicted positron by Carl D. Anderson¹³. Schroedinger¹⁴ analysed the Dirac relativistic quantum-mechanical equation's solution for a free electron. Schroedinger found a very high frequency and very small amplitude "trembling" or *zitterbewegung* motion of the electron in addition to its linear motion, which he explained as an oscillation between positive and negative energy states of the electron. Huang¹⁵ showed that this *zitterbewegung* motion can instead be associated with a high frequency internal circulation of energy in the electron that could account for the electron's experimental angular momentum or spin. Hestenes¹⁶ showed that the Dirac equation, when analysed using geometric algebra, is consistent with light-speed *zitterbewegung*-frequency helical circulation of the electron's charge. This could explain the electron's spin and help explain the electron's magnetic moment. Williamson and van der Mark¹⁷ proposed that the electron's spin can be explained by a double-looped circulation of a photon having a wavelength equal to the electron's Compton wavelength $\lambda_{\text{Compton}} = h / mc = 2.43 \times 10^{-12}$ m. The Compton wavelength is the wavelength of a photon having the same energy as that of a resting electron. This double-looping circulation of a Compton-wavelength photon would give a resting electron the *zitterbewegung* frequency of $\nu_{\text{zit}} = 2mc^2 / h = 2.47 \times 10^{20}$ Hz. The present article shows how the electron's *zitterbewegung* frequency as well the electron's energy structure can arise naturally from a double-helix photon model transforming into a quantum vortex electron and positron model during electron-positron pair production.

The present article proposes that the two component particles of the double-helix photon model are quantum-mechanically entangled. Two particles such as two electrons or two photons are quantum-mechanically entangled if their quantum wave functions describe a single quantum object. The quantum wave function of an entangled pair of particles is not just the linear sum of the quantum wave functions of the two individual particles. Measurement of the quantum state of one of two quantum-mechanically entangled particles immediately produces a corresponding quantum state of the second particle, even if the particles are separated beyond the possibility of light-speed communication between them that could produce such correspondence. The concept of quantum-mechanical entanglement was discovered by Einstein, Podolsky and Rosen¹⁸, and given the name “entanglement” (“veänkung”) by Schroedinger¹⁹. It was first experimentally confirmed by Aspect et al²⁰.

When a photon is transformed into an electron-positron pair by passing near an atomic nucleus, the electron-positron pair is found to be quantum-mechanically entangled. The author proposes here that the two spin-½ half-photons forming a composite photon, as suggested by de Broglie², are also quantum-mechanically entangled. The two circulating superluminal energy quanta in the present double-helix photon model are proposed to act together as a single quantum object—the photon. Measurement of the quantum mechanical state of one superluminal energy quantum (or one spin-½ charged half-photon) would immediately put the other superluminal energy quantum into a corresponding quantum mechanical state consistent with the quantum mechanical state of the double-helix photon.

If the double-helix photon model is quantum-mechanically entangled, this could make it more difficult to separately detect or measure the two superluminal energy quanta proposed to compose it. The double-helix photon model makes the strong experimental prediction that two opposite entangled charges of magnitude $Q = e\sqrt{2/\alpha} = 16.6e$ will be found on close experimental examination of the photon during the process of electron-positron pair production.

This article is not meant to review the various 3-D geometrical models of the photon and the electron. The present article suggests how a proposed 3-D double-helical model of the photon can be transformed into a proposed 3-D closed-helical model of the electron and the positron during electron-positron pair production. In the proposed transformation process, amplitude and frequency parameters of the double-helix photon model equal the corresponding amplitude and frequency parameters of the electron and positron models.

A key feature of modelling this transformation process is that the incoming photon is proposed to be a double-helix composite structure of two mutually circulating oppositely-charged single-helix half-photons that separate during electron-positron pair production and curl up their trajectories to become a quantum vortex electron and a quantum vortex positron pair. A second key feature is that both the double-helix photon model and the quantum vortex electron and positron models are proposed to be internally superluminal by means of a proposed helically-circulating electrically-charged point-like superluminal energy quantum. This internal superluminality is maintained before and after the transformation process, even though the double-helix photon model itself moves forward at light speed and the quantum vortex electron and positron models move forward at sub-light speeds.

2. Summary of the Superluminal Double-Helix Photon Model

The present article further analyzes the superluminal double-helix charged dipole model of the superluminal double-helix photon model proposed by Gauthier⁹. As in Gauthier⁹ each spin-½ half-photon is composed of an electrically charged superluminal energy quantum moving helically at $c\sqrt{2}$ with a forward helical angle of 45° and with a helical radius of $\lambda/2\pi$ and diameter λ/π , where λ is the wavelength of the composite photon model. The equal and opposite electric charges on the charge dipole are found by calculation to be $Q = \pm e\sqrt{2/\alpha} \cong \pm 16.6e$ where e is the electron’s charge magnitude 1.602×10^{-19} C and α is the fine structure constant $\alpha = e^2/4\pi\epsilon_0\hbar c \cong 1/137.04$ from quantum electrodynamics (QED). The superluminal energy quantum in each spin-½ charged half-photon makes one full turn of its helical trajectory for each half-photon (and each photon) wavelength. The calculations for the x , y and z -components of the photon model’s spin are given explicitly,

showing that the composite double-helix photon model has a calculated total spin $S = \hbar = h/2\pi$. The 45° forward helical angle of the double-helix photon model is also calculated explicitly from the helix equations. In addition, the inertial mass M of the double-helix photon model is calculated using Newton's second law of motion applied to the circulating internal momenta of the double-helix photon model, to give $M = E/c^2 = h\nu/c^2$.

3. The equations for both helically-moving superluminal energy quanta in the double-helix photon model

In the proposed superluminal double-helix model of a spin $1\hbar$ photon composed of two spin $\frac{1}{2}\hbar$ charged half-photons, the two oppositely-charged superluminal energy quanta are transverse to each other and move together in a double helical trajectory. The parametric equations for the superluminal energy quantum's position and momentum components for the first and the second half-photon are given in equation (1) and equation (2) respectively. Equation (2) is obtained by setting the x and p_x and the y and p_y components of equation (2) equal to the negative values of the x and p_x and the y and p_y components of equation (1). The z and p_z components are the same for both sets of equations.

When the photon model's two helically-moving superluminal energy quantum's coordinates are expressed in terms of the photon's wavelength λ and angular velocity ω , we get the parametric coordinates of the two helices of the double-helix spin $+1\hbar$ photon model to be

$$\begin{aligned} x_1(t) &= \frac{\lambda}{2\pi} \cos(\omega t) & p_{x1}(t) &= -\frac{h}{2\lambda} \sin(\omega t) \\ y_1(t) &= \frac{\lambda}{2\pi} \sin(\omega t) & p_{y1}(t) &= \frac{h}{2\lambda} \cos(\omega t) \\ z_1(t) &= ct & p_{z1}(t) &= \frac{h}{2\lambda} \end{aligned} \quad (1)$$

and

$$\begin{aligned} x_2(t) &= -\frac{\lambda}{2\pi} \cos(\omega t) & p_{x2}(t) &= \frac{h}{2\lambda} \sin(\omega t) \\ y_2(t) &= -\frac{\lambda}{2\pi} \sin(\omega t) & p_{y2}(t) &= -\frac{h}{2\lambda} \cos(\omega t) \\ z_2(t) &= ct & p_{z2}(t) &= \frac{h}{2\lambda} \end{aligned} \quad (2)$$

A 3-D graphic of the superluminal double-helix spin 1 photon model is shown in figure 1.

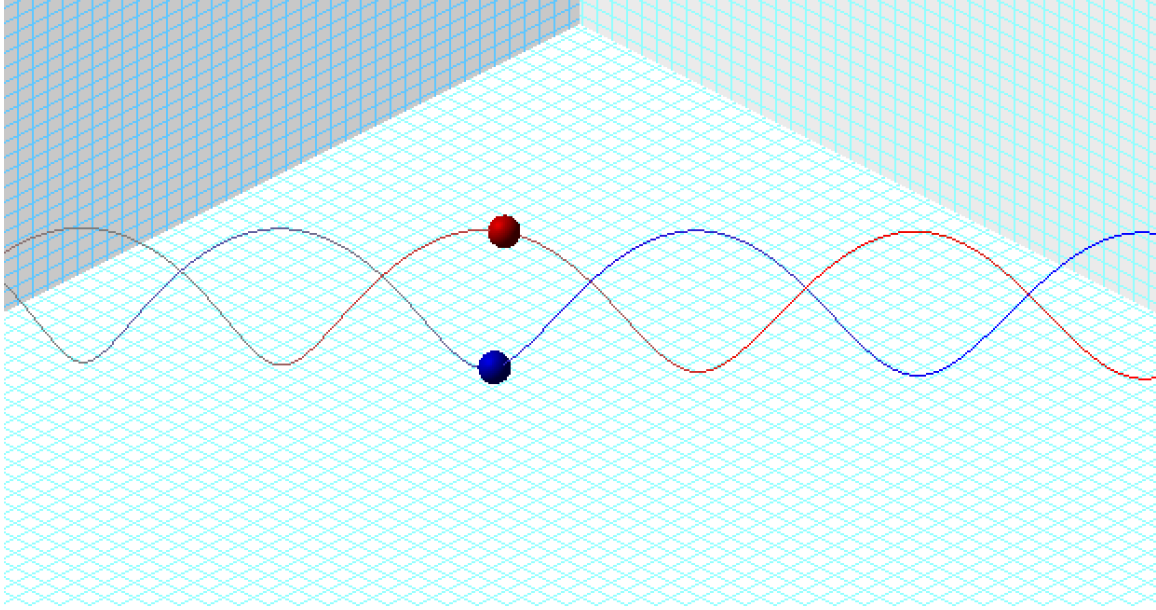


Figure 1. The superluminal double-helix model of the photon, showing the two superluminal energy quanta (which are actually point-like) moving on 45-degree helical trajectories at a speed $c\sqrt{2}$, separated by a distance $D = \lambda / \pi$ where λ is the wavelength of the photon. Each superluminal quantum composes a spin- $1/2$ half-photon. The double-helix photon model has calculated spin $S = 1\hbar$.

The parametric equations for the spin $-1\hbar$ double-helix photon are obtained by reversing the signs of the y and p_y components in both equation (1) and equation (2) above. From equation (1) and equation (2), the distance D between the two superluminal quanta as they move helically opposite to each other, each with helical radius $R = \lambda / 2\pi$, is the double-helix photon's helical diameter $D = 2R = \lambda / \pi$.

4. The speed of the superluminal energy quantum for the spin- $1/2$ charged half-photon model

The speed $v(t)$ of each superluminal energy quantum in the double-helix photon model is derived by differentiating the position components in equation (1) above, giving equation (3) and equation (4).

$$\begin{aligned}
 v_x(t) &= dx(t) / dt = -\frac{\lambda\omega}{2\pi} \sin(\omega t) = -c \sin(\omega t) \\
 v_y(t) &= dy(t) / dt = \frac{\lambda\omega}{2\pi} \cos(\omega t) = c \cos(\omega t) \\
 v_z(t) &= dz(t) / dt = c
 \end{aligned} \tag{3}$$

$$\begin{aligned}
 v(t)^2 &= v_x(t)^2 + v_y(t)^2 + v_z(t)^2 \\
 &= [-c \sin(\omega t)]^2 + [c \cos(\omega t)]^2 + c^2 \\
 &= c^2 [\sin^2(\omega t) + \cos^2(\omega t)] + c^2 \\
 &= c^2 + c^2 \\
 &= 2c^2
 \end{aligned} \tag{4}$$

Therefore $v(t) = \sqrt{2c^2} = c\sqrt{2}$ for the speed of each superluminal energy quantum in the spin- $1/2$ charged half-photon model.

5. Calculation of the total momentum $p = h/\lambda$ of the double-helix photon model

The total momentum is found by calculating the total x , y and z momentum components for the two helical particles in equation (5) and equation (6).

$$\begin{aligned}
 p_{xtotal}(t) &= p_{x1}(t) + p_{x2}(t) = -\frac{h}{2\lambda}\sin(\omega t) + \frac{h}{2\lambda}\sin(\omega t) = 0 \\
 p_{ytotal}(t) &= p_{y1}(t) + p_{y2}(t) = \frac{h}{2\lambda}\cos(\omega t) + [-\frac{h}{2\lambda}\cos(\omega t)] = 0 \\
 p_{ztotal}(t) &= p_{z1}(t) + p_{z2}(t) = \frac{h}{2\lambda} + \frac{h}{2\lambda} = \frac{h}{\lambda}
 \end{aligned} \tag{5}$$

The total momentum p_{total} of the double-helix photon model is then given by

$$\begin{aligned}
 p_{total} &= \sqrt{p_{xtotal}(t)^2 + p_{ytotal}(t)^2 + p_{ztotal}(t)^2} \\
 &= \sqrt{0^2 + 0^2 + (h/\lambda)^2} = h/\lambda
 \end{aligned} \tag{6}$$

which is the experimental value of a photon's momentum.

6. Calculation of the 45° forward helical angle of the double-helix photon model

The forward helical angle θ of the first composite-photon helical trajectory given by equation (1), is calculated according to equation (7).

$$\begin{aligned}
 \tan\theta &= v_{transverse} / v_{longitudinal} \\
 &= \sqrt{v_x(t)^2 + v_y(t)^2} / v_z(t) \\
 &= \sqrt{[dx_1(t)/dt]^2 + [dy_1(t)/dt]^2} / [dz_1(t)/dt] \\
 &= \sqrt{[(\frac{\lambda}{2\pi})^2(-\omega\sin(\omega t))]^2 + [(\frac{\lambda}{2\pi})^2(\omega\cos(\omega t))]^2} / d(ct)/dt \\
 &= \sqrt{[(\frac{\lambda\omega}{2\pi})^2(\sin^2(\omega t) + \cos^2(\omega t))] / c} \\
 &= \sqrt{(\lambda v)^2[\sin^2(\omega t) + \cos^2(\omega t)]} / c \\
 &= \sqrt{(c)^2[\sin^2(\omega t) + \cos^2(\omega t)]} / c \\
 &= \sqrt{(c)^2[1]} / c \\
 &= c / c \\
 &= 1
 \end{aligned} \tag{7}$$

This gives the forward helical angle $\theta = \tan^{-1}(1) = 45^\circ$. The same 45° result is obtained for the forward helical angle of the second superluminal particle's helical trajectory, given parametrically in equation (2).

7. Calculation of the x , y and z -components of the spin of the composite photon model

The vector equation for the calculation of the angular momentum or spin of an object is $\vec{s} = \vec{R} \times \vec{P}$. The spin component calculation formulas are shown in equation (8).

$$\begin{aligned}
s_x &= yp_z - zp_y \\
s_y &= zp_x - xp_z \\
s_z &= xp_y - yp_x
\end{aligned} \tag{8}$$

In the case of the double-helix photon model, both helices from equations (1) and equation (2) are included together in the calculation, shown below in equation (9), equation (10) and equation (11):

$$\begin{aligned}
s_{x \text{ total}}(t) &= \{y_1(t)p_{z1}(t) - z_1(t)p_{y1}(t)\} + \{y_2p_{z2}(t) - z_2(t)p_{y2}(t)\} \\
&= \frac{\lambda}{2\pi} \sin(\omega t) \frac{h}{2\lambda} - ct \frac{h}{2\lambda} \cos(\omega t) + \left(-\frac{\lambda}{2\pi} \sin(\omega t)\right) \frac{h}{2\lambda} - ct \left(-\frac{h}{2\lambda} \cos(\omega t)\right) \\
&= 0
\end{aligned} \tag{9}$$

$$\begin{aligned}
s_{y \text{ total}}(t) &= \{z_1(t)p_{x1}(t) - x_1(t)p_{z1}(t)\} + \{z_2p_{x2}(t) - x_2(t)p_{z2}(t)\} \\
&= ct \left(-\frac{h}{2\lambda} \sin(\omega t)\right) - \frac{\lambda}{2\pi} \cos(\omega t) \frac{h}{2\lambda} + ct \frac{h}{2\lambda} \sin(\omega t) - \left(-\frac{\lambda}{2\pi} \cos(\omega t)\right) \frac{h}{2\lambda} \\
&= 0
\end{aligned} \tag{10}$$

$$\begin{aligned}
s_{z \text{ total}}(t) &= \{x_1(t)p_{y1}(t) - y_1(t)p_{x1}(t)\} + \{x_2p_{y2}(t) - y_2(t)p_{x2}(t)\} \\
&= \frac{\lambda}{2\pi} \cos(\omega t) \frac{h}{2\lambda} \cos(\omega t) - \frac{\lambda}{2\pi} \sin(\omega t) \left(-\frac{h}{2\lambda} \sin(\omega t)\right) \\
&\quad + \left(-\frac{\lambda}{2\pi} \cos(\omega t)\right) \left(-\frac{h}{2\lambda} \cos(\omega t)\right) - \left(-\frac{\lambda}{2\pi} \sin(\omega t)\right) \frac{h}{2\lambda} \sin(\omega t) \\
&= \frac{h}{4\pi} (2\sin^2(\omega t) + 2\cos^2(\omega t)) \\
&= \frac{h}{2\pi} (\sin^2(\omega t) + \cos^2(\omega t)) \\
&= \frac{h}{2\pi} (1) \\
&= \frac{h}{2\pi} \\
&= \hbar
\end{aligned} \tag{11}$$

The z -component of the spin of the double-helix photon model is found to be $\hbar = h/2\pi$, the experimental value of the spin of the photon. The x and y -components of the composite photon's spin are both found to be zero. If the double-helix composite photon model has the opposite helical direction compared to that contained in the double-helix formulas in equation (1) and equation (2), the z -component of spin of the composite photon model is found to be $-\hbar$, while the x and y -components of spin remain zero.

8. Calculation of the electric charge on each superluminal energy quantum in the double-helix photon model

In the double-helix model, the two helically-moving superluminal quanta carry an electric charge Q and $-Q$ respectively, whose attractive Coulomb force keeps them moving in their double-helical

trajectories. Each charge's x and y coordinates define a circle with radius $\lambda/2\pi$ and angular frequency ω . As seen from equation (1), the transverse component of momentum of the superluminal energy quantum of each half-photon is $p_{\text{trans}} = h/\lambda_{\text{half}} = h/2\lambda = \frac{1}{2}\frac{h}{\lambda} = \frac{1}{2}p_{\text{photon}}$.

The transverse momentum vector \vec{p}_{trans} of each superluminal energy quantum is rotating in a circle at the photon's angular velocity ω . This produces a rate of change with time $d\vec{p}_{\text{trans}}/dt$ of this rotating transverse momentum vector. If a momentum vector of magnitude p_{trans} rotates in a circle with angular velocity ω , then the rate of change of vector momentum equals a centripetal force of magnitude $F_{\text{cent}} = |\vec{F}_{\text{cent}}| = |d\vec{p}_{\text{trans}}/dt| = \omega p_{\text{trans}}$. The Coulomb attractive force \vec{F}_{coul} between the two opposite superluminal charges Q and $-Q$, separated by the distance D , is the centripetal force \vec{F}_{cent} on each charged superluminal energy quantum. We set the magnitudes of these two forces \vec{F}_{coul} and \vec{F}_{cent} equal in the following calculation and solve for Q . We use the relations $\omega = 2\pi\nu = 2\pi c/\lambda$ and $D = \lambda/\pi$, and also the relation $\alpha = e^2/4\pi\epsilon_0\hbar c = 1/137.04$ to give equation (12).

$$\begin{aligned}
F_{\text{coul}} &= F_{\text{cent}} \\
\frac{Q^2}{4\pi\epsilon_0 D^2} &= dp_{\text{trans}}/dt = \omega p_{\text{trans}} \\
\frac{Q^2}{4\pi\epsilon_0 (\lambda/\pi)^2} &= (2\pi \frac{c}{\lambda})(\frac{1}{2}\frac{h}{\lambda}) \\
\frac{Q^2 \pi^2}{4\pi\epsilon_0 \lambda^2} &= \frac{\pi c h}{\lambda^2} \\
\frac{Q^2 \pi}{4\pi\epsilon_0} &= c h \\
\frac{Q^2 \pi}{4\pi\epsilon_0} &= c h \left(\frac{2\pi}{2\pi}\right) = 2\pi c \hbar \\
\frac{Q^2}{4\pi\epsilon_0 \hbar c} &= 2 \\
\frac{e^2}{4\pi\epsilon_0 \hbar c} &= \frac{2e^2}{Q^2} \\
\alpha &= \frac{2e^2}{Q^2} \\
Q^2 &= \frac{2}{\alpha} e^2 \\
Q &= e\sqrt{\frac{2}{\alpha}} = e\sqrt{\frac{2}{1/137.04}} = e\sqrt{274.08} = 16.6e
\end{aligned} \tag{12}$$

9. The electrical potential energy of the composite photon model

The double-helix photon model has point-like charges Q and $-Q$ (where $Q = e\sqrt{2/\alpha}$ as above) separated by their double-helix diameter $D = \lambda/\pi$ as calculated earlier. So the two charges will have

an electrical potential energy $U = -Q^2 / 4\pi\epsilon_0 D$. A photon of wavelength λ also has energy $E = h\nu = hc / \lambda$. In equation (13) we now calculate the ratio U / E of these two energies in the double-helix photon model.

$$\begin{aligned}
U / E &= \frac{-Q^2 / 4\pi\epsilon_0 D}{hc / \lambda} \\
&= \frac{(-2e^2 / \alpha) / 4\pi\epsilon_0 (\lambda / \pi)}{hc / \lambda} \\
&= (1 / \alpha)(e^2 / 4\pi\epsilon_0 hc)(-2\pi) \\
&= (1 / \alpha)(e^2 / 4\pi\epsilon_0 \hbar c)(-1) \\
&= (1 / \alpha)(\alpha)(-1) \\
&= -1
\end{aligned} \tag{13}$$

This means that the electrical potential energy of the two electric charges forming the double-helix photon model is the negative of the energy of the photon being modelled. Since potential energy is a relative quantity, this calculation assumes that the potential energy of the two opposite electric charges in the model would be zero if they were infinitely far apart.

This result may be more meaningful if it is compared with the ratio of the electrical potential energy U to the total kinetic energy KE_{total} of two circling oppositely charged particles each with mass m , such as an electron and a positron with charges $-e$ and $+e$ forming an atom of positronium. The opposite-charged particles circle around each other as a result of their mutual Coulomb force of attraction. Their value of U / KE_{total} here is calculated in equation (14) and equation (15).

In a simple positronium model, each charged particle circles with a radius R and a centripetal acceleration given in the usual way by $a_{cent} = v^2 / R$, produced by the mutually-attractive Coulomb force $F_{coul} = ke^2 / (D)^2 = ke^2 / (2R)^2$, since $D = 2R$ is the separation of the two charged particles in a simple positronium model. The electrical constant k equals $1 / 4\pi\epsilon_0$. Using Newton's 2nd law in equation (14):

$$\begin{aligned}
F &= ma \\
F_{coul} &= ma_{cent} \\
ke^2 / (D)^2 &= mv^2 / R \\
ke^2 / (2R)^2 &= mv^2 / R \\
ke^2 / 4R^2 &= mv^2 / R \\
ke^2 / 4R &= mv^2
\end{aligned} \tag{14}$$

The electrical potential energy of the two circling charges is $U = -ke^2 / D = -ke^2 / 2R$. The total non-relativistic kinetic energy of the two circulating electron charges is $KE_{total} = 2 \times \frac{1}{2}mv^2 = mv^2$. Using equation (14), the ratio of the electrical potential energy U to the total kinetic energy KE_{total} of the two circling charges is therefore given in equation (15).

$$\begin{aligned}
U / KE_{total} &= \frac{-ke^2 / 2R}{mv^2} \\
&= \frac{-ke^2 / 2R}{ke^2 / 4R} \\
&= -2
\end{aligned} \tag{15}$$

This means that the ratio of the electrical potential energy to photon energy in the double-helix photon model is only half of the ratio of the electrical potential energy to total kinetic energy of the circling electron-positron pair in positronium.

In the case of the double-helix photon model, the opposite electric charges on the two half-photons are held together by their mutually attractive Coulomb forces and move at superluminal speed along a double helix. In the circling electron-positron example, the two particles are held together by the attracting Coulomb force to form an atom of positronium. In fact, a positronium atom only exists for a tiny fraction of a second before the electron and positron mutually annihilate to yield two or three (or more) photons.

10. No magnetic force between the two superluminal double-helix charged particles

The magnetic force between two moving charged point-particles whose velocities are perpendicular to each other is zero. This is because each charge acts like a small electric current that produces a magnetic field making concentric rings whose magnetic field direction along the rings is at right angles to the velocity of the moving charge. If a nearby second point charge has a velocity vector that is perpendicular to the velocity vector of the first charge, the angle between the magnetic field of the first charge and the velocity vector of the second charge will either equal 0° or 180° . The force on the second charge from the magnetic field of the first charge (which is proportional to the sine of the angle between the magnetic field of the first charge and the velocity vector of the second charge), will then equal zero since $\sin 0^\circ = \sin 180^\circ = 0$.

It was shown above that the forward helical angles of the double-helix photon model are both 45° . The two superluminal particles are moving opposite to each other in a double-helical trajectory. So their two 45° forward helical angles are directed away from the longitudinal direction of the composite photon model. The total angle θ_{total} between the velocity vectors of the two helically-circulating superluminal particles is therefore $\theta_{total} = 45^\circ + 45^\circ = 90^\circ$. By symmetry, this total angle between the velocity vectors of the two superluminal particles will remain 90° through each full helical cycle. So the magnetic force on each of the two helically-moving superluminal charged particles from the other particle in the photon model is always zero. The total force on each of the two helically-circulating superluminal charged particles is therefore only due to the Coulomb attractive force of the other particle.

11. Inertial mass $M=E/c^2$ of the double-helix photon model calculated from Newton's second law

Newton's second law is $\vec{F} = m\vec{a} = d\vec{p}/dt$, where \vec{F} is the net force on an object. Here m is the object's inertial mass, \vec{a} is the acceleration of the object, and $d\vec{p}/dt$ is the rate of change of the object's vector momentum \vec{p} . If a particle with momentum \vec{p} has circular motion, the rate of change $d\vec{p}/dt$ of the vector momentum can be calculated, as well as the centripetal acceleration \vec{a}_c of the object towards the center of the circle that the particle is moving around. In the case of the double-helix composite photon model with wavelength λ , each half-photon moves in a helical trajectory with a transverse momentum component $p_{trans} = h/2\lambda$ as seen in equation (1). The radius of each helical trajectory is $R = \lambda/2\pi$ as also seen in equation (1). The transverse momentum component p_{trans} of the superluminal quantum composing each half-photon rotates circularly with the angular velocity ω of the double-helix photon. For a photon, $\omega = 2\pi\nu = 2\pi c/\lambda$ since $\nu = c/\lambda$. For the circularly rotating transverse momentum component \vec{p}_{trans} , basic vector analysis gives $d\vec{p}_{trans}/dt = \omega p_{trans}$ directed towards the center of the circle of rotation. The centripetal acceleration a_{cent} of the circling momentum p_{trans} is given by $a_{cent} = R\omega^2$, also directed towards the center of the circle of rotation. The inertial mass m_{half} of each of the half-photons composing the double-helix photon is then given by

$m_{\text{half}} = (d\bar{p}_{\text{trans}} / dt) / \bar{a}_{\text{cent}}$. The total inertial mass M of the double-helix photon model is then given by equation (16).

$$\begin{aligned}
M &= 2m_{\text{half}} \\
&= 2(d\bar{p}_{\text{trans}} / dt) / a_{\text{cent}} \\
&= 2(\omega p_{\text{trans}}) / (R\omega^2) \\
&= 2p_{\text{trans}} / R\omega \\
&= 2(h/2\lambda) / (\lambda/2\pi \times 2\pi c / \lambda) \\
&= h / c\lambda \\
&= h / (c \times c / \nu) \\
&= h\nu / c^2 = E_{\text{photon}} / c^2
\end{aligned} \tag{16}$$

The photon model's inertial mass is calculated to be the energy of the photon divided by the square of the speed of light. This is the case even though the invariant mass of a photon is zero.

12. The double-helix photon model and electron-positron pair production

An electron and a positron are produced most commonly when a photon of sufficient energy (greater than 1.022 MeV, corresponding to the combined mass of an electron and a positron) passes near an atomic nucleus. This is one example of electron-positron pair production. The present composite photon model lends itself to a relatively straightforward (if oversimplified) explanation of this process. When the composite photon is in the sufficiently strong electric field of an atomic nucleus, the electric field of the nucleus acts on the two helically-moving electric charges in the composite photon and causes the two spin- $\frac{1}{2}$ charged half-photons to reduce their electric charge from $\pm 16.6e$ to $\pm 1e$. The electric charges are now no longer large enough to attract each other sufficiently to maintain their double-helical trajectory. The two spin- $\frac{1}{2}$ charged half-photons, now with charges e and $-e$, separate and the trajectories of the two spin- $\frac{1}{2}$ charged half-photons curl up separately to form an electron and a positron. By curling up, the two spin- $\frac{1}{2}$ charged half-photons each gain the electron's invariant mass m of $0.511 \text{ MeV}/c^2$ that they did not have when travelling together as the composite photon.

Electron-positron pairs are produced when a sufficiently energetic photon, of at least the energy of an electron plus a positron, or $E = 2mc^2$, passes near an atomic nucleus and is converted to an electron and a positron. The atomic nucleus absorbs excess momentum from the photon to electron-pair conversion but doesn't otherwise participate in the conversion process. Parametric equations for the x , y and z -coordinates of a proposed circulating superluminal energy quantum forming a superluminal quantum-vortex model of a spin $+\frac{1}{2}\hbar$ relativistic electron or positron are given in equation (17).

$$\begin{aligned}
x(t) &= \frac{\lambda_c}{4\pi} \left(\frac{1}{\gamma^2} + \frac{1}{\gamma} \cos(\gamma\omega_{\text{zitt}}t) \right) \cos(\gamma\omega_{\text{zitt}}t) \\
y(t) &= \frac{\lambda_c}{4\pi} \left(\frac{1}{\gamma^2} + \frac{1}{\gamma} \cos(\gamma\omega_{\text{zitt}}t) \right) \sin(\gamma\omega_{\text{zitt}}t) \\
z(t) &= \frac{\lambda_c}{4\pi\gamma} \sin(\gamma\omega_{\text{zitt}}t) + vt
\end{aligned} \tag{17}$$

where $\frac{\lambda_c}{4\pi} = \frac{\hbar}{2mc} = 1.93 \times 10^{-13} \text{ m}$ is the radius of the circular axis of the resting quantum-vortex electron model and $\omega_{\text{zitt}} = 2mc^2/\hbar = 1.55 \times 10^{21} \text{ radians/sec}$ is the resting electron's *zitterbewegung* angular velocity.

In the non-relativistic limit, where $\gamma \rightarrow 1$, these parametric equations for a spin $+\frac{1}{2}\hbar$ (spin-up) electron become equation (18).

$$\begin{aligned}
x(t) &= \frac{\lambda_C}{4\pi} (1 + \cos(\omega_{zitt}t)) \cos(\omega_{zitt}t) \\
y(t) &= \frac{\lambda_C}{4\pi} (1 + \cos(\omega_{zitt}t)) \sin(\omega_{zitt}t) \\
z(t) &= \frac{\lambda_C}{4\pi} \sin(\omega_{zitt}t) + vt
\end{aligned} \tag{18}$$

The parametric equations for the spin $-\frac{1}{2}\hbar$ (spin-down) quantum-vortex electron and positron models are obtained by reversing the sign of the $y(t)$ components in the relativistic and non-relativistic equations above.

The proposal is that two spin- $\frac{1}{2}$ half-photons, each composed of a helically-circulating superluminal energy quantum, are separated during electron-positron pair production from a double-helical photon model. These two superluminal energy quanta curl up their respective trajectories to form closed-helix models of an electron and positron. This electron model is called the quantum vortex model of the electron. $R_o = \lambda_{\text{Compton}} / 4\pi$ in the equations above (where $\lambda_{\text{Compton}} = h / mc = 2.43 \times 10^{-12} \text{m}$ is the Compton wavelength) is the helical radius of the quantum-vortex electron model. R_o is also the radius of a double-helix photon model of energy $E = 2mc^2 = 1.022 \text{ MeV}$, which is the sum of the rest energies of an electron and positron, each of $E_o = mc^2 = 0.511 \text{ MeV}$. The angular velocity $\omega_{zitt} = 2\pi v_{zitt} = 2mc^2 / \hbar = 1.55 \times 10^{21}$ radians/sec is the electron's *zitterbewegung* angular velocity predicted by the relativistic Dirac equation.

The circulating superluminal energy quantum for the electron has a point-like electric charge of $-1e$, while for a positron the electric charge is $+1e$. The superluminal energy quantum in a resting quantum-vortex electron circulates with angular frequency ω_{zitt} in a closed helical trajectory whose circular helical axis has a circumference $C = \lambda_{\text{Compton}} / 2$ and radius $R_o = \lambda_{\text{Compton}} / 4\pi$. The superluminal energy quantum in the quantum-vortex model moves along the surface of a mathematical horn torus of helical radius $R_o = \lambda_{\text{Compton}} / 4\pi$. From equation (18), the calculated maximum speed of the superluminal energy quantum in a resting quantum vortex electron model, when the electron's speed v is zero, is $V_{\text{max}} = c\sqrt{5} = 2.236c$. This is the speed of the superluminal energy quantum when it crosses the outer equator of the mathematical horn torus. The minimum speed of the superluminal energy quantum is calculated from equation (18) when the electron's speed v is zero to be $V_{\text{min}} = c$. This is the instantaneous speed of the superluminal energy quantum when it passes through the exact center of the mathematical horn torus. See figure 2 below. The double-helix photon travels forward with a velocity c , while having a constant internal superluminal speed $c\sqrt{2} = 1.414c$.

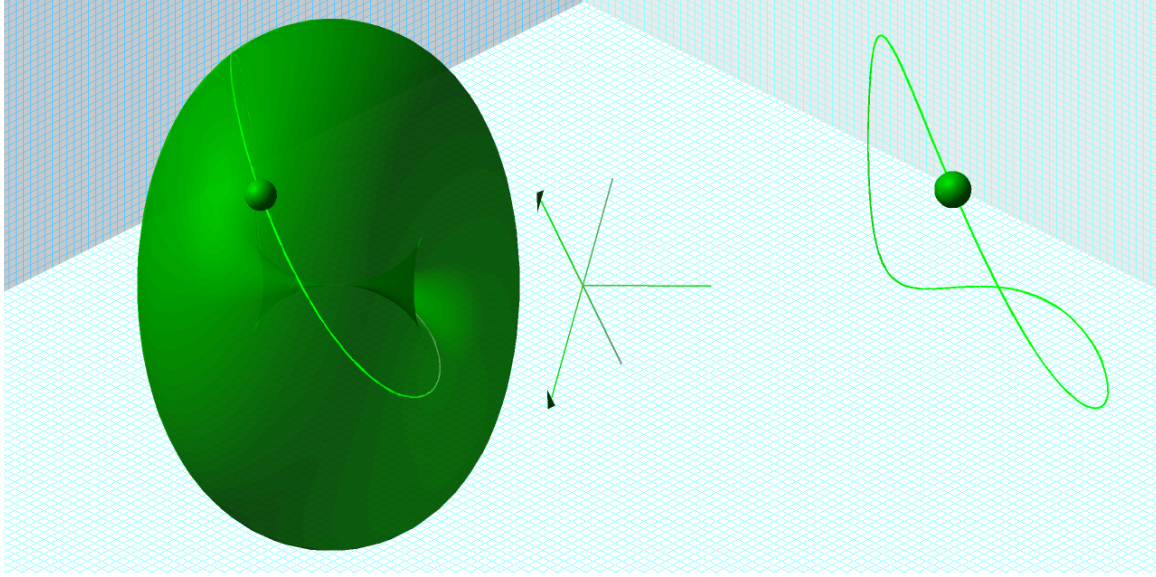


Figure 2. Superluminal half-photon quantum-vortex resting electron model formed from a superluminal spin- $\frac{1}{2}$ charged half-photon model. The superluminal energy quantum moves on the surface of a mathematical horn torus with maximum speed $V_{\max} = c\sqrt{5}$ and minimum speed $V_{\min} = c$.

The calculated z -component of the magnetic moment \vec{m} of the quantum vortex electron model is found to be $m_z = -0.75\mu_B$, where $\mu_B = e\hbar/2m_e = 9.274 \times 10^{-24} J T^{-1}$ is the Bohr magneton. See https://en.wikipedia.org/wiki/Bohr_magneton. The quantum vortex's magnetic moment is therefore 75% of the value obtained from the Dirac equation for the electron's magnetic moment. For comparison, the z -component of the magnetic moment of an electric charge e moving at light speed in a circle whose circumference is $\frac{1}{2}\lambda_{\text{Compton}}$ is found to be $m_z = -0.50\mu_B$. The standard formula used for calculating the magnetic moment of a closed 3-dimensional current loop is given in equation (19).

$$\vec{m} = \frac{I}{2} \int_0^T \vec{r}(t) \times d\vec{r}(t) \quad (19)$$

where T is the period of one complete cycle.

In the quantum vortex resting electron model, the electric current is produced by the superluminal energy quantum having charge $-e$ that is moving superluminally in the closed helical trajectory given in equation (18) for a resting electron. The z -component of the quantum vortex's magnetic moment, using the above general formula for \vec{m} , is found from equation (19) to be equation (20).

$$m_z = -\frac{e}{4\pi} \int_0^{2\pi} x(\theta)Vy(\theta) - y(\theta)Vx(\theta)d\theta \quad (20)$$

where $\theta = \omega_{\text{zitt}} t$ goes from 0 to 2π in one cycle of the quantum-vortex electron. The details of this magnetic moment calculation are given in the appendix of Gauthier²².

13. The double-helix photon equations for electron-positron pair production

During electron-positron pair production from a single photon (when the photon is nearby an atomic nucleus), the photon has to have a minimum energy $E = 2mc^2$ so that it has enough energy to form an

electron and a positron each with energy mc^2 . The wavelength λ of such a photon is found from $E = 2mc^2 = h\nu = hc/\lambda$ to be $\lambda = h/2mc = \lambda_{\text{Compton}}/2$ where $\lambda_{\text{Compton}} = h/mc = 2.43 \times 10^{-12}$ m is the Compton wavelength, which is the wavelength of a photon having energy mc^2 . Similarly, the angular frequency ω of a photon with energy $E = 2mc^2$ is found from $\hbar\omega = 2mc^2$ to be $\omega = 2mc^2/\hbar = \omega_{\text{zitt}}$ where $\omega_{\text{zitt}} = 2\pi\nu_{\text{zitt}} = 2\pi \times 2mc^2/h$ is the *zitterbewegung* angular velocity within the Dirac electron, found from the Dirac Equation.

If we insert the values $\lambda = \lambda_C/2$ and $\omega = \omega_{\text{zitt}}$ (where $\lambda_C = \lambda_{\text{Compton}} = h/mc$) into the position and momentum coordinates of the first half-photon helix given in equation (1), we get equation (21). The amplitude $\lambda_C/4\pi$ and angular velocity ω_{zitt} of each of the superluminal half-photons in equation (21)

$$\begin{aligned}
 x_1(t) &= \frac{\lambda_C}{4\pi} \cos(\omega_{\text{zitt}}t) & p_{x1}(t) &= -\frac{h}{\lambda_C} \sin(\omega_{\text{zitt}}t) \\
 y_1(t) &= \frac{\lambda_C}{4\pi} \sin(\omega_{\text{zitt}}t) & p_{y1}(t) &= \frac{h}{\lambda_C} \cos(\omega_{\text{zitt}}t) \\
 z_1(t) &= ct & p_{z1}(t) &= \frac{h}{\lambda_C}
 \end{aligned} \tag{21}$$

in the double-helix photon model of energy $E = 2mc^2$, and the equal helical radius $\lambda_C/4\pi$ and angular frequency ω_{zitt} of the superluminal half-photon quantum-vortex resting electron model in equation (18) strongly suggest that each of the half-photons of the double-helix photon model with total energy $E = 2mc^2$ can, in the process of electron-positron pair production, separate from the other half-photon. The separated half-photon can then curl up its half-photon helical trajectory into a closed helix with the same helical radius $\lambda_C/4\pi$ and same angular velocity ω_{zitt} as the superluminal half-photon in equation (21). The circular axis of this closed helix has a circumference of length equal to one half-photon wavelength $\lambda = \lambda_C/2$ and radius $R_o = \lambda_C/4\pi$. This is the orbital radius required to give an electron model composed of a circling half-photon of linear momentum $p = h/\lambda_C$ from equation (21) the required spin $s = R_o \times p = (\lambda_C/4\pi) \times (h/\lambda_C) = h/4\pi = \frac{1}{2}\hbar$ of an electron. Each superluminal spin- $1/2$ half-charged photon produced from a double-helix photon model that has just the right energy $E = 2mc^2$ for producing an electron-positron pair, can curl up its helical trajectory and, without changing its wavelength $\lambda_C/2$, its helical radius $\lambda_C/4\pi$ or its angular velocity ω_{zitt} , produce the electron and positron superluminal half-photon quantum vortex models described by equation (18). Figure 3 below shows a diagram of the double-helix photon forming quantum-vortex electron and positron models in electron-positron pair production.

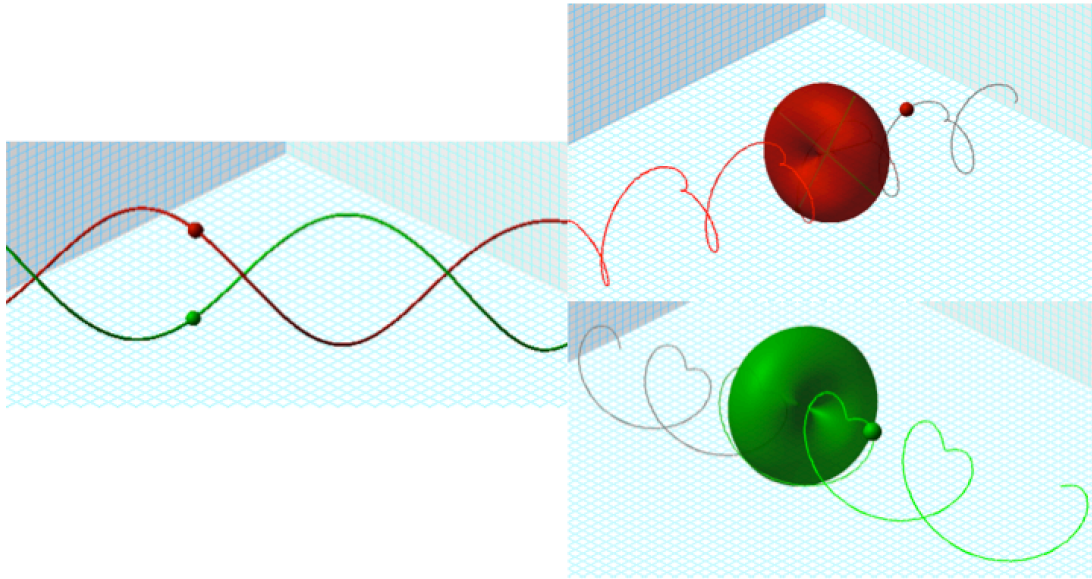


Figure 3. The two superluminal energy quanta forming charged spin- $\frac{1}{2}$ half-photons in the double-helix photon model separate when passing near an atomic nucleus (not shown) and each superluminal half-photon's helical trajectory curls up to form an internally superluminal quantum-vortex electron and positron which move away from their region of formation. The superluminal energy quantum travels on the surface of a moving mathematical torus having the electron's velocity.

Figure 3 shows a double-helix photon coming in from the left, with its two helically-circulating positively (red) charged and negatively (green) charged superluminal energy quanta moving at speed $c\sqrt{2}$. The charge values in the double-helix photon are $Q = \pm e\sqrt{2/\alpha} = \pm 16.6e$. When passing near an atomic nucleus (not shown), each of the two oppositely-charged superluminal quanta cancels all but $\pm 1e$ of their electric charge. Due to the instability of the trajectory of each charged spin- $\frac{1}{2}$ half-photon when separated from the other charged half-photon, the spin- $\frac{1}{2}$ half-photons do not continue with open-helical trajectories, but curl up their trajectories to become a superluminal half-photon quantum-vortex electron and positron. These move off at an angle to the right, away from where they were formed.

14. The quantum vortex electron model for the resting electron

Electron-positron pair production generally occurs near an atomic nucleus, which absorbs a small amount of momentum in the process. The amount of kinetic energy absorbed by the atomic nucleus during electron-positron pair production is almost insignificant due to the relative mass of an atomic nucleus compared to the mass of an electron. In any case this will not affect the present discussion.

When the author learned about de Broglie's 1930's spin- $\frac{1}{2}$ half-photon hypothesis for a composite photon, he realized that a double-helix photon model could be composed of two oppositely-charged spin- $\frac{1}{2}$ half-photons. The frequency (and wavelength) of the double-helix photon model is the same as the frequency (and wavelength) of the two spin- $\frac{1}{2}$ half-photons composing the double-helix photon model. The radius of each of the helical-moving half-photons is $R = \lambda / 2\pi$, the same as the radius of the double-helix photon model. A double-helix photon of energy $E = 2mc^2 = h\nu$ (which is the energy of a photon that can be converted into an electron-positron pair) would have frequency $\nu = 2mc^2 / h = \nu_{\text{zitt}}$. This double-helix photon would have the *zitterbewegung* frequency associated (through the Dirac equation) of a single electron or positron. The wavelength λ_{zitt} of this *zitterbewegung* double-helix photon is $\lambda_{\text{zitt}} = c / \nu_{\text{zitt}} = c / (2mc^2 / h) = h / 2mc = \lambda_{\text{Compton}} / 2$. Its radius

would be $R = \lambda / 2\pi = \lambda_{zitt} / 2\pi = (\lambda_{Compton} / 2) / 2\pi = \lambda_{Compton} / 4\pi = R_o$. Both spin- $1/2$ charged half-photons in the double-helix photon model have this same radius $R_o = \lambda_{zitt} / 2\pi = \lambda_{Compton} / 4\pi$, which is also the radius of the helical axis in the proposed quantum vortex resting electron model.

The quantum-vortex electron model is based on the spin- $1/2$ charged photon model in Gauthier²³ but the spin- $1/2$ charged photon model is replaced by a spin- $1/2$ charged half-photon model whose frequency for a resting electron is the *zitterbewegung* frequency $\nu_{zitt} = 2mc^2 / h$ and whose wavelength is $\lambda_{zitt} = c / \nu_{zitt} = \lambda_{Compton} / 2$. The energy of the spin- $1/2$ half-photon composing the quantum vortex resting electron model is $E_o = mc^2$ because it has half the energy of the double-helix photon of energy $E = 2mc^2$ that can produce an electron-positron pair. The spin- $1/2$ charged half-photon composing the quantum-vortex electron model therefore has half the energy but the same frequency, wavelength and helical radius as its corresponding double-helix photon.

In summary, the resting quantum-vortex electron model is composed of a circling a spin- $1/2$ half-photon model of energy $E_o = mc^2$, internal frequency $\nu_{zitt} = 2mc^2 / h$, and helical radius $R_o = \lambda_{Compton} / 4\pi$. This spin- $1/2$ charged half-photon moves along a circular axis of radius R_o corresponding to a circle of circumference $C = 2\pi R_o = \lambda_{Compton} / 2$, which corresponds to the quantum-vortex electron's internal *zitterbewegung* frequency $\nu_{zitt} = 2mc^2 / h$. In the quantum-vortex resting electron model, $E_o = mc^2$ is the energy and $\nu_{zitt} = 2mc^2 / h$ is the frequency of the spin- $1/2$ half-photon coming from a double-helix photon model of energy $E = 2E_o = 2mc^2$, frequency $\nu_{zitt} = 2mc^2 / h$, wavelength $\lambda_{Compton} / 2$ and helical radius $R_o = \lambda_{Compton} / 4\pi$.

15. The quantum vortex electron model for the relativistic electron

The quantum-vortex model of a resting electron above is derived from an incoming double-helix photon model having the minimum energy $E = 2mc^2$ to form a quantum-vortex resting electron and positron, each of rest energy $E_o = mc^2$. But electron-positron pair creation also occurs with incoming photon energy $E = 2\gamma mc^2$ and frequency $\nu = E / h = 2\gamma mc^2 / h = \gamma \nu_{zitt}$. In this case an electron-positron pair is produced that is moving relativistically.

In this case of relativistic electron-positron pair production, each of the spin- $1/2$ half-photons composing an $E = 2\gamma mc^2$ double-helix photon will get half of this total energy and become an electron or a positron. The frequency of this $E = 2\gamma mc^2$ photon is given by $E = 2\gamma mc^2 = h\nu$, or $\nu = 2\gamma mc^2 / h = \gamma \nu_{zitt}$ where $\nu_{zitt} = 2mc^2 / h$ is the *zitterbewegung* frequency of the Dirac electron. Each of the spin- $1/2$ charged half-photons retains its energy $E = \gamma mc^2$ and frequency $\nu = \gamma \nu_{zitt}$ in the relativistic quantum vortex electron and positron that is formed from this spin- $1/2$ charged photon. The wavelength of the $E = 2\gamma mc^2$ photon forming and electron-positron pair is given by $E = 2\gamma mc^2 = h\nu = h / \lambda$. This gives $\lambda = h / 2\gamma mc = \lambda_{Compton} / 2\gamma$ where $\lambda_{Compton} = h / mc = 2.426 \times 10^{-12}$ m is the Compton wavelength for an electron. Each of the spin- $1/2$ half-photons composing this double-helix photon of energy $E = 2\gamma mc^2$ has the same wavelength $\lambda = \lambda_{Compton} / 2\gamma$ as this double-helix photon. The radius R of the double-helix photon of energy $E = 2\gamma mc^2$ is given by $R = \lambda / 2\pi = (\lambda_{Compton} / 2\gamma) / 2\pi = \lambda_{Compton} / 4\pi\gamma = R_o / \gamma$ where $R_o = \lambda_{Compton} / 4\pi = \hbar / 2mc$. The helical radius of each half-photon in the double-helix photon is the same as the helical radius of the double-helix photon and so is also given by $R = R_o / \gamma$.

Each spin- $1/2$ charged photon from this $E = 2\gamma mc^2$ double-helix photon therefore has the frequency $\nu = \gamma \nu_{zitt}$, the angular velocity $\omega = \gamma \omega_{zitt}$, the wavelength $\lambda = \lambda_{Compton} / 2\gamma$ and the helical radius

$R_{\text{helix}} = R_o / \gamma = \lambda_{\text{Compton}} / 4\pi\gamma$ that is found in the relativistic quantum vortex electron and positron models given in equation (17). There is no difference between the energy, the frequency, the wavelength or the helical radius of each spin- $\frac{1}{2}$ charged half-photon that is part of the double-helix photon of energy $E = 2\gamma mc^2$, and the energy, frequency, wavelength and helical radius of the spin- $\frac{1}{2}$ charged half-photon composing the relativistic quantum-vortex electron or positron model. Each spin- $\frac{1}{2}$ charged half-photon in an $E = 2\gamma mc^2$ double-helix photon has a straight helical axis but in the electron and positron models the helical axis of each spin $\frac{1}{2}$ charged half-photon is curved. For simplicity we are assuming here that the electron and positron are produced with equal energies in the laboratory frame. If this is not the case, the produced electron and positron will have their individual values of γ but they will still share the total energy of the incoming photon that produced them.

The answer to this question about the structure of the quantum-vortex electron model in relativistic electron-positron pair production was partly anticipated in Gauthier²³. This article proposed a relativistic electron model composed of a helically-circulating spin- $\frac{1}{2}$ charged photon (not “half-photon” as it is currently called). A spin- $\frac{1}{2}$ charged photon was thought to be required so that the electron model would keep its spin $\frac{1}{2} \hbar$ at relativistic velocities and not just have spin $\frac{1}{2} \hbar$ for a resting or slow-moving electron, which a spin $1 \hbar$ photon circling in a double-loop with a radius $R_o = \lambda_{\text{Compton}} / 4\pi = \hbar / 2mc$ might produce. This generic relativistic spin- $\frac{1}{2}$ charged-photon electron model (which only describes the helical-axis trajectory of a generic light-speed spin- $\frac{1}{2}$ charged-photon model composing the relativistic electron model) can accommodate the detailed internally-superluminal spin- $\frac{1}{2}$ charged half-photon model of the present article.

In a relativistic quantum-vortex electron model with velocity v , the axis of the circulating spin- $\frac{1}{2}$ charged half-photon, as in Gauthier²³, is an open helical trajectory of radius $R = \lambda_{\text{Compton}} / 4\pi\gamma^2 = R_o / \gamma^2$ rather than being a circle of radius $R_o = \lambda_{\text{Compton}} / 4\pi$ as in the resting quantum-vortex electron. This result is explained below.

This result comes from special relativity and the geometry of the helical axis of the moving spin- $\frac{1}{2}$ charged half-photon. The open-helix trajectory of the spin- $\frac{1}{2}$ half-photon’s helical axis in a relativistic quantum-vortex electron model is the result of the transverse circular speed of the spin- $\frac{1}{2}$ photon within the electron model, combined with the longitudinal speed v of the moving electron model itself. These combined motions of the spin- $\frac{1}{2}$ half-photon composing the relativistic quantum-vortex electron model gives the spin- $\frac{1}{2}$ half-photon an open helical axis along which it moves with speed c . The speed c of the helically-circulating half-photon along its helical axis in a moving or relativistic quantum-vortex electron model is the same as the speed c of the helically-circulating charged half-photon moving along a circular trajectory in a resting quantum vortex electron model. This is because, according to special relativity, the speed of light is constant, independent of the rest frame in which the speed of light is measured. In the relativistic electron model, while the spin- $\frac{1}{2}$ half-photon moves forward along this helical-axis trajectory with velocity c , the longitudinal component of this rotating velocity c is v , the speed of the relativistic quantum vortex electron model itself. The forward helical angle θ of the helical-axis trajectory is given by $\cos\theta = v/c$. The wavelength of the spin- $\frac{1}{2}$ half-photon moving along this helical axis trajectory is contracted (as seen above) by a factor of γ due to the increased energy of the spin- $\frac{1}{2}$ charged photon forming the moving quantum vortex electron model. This helical axis now makes one full helical turn for each γ -contracted wavelength. The circumference $2\pi R$ of the helix formed by this helical axis trajectory is equal to the γ -contracted half-photon wavelength times $\sin\theta$. This is because geometrically, if one wavelength $\lambda_{\text{Compton}} / 2\gamma$ of one full turn of this helical axis is mathematically rolled out flat, the rolled-out γ -contracted wavelength $\lambda_{\text{Compton}} / 2\gamma$ is the hypotenuse of a rolled-flat triangle whose hypotenuse makes the angle θ with the longitudinal direction of motion of the electron model. The triangle’s side opposite θ is the rolled-out helix’s circumference $2\pi R$. The relationship $\cos\theta = v/c$ implies that $\sin\theta = \sqrt{1 - v^2/c^2} = 1/\gamma$. This gives $2\pi R = (\lambda_{\text{Compton}} / 2\gamma)\sin\theta = (\lambda_{\text{Compton}} / 2\gamma) \times (1/\gamma) = \lambda_{\text{Compton}} / 2\gamma^2$.

This gives radius R of the helical trajectory the charged half-photon's axis to be $R = \lambda_{\text{Compton}} / 4\pi\gamma^2 = R_o / \gamma^2$. This geometrical result is incorporated into the equation (17) for the relativistic quantum vortex electron model since $R_o = \lambda_{\text{Compton}} / 4\pi$. This derivation is also given in Gauthier²³

Figure 4 below, taken from Gauthier²³ shows the helical trajectory with forward angle θ of the proposed spin- $\frac{1}{2}$ charged half-photon composing a relativistic quantum-vortex electron. This trajectory with forward angle θ of the helically-moving relativistic charged half-photon with velocity c , energy $E = \gamma mc^2$ and linear momentum γmc , is compared to the horizontal linear velocity v and linear momentum $p = \gamma mv$ of the relativistic quantum-vortex electron itself. The term “charged photon” in the figure should now be understood as “charged spin- $\frac{1}{2}$ half-photon”.

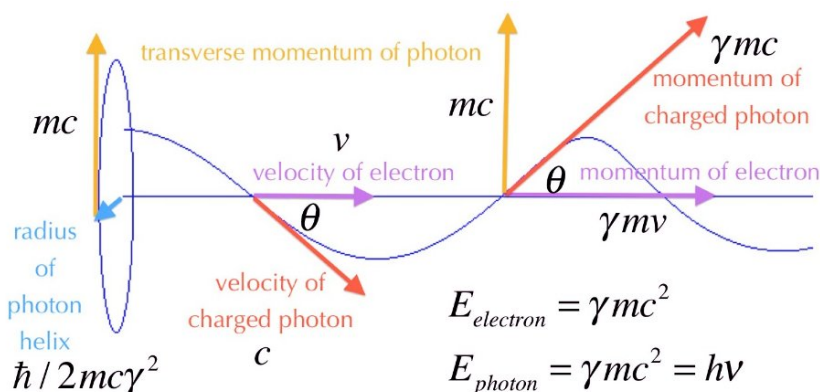


Figure 4. This figure shows the helical trajectory with forward angle θ of the charged spin- $\frac{1}{2}$ half-photon composing the relativistic quantum-vortex electron. The term “charged photon” in the figure should now be understood as “charged spin- $\frac{1}{2}$ half-photon”. The figure shows the velocity c and the helically-circulating momentum γmc of the charged spin- $\frac{1}{2}$ half-photon along its open-helical axis. The figure also shows the horizontal velocity v and the relativistic momentum γmv of the relativistic quantum-vortex electron as a whole. Nothing is superluminal in this diagram. In this figure, $\theta = 45^\circ$, $v = c / \sqrt{2} = 0.707c$ and $\gamma = \sqrt{2} = 1.414$. The helical radius $R = \hbar / 2mc\gamma^2$ is therefore $1/\gamma^2 = \frac{1}{2}$ of the radius of the circular axis of a resting electron, shown at the left.

Figure 5 below shows a 3-D side view of the resting quantum vortex electron that was shown from a different viewpoint in figure 2.

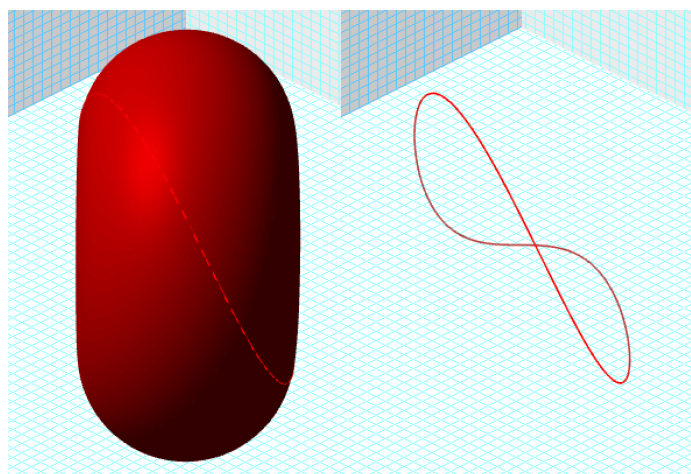


Figure 5. 3-D graphic of a side view the resting quantum vortex electron model shown in figure 2, where $v = 0c$ and $\gamma = 1.0$. The trajectory of the superluminal energy quantum composing the quantum vortex electron model lies on the surface of a mathematical horn torus and passes through its center. The graphic on the left shows the superluminal energy quantum's trajectory on the mathematical horn torus. On the right is the superluminal energy quantum's trajectory by itself. When $v = 0$, the width of the resting electron model above, found from equation (18), is $\lambda_{\text{Compton}} / 2\pi = \hbar / mc = 3.86 \times 10^{-13}$ m.

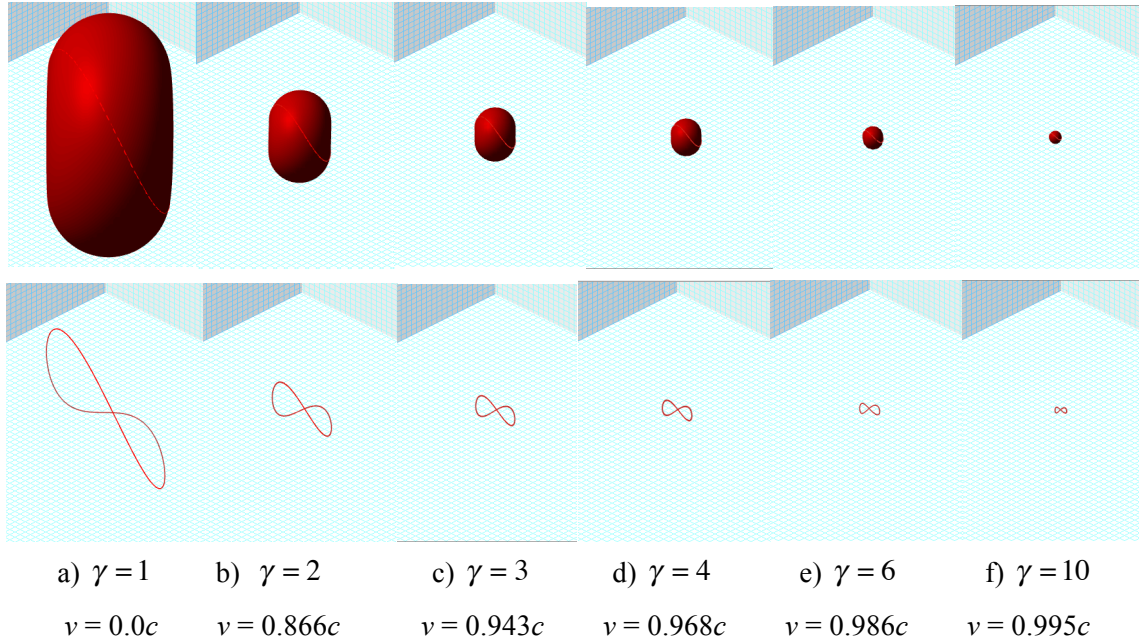


Figure 6. These six 3-D graphic pairs show how the size and shape of the relativistic superluminal quantum-vortex electron model's mathematical torus and trajectory change with the electron model's increasing velocity v and with γ , where $\gamma = (1 - v^2/c^2)^{-1/2}$. In figure 6 a-f, γ varies from 1, where $v = 0$, to 10, where $v = 0.995c$. The 3-D trajectory of the circulating superluminal energy quantum composing the electron model decreases in size in proportion to $1/\gamma$. The mathematical surface along which the superluminal energy quantum moves with the speed of the electron model, changes from a horn torus when $v = 0$, to a spheroidal torus as γ increases to 100 or more.

Figure 6 above shows the 3-D mathematical tori and accompanying superluminal energy quantum trajectories along their respective tori as the relativistic quantum vortex electron model moves to the right with the increasing values of v and γ shown below each of the six toroidal figures. The toroidal figures and superluminal trajectories are generated from the relativistic quantum vortex equation (17). The toroidal sizes decrease approximately as $1/\gamma$. The spin- $1/2$ half-photon axis' helical radius in the relativistic electron model's equation (17) decreases as R_0/γ^2 . This term goes more rapidly towards zero than the R_0/γ term for the radius of the superluminal energy quantum's helical trajectory of the spin- $1/2$ charged half-photon itself. The result is that the mathematical horn torus shown in the first diagram becomes both smaller and more spherical with increasing γ . The superluminal quantum's trajectory changes its shape correspondingly as well. The actual superluminal quantum trajectories in a moving quantum vortex electron model are open trajectories, as indicated in figure 3, but relative to the subluminal-moving mathematical tori on which the superluminal energy quanta move, the trajectories of the superluminal quanta appear to be closed.

16. Discussion

16.1. Evolution of the superluminal charged-dipole double-helix photon model

In 1995 Gauthier²¹ proposed his first internally superluminal model of the photon, with each photon composed of millions of sub-quantum helically-moving microvita—hypothetical entities proposed to compose physical particles. This model was transformed in Gauthier⁹ into an internally superluminal charged dipole double-helix photon model. Due to the lack of experimental evidence that a photon is composite, Gauthier²² proposed a superluminal uncharged single-helix spin-1 photon model and also a superluminal charged single-helix, internally-double-looping spin-1/2 resting electron model. Gauthier²³ extended the resting electron model to become a relativistic electron model, composed of a helically-moving spin-1/2 charged photon that generates the electron's de Broglie wavelength.

The author then learned that de Broglie² had previously hypothesized that a photon is composed of two spin-1/2 half-photons. In light of de Broglie's spin-1/2 half-photon hypothesis for a composite photon, a terminology change was needed for "spin-1/2 charged photon" for the object proposed by Gauthier (13) to compose an electron. The term "spin-1/2 charged photon" in Gauthier²³ is now to be understood as a "spin-1/2 charged half-photon", to be consistent with de Broglie's composite photon hypothesis and also to be consistent with the fact that, experimentally, photons are neutral and generally have spin-1. In the present article, the double-helix photon is composed of two superluminal oppositely-charged spin-1/2 charged half-photons.

16.2. The fine structure constant $\alpha = 1/137.04$ in the double-helix photon model

A surprising result in the superluminal double-helix photon model is that its two electric charges Q and $-Q$ on the circulating superluminal energy quanta were found to be related to the electron's charge e by the fine structure constant alpha: $\alpha = 1/137.04$ from quantum electrodynamics (QED) by $Q = e\sqrt{2/\alpha} = 16.6e$. Alpha is the measure of the strength of interaction between an electron and a photon in QED. Whether this result can lead to a better understanding of the photon or QED or both, remains to be seen.

16.3. Quantum waves generated by the composite photon model

In the Gauthier²³ spin-1/2 charged photon model of the electron (which now should be called the spin-1/2 charged half-photon model of the electron) the charged half-photon composing the electron model moves forward along its helical axis trajectory at light speed c to form the electron, which travels longitudinally at sub-light speed v . The quantum wave is proposed to be emitted by the helically-moving charged half-photon. This quantum wave is a plane quantum wave function $\Phi(\vec{r}, t) = A \exp[i(\vec{k}_{total} \cdot \vec{r} - \omega t)]$ where \vec{k}_{total} is the wave vector of the circulating charged half-photon forming the electron and ω is its angular frequency. That quantum plane wave function when intersecting the helical axis of the charged spin-1/2 half-photon generates the electron's relativistic de Broglie wavelength $\lambda_{db} = h / \gamma m v$ along this axis.

In the present double-helix photon model, the same basic quantum wave function formula for a plane quantum wave function can be used: $\Phi_{photon}(\vec{r}, t) = A \exp[i(\vec{k} \cdot \vec{r} - \omega t)]$ where $\vec{k} = 2\pi / \lambda$ is the wave vector of a plane wave of electromagnetic radiation for the double-helix composite photon model of wavelength λ , and ω is the angular velocity of the photon model. Each half-photon in the composite photon could emit such a wave function, producing an entangled composite quantum wave function for the double-helix photon. The double-helix photon model generates its quantum wave function as it moves forward at light speed. This wave function predicts the probability of finding the photon in a future place and time. The proposed quantum plane wave function would be for a double-helix photon in a coherent beam of electromagnetic radiation such as a laser beam, where a plane quantum wave function is a good description of the distribution of photons in the laser beam as a whole.

16.4. Stability of the relativistic quantum vortex electron model

Both the photon and the electron are very stable quantum particles that can exist for billions of years in the universe if they do not meet with other particles that absorb or transform them. This article considers a double-helix model of a stable photon that interacts with a nearby atomic nucleus and forms quantum-vortex models of a stable electron-positron pair. The component that the double-helix photon and the quantum-vortex electron have in common is a proposed electrically-charged helically-moving superluminal energy quantum that moves forward at light speed and composes both the double-helix photon model and the quantum-vortex electron model. The double-helix photon model, composed of two superluminal electrically-charged spin- $\frac{1}{2}$ half-photons, separates to form a quantum-vortex model of an electron and a positron. The electron and positron models are each composed of a single charged spin- $\frac{1}{2}$ half-photon from the double-helix photon, although the magnitude of the electric charge on each spin- $\frac{1}{2}$ half-photon changes in the process of electron-positron pair production.

The trajectory of a single open-helix half-photon is proposed to be unstable. Two oppositely charged half-photons are required to form a composite photon with stable double-helix trajectories. One individually-unstable charged single-helix half-photon may, when its photon passes near an atomic nucleus, become separated from its counterpart single-helix half-photon. Each half-photon will then curl up its open-helical trajectory to form an electron or a positron model whose half-photon moves along a closed helical trajectory, in the case of a resting electron or positron. This closed-helical trajectory of the half-photon composing the electron model could minimize the half-photon's instability by being a self-stabilizing quantum vortex. An electron is a stable particle because it cannot by itself transform into another particle or particles without violating conservation of momentum, conservation of energy, conservation of charge or any other conservation law that is considered inviolable for fundamental particles. It can however join with a positron to become a positronium atom that then transforms into two, three or more photons. In the present quantum vortex electron model, the inability of a single curled-up single-helix superluminal half-photon from a double-helix photon to spontaneously transform itself into one or more other particles is what gives an electron its stability to exist for billions of years.

A sufficiently energetic double-helix photon passing near an atomic nucleus can divide into two superluminal single-helix half-photons that form a higher mass muon-antimuon pair or an even higher mass tau-antitau pair. The muon and the tau are both in the electron's family and therefore should have a similar internal energy structure as that of the electron. The muon and the tau could each be composed of a higher-energy curled-up superluminal single-helix charged half-photon. Unlike the electron, however, the muon and the tau are unstable. A negative muon can decay into an electron, a muon neutrino and an electron antineutrino without violating any physical conservation laws.

The more massive and also unstable tau can decay in a variety of ways into other less-massive particles without violating accepted conservation laws. The electron cannot decay into anything else without violating physical conservation laws, electric charge conservation in particular. This makes the electron de facto a stable particle, even if it is composed of a potentially unstable charged single-helix half-photon.

In this single-helix half-photon approach to particle composition, the electron can be considered to be the ground state of the electron-muon-tau family. Just as an atom in its ground state does not radiate energy, the electrically-charged superluminal closed-helix electron model does not radiate energy due to its stabilized closed-helical quantum-vortex structure. Moving in a closed helix of circular axis length $\lambda_{\text{Compton}}/2$ and with a *zitterbewegung* frequency $\nu_{\text{zitt}} = 2mc^2/h$, the circulating half-photon forming an electron is self-stabilizing and has no allowed lower energy state. The muon and tau are similarly, if temporarily, self-stabilized in their own internal $\lambda_{\text{Compton}}/2$ circular orbits, where $\lambda_{\text{Compton}} = h/mc$ is calculated using the larger mass of the muon or the still-larger mass of the tau. These two particles can both decay to lower energy states without violating conservation laws.

Considering what may happen to a single superluminal single-helical half-photon from a double-helix photon during pair-production sheds light on how an individually unstable half-photon can form

a stabilized half-photon particle (an electron) or an unstable half-photon particle such as a muon or a tau.

In the process of a double-helix photon producing a quantum-vortex electron-positron pair, there is a change from the positive or negative charge $Q = e\sqrt{2/\alpha} = 16.6e$ on each half-photon composing the double-helix photon model, to the charges $+e$ and $-e$ on a positron and an electron. There must be a transfer of electric charge from one of the half-photons to the other for this to happen. The quantity α is the fine structure constant $\alpha = 1/137.04$ in quantum electrodynamics (QED). It appears here in the calculation of the electric charges required to maintain a stable superluminal double-helix photon model held together by Coulomb attraction. It should be remembered that a sufficiently energetic photon can produce many other types of particle-antiparticle pairs, such as proton-antiproton pairs and neutron-antineutron pairs. It is by no means clear how a single charged half-photon can transform itself into a multi-particle composite object like a proton or neutron, each composed of 3 charged quarks and the various uncharged gluons that help stabilize a proton or neutron. Does a charged half-photon carry “seeds” for the formation of quarks and gluons as well as “seeds” for electrons that can sprout in energetically favourable circumstances? Similarly, when an electron and a positron mutually annihilate, they can produce two, three or more photons without violating any known physical laws. How do physical laws determine or influence what transformation outcome occurs? If two photons are produced when an electron and a positron mutually annihilate, there would be a two pairs of half-photons produced, only one pair of which, if either, could have come directly from the electron and the positron that mutually annihilated. There is much room for further research on particle creation and annihilation in light of the superluminal double-helix photon model and the superluminal quantum-vortex electron model.

17. Conclusions

An internally-superluminal double-helical quantum-mechanically self-entangled oppositely-charged-dipole model of the photon is proposed. It can transform into a relativistic electron and positron, each composed of a superluminal half-photon having a quantitative geometrical continuity with the double-helix photon model. The photon and electron models provide a new way to view the *zitterbewegung* frequency description of the electron coming from the solution to the Dirac equation for a relativistic electron. The double helix photon model is composed of two oppositely-charged spin- $1/2$ half-photons moving side-by-side in internally-superluminal double-helical trajectories, consistent with de Broglie’s hypothesis of a composite photon composed of two spin- $1/2$ half-photons. The photon model has a calculated inertial mass $M = E/c^2 = h\nu/c^2$ based on Newton’s second law $\vec{F} = M\vec{a} = d\vec{p}/dt$, applied to the rotating internal momenta of the superluminal energy quanta composing the photon model. The double-helix photon model suggests a new approach to describing electron-positron pair production. Due to the calculated dipole charge $Q = \pm e\sqrt{2/\alpha} = \pm 16.6e$ on the two helically-circulating superluminal energy quanta composing this photon model, a possible connection of the photon model to quantum electrodynamics (QED) is also hinted, and a strong experimental test of the double-helix photon model – the detection of this charge Q – is provided.

The proposed superluminal double-helix photon model may be transformed relatively seamlessly into a superluminal single-helix quantum-vortex model of a relativistic electron and positron. The combined energies of the two spin- $1/2$ half-photons in a sufficiently energetic double-helix photon become the shared energies of the relativistic quantum-vortex electron and positron that are produced in electron-positron pair production. The parameters of energy, frequency, wavelength and helical radius of each spin- $1/2$ half-photon composing the double-helix photon remain the same in the transformation of the half-photons into the relativistic electron and positron quantum-vortex models. These photon and electron models clearly oversimplify the process of electron-positron pair production from a sufficiently energetic photon, since other particle-antiparticle pairs are sometimes produced. The superluminal aspect of the photon and electron models may challenge ideas about the speed of light as the upper speed limit for physical particles. However, the double-helix photon model and the quantum-vortex electron model are both only internally superluminal and may be compatible

with special relativity's restrictions on quantum particles as a whole. The double-helix photon model still travels forward at light-speed c , while the relativistic quantum-vortex model of the electron as a whole travels forward always at less than light-speed c . Still, the quantitative parameter constancies of the proposed spin- $\frac{1}{2}$ charged half-photon as it is transformed from a double-helix photon into a relativistic quantum-vortex electron or positron suggest that this transformation process and the reverse transformation process of particle-antiparticle annihilation into photons may be modelled in a novel way that could give some deeper insights into the fundamental processes of converting light into matter, and vice versa.

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