The Binary Photon: A Heuristic Proposal to Address the Enigmatic Properties of Light

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The quantum mechanical photon is described as a mathematical point-like elementary bosonic particle that is characterized by its energy ($\hbar\omega$), linear momentum ($\hbar k$), and angular momentum ($\hbar$), and that propagates a circularly-polarized electromagnetic force at the speed of light (c). The quantum mechanical photon is also considered to be its own antiparticle. With this model of the photon, it is impossible, in principle, to visualize how the photon transfers energy, linear momentum, angular momentum, or the electromagnetic force to matter, and how a photon interacts with nearby photons resulting in interference effects. I have explained the enigmatic properties of the quantum mechanical photon with the model of the binary photon, which postulates that that photon is not an elementary particle and its own antiparticle, but a composite entity composed of a particle of matter and its conjugate antiparticle of antimatter. These conjugate particles are known as semiphotons. Unlike the quantum mechanical photon, the binary photon has extension is space, giving intelligibility and understandability to concepts such as the energy distribution within a photon, the cross-section of a photon, the angular momentum of a photon, the rotational energy of a photon, and the electromagnetic fields of a photon. In this contribution, I depict the wave functions, which are solutions to the Schrödinger equation for a boson, in three-dimensional Euclidean space. The wave functions describe the paths of the corpuscular semiphotons in three-dimensional Euclidean space and unidirectional and absolute Newtonian time. The wave functions that describe the movement of semiphotons give intelligibility and understandability to the wave-particle duality, and they yield the mechanical properties of the binary photon.

By assuming that the binary photon is electrically neutral as a consequence of the semiphotons having equal and opposite charge, I show that the propagating binary photon produces a transverse sinusoidal electric field and a three-dimensional magnetic field that are orthogonal to each other and a quadrature out-of-phase with each other. The phase characteristics of the electric and magnetic fields are consistent with Faraday's law and the Ampere-Maxwell law, but inconsistent with Maxwell's electromagnetic waves, which were derived upon the assumption that light is electrically neutral due to the absence of charge ($\nabla \cdot E = 0$). By endowing the quantum of light with equal and opposite charge and using Maxwell's equations, the model of the binary photon offers an alternative way to address the principle of relativity that demands that there are no preferred frames in reckoning the speed of light. In this contribution, I provide animations that are not only consistent with the canonical mechanical and electromagnetic properties of light, but in addition, they give *Anschaulichkeit,* intelligibility, and understandability to the nature of light.

Many people consider that science is the body of existing knowledge and scientists add to this knowledge in a straightforward, logical manner. This commonly accepted viewpoint is at variance with what another Nobelist, Szent-Györgyi, said, "A discovery must be, by definition, at variance with existing knowledge." The fact that well-meaning people and good scientists can have such opposing views shows that C. P. Snow's division of our society into two cultures of arts and science is wrong; there are two cultures in science itself. However, there is truly but one culture in which art, literature, music, and science are one, for all the basic attributes of the arts—of beauty, aesthetics, simplicity and the wonderment of the human condition—can be expressed in many ways, but are an essential part of our civilization.

S.R. Ovshinsky [1]

1. Introduction

The model of the binary photon presented here originated in an investigation of the second law of thermodynamics [2]. The goal of that investigation was to explain why the Carnot cycle occurred with a unidirectional order of events in time even though there was no change of entropy. The asymmetry was resolved by postulating that the order of events in time was a result of matter having a positive mass. I found that if matter had a negative mass, then the order of events in time would be reversed [3]. Since CPT (charge, parity, time) symmetry [4], which is the standard symmetry that relates matter to antimatter, states that antimatter is equivalent to matter going backwards in time [5], I developed CPM (charge, parity, mass) symmetry [6] based on the biologist's notion of unidirectional time [7,8] to relate matter to antimatter.

I postulated that with CPM symmetry, antimatter could be described completely and economically as having a negative mass that proceeds forward in time instead of having a positive mass as defined by Dirac [9] that proceeds backwards in time. With this definition, the vacuum is emptied and the Dirac Sea becomes superfluous. Real photons serve the functions of virtual particles [10,11]. On the cosmological scale, dark matter is replaced by antimatter [12,13] and dark energy [14] by real photons that provide a counterforce to expansion as a result of radiation friction [15].

I then exhumed the concept of the binary photon proffered a century ago by Bragg [16], de Broglie [17], Born [18,19], Jordan [20], and others, and I postulated that the photon was not an elementary particle but a composite entity composed of a particle of matter and a particle of antimatter that were conjugate in terms of charge, parity, and mass. Due to the gravitational force, negative mass particles accelerate towards positive mass particles while positive mass particles accelerate away from negative mass particles [21,22]. In a binary photon composed of positive and negative mass, the gravitational force between the semiphotons determines the direction of propagation of the binary photon, and consequently, the leading semiphoton must be composed of positive mass and the following semiphoton must be composed of negative mass.

The binary photon, like light, must be electrically neutral. Therefore I postulated that the two semiphotons that make up the binary photon must have equal and opposite electric charge [23,24]. The gravity-dependent Coulombic force between the semiphotons determines the magnitude of the motive force responsible for the propagation of the binary photon [25]. As they move, the electrically-charged semiphotons generate a magnetic field according to the Ampere-Maxwell law, and an electromotive force consistent with Faraday's law and Lenz's law. The electromotive force caused by the induced magnetic field restricts the velocity of the center of gravity of the binary photon to the speed of light—a *sine qua non* for a model of light.

The electrically-charged semiphotons also generate a time-varying electromagnetic field at the center of gravity of the binary photon [26], consistent with the function of the photon in the standard model as the carrier of the electromagnetic force [27]. The time-varying electromagnetic field of the binary photon is a novel solution to Einstein's most famous thought experiment [28], when he [29] realized, "*If I pursue a beam of light with velocity c (velocity of light in a vacuum), I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest.*"

However Einstein [29] noted that, "*there seems to be no such thing, whether on the basis of experience or according to Maxwell's equations. From the beginning it appeared to me intuitively clear that, judged from the standpoint of such an observer, everything would have to happen according to the same laws as for an observer who, relative to the earth, was at rest. For how, otherwise, should the first observer know, i.e., be able to determine, that he is in a state of fast uniform motion. One sees that in this paradox the germ of the special relativity theory*." The paradox of the "*spatially oscillatory electromagnetic field at rest"* is equally resolved by the model of the binary photon.

Just as there are no preferred frames of reference in the theory of special relativity when it comes to observing light, there are no preferred frames for the binary photon. The model of the binary photon allows for the relativity of simultaneity to be a result of Doppler-shifted binary photons [30] instead of the relativity of time itself.

Quantum mechanics was conceived by Max Born and Werner Heisenberg as a theory that describes a world of elementary particles that cannot be visualized in principle [31,32]. As an alternative, I have found wave function solutions to the Schrödinger equation for a boson that describe the paths of the semiphotons around the center of gravity of the binary photon in Euclidean space and Newtonian time in a picturable manner [33]. Here I use Mathematica® animations to illustrate the paths of the semiphotons in Euclidean space and Newtonian time, and to demonstrate the electromagnetic fields of the binary photon that would appear to an observer at rest with respect to the binary photon as a "*spatially oscillatory electromagnetic field at rest*."

2. Results and Discussion

The model of the binary photon is constrained by the principle of relativity, which states that there is no preferred reference frame for the laws of mechanics, optics, or electromagnetism, and the principle of the constancy of the speed of light [34]. It is also constrained by the paradoxical observation that light is both electrically neutral and the carrier of the electromagnetic force. In addition, the model of the binary photon is based on the fact that the total energy (E) of the binary photon is equal to $\hbar\omega$, its linear momentum (p) is equal to $\hbar k$, such that the ratio of the total energy to the linear momentum is equal to the speed of light (c); and its angular momentum (L) is equal to $\hbar$, which is the same for every photon. The total energy of the binary photon is equipartitioned into rotational energy and translational energy [33,35].

In order to characterize the binary photon in terms of its angular momentum, I began with the classical equation:

$$L = mvr \tag{1}$$

Where, m is considered to be the mass of the binary photon, v is the angular velocity of its rotation, and r is its radius of rotation. The mass is considered positive when the binary photon interacts with matter, negative when the binary photon interacts with antimatter, and undefined when the binary photon is in free space. Since for light, $L = \hbar$ [36] and $v = c$ [37], the angular momentum of the binary photon is given by:

$$L = \hbar = mcr \quad (2)$$

Since any binary photon has a fixed amount of energy, then the mass of the binary photon can be calculated from the following concatenation of well-known equations [38,39]:

$$E = mc^2 = \hbar\omega \quad (3)$$

from which we can calculate the mass of the binary photon:

$$m = \frac{\hbar\omega}{c^2} \quad (4).$$

By substituting Eqn. (4) into Eqn. (2), we can determine the radius of the binary photon:

$$L = \hbar = \frac{\hbar\omega}{c} r \quad (5)$$

Solving for r, we get:

$$r = \frac{c}{\omega} = \frac{1}{k} = \frac{\lambda}{2\pi} \quad (6).$$

Thus the radius of the binary photon is proportional to its wavelength. Consequently, the curvature of the binary photon is inversely proportional to its wavelength. The shorter the wavelength, the more the binary photon approximates a geometrical point and the longer the wavelength, the more the binary photon approximates an infinite plane wave.

As long as the parities of the leading semiphoton and the following semiphoton are opposite, then their angular momenta will add to give $\hbar$. Formally, there can exist four types of binary photons with different combinations of semiphotons that will give an angular momentum of $\pm\hbar$. In two types of binary photons, the signs of the charge and parity of each semiphoton are opposite (Table 1a) and in the other two types of binary photons, the signs of the charge and parity of each semiphoton are the same (Table 1b).

The binary photons have angular momentum that is either parallel ($-\hbar$) or antiparallel ($+\hbar$) to the direction of propagation. For simplicity's sake, I will only describe the binary photons where the charge and parity of the semiphotons have opposite signs (Table 1a). Assume that the leading semiphoton has a positive mass that rotates either anticlockwise ($P = +1$) or clockwise ($P = -1$) around the axis of propagation and the following semiphoton has a negative mass that rotates either clockwise or anticlockwise, respectively.

Table 1a. Binary Photons Composed of Conjugate Pairs of Semiphotons where the Charge (q) and Parity (P) of the Semiphotons have Opposite Signs.

Leading Semiphoton	Following Semiphoton	Angular Momentum
$+m, +q, -P$	$-m, -q, +P$	$+\hbar$ (antiparallel)
$+m, -q, +P$	$-m, +q, -P$	$-\hbar$ (parallel)

Table 1b. Binary Photons Composed of Conjugate Pairs of Semiphotons where the Charge (q) and Parity (P) of the Semiphotons have the Same Sign.

Leading Semiphoton	Following Semiphoton	Angular Momentum
$+m, +q, +P$	$-m, -q, -P$	$+\hbar$ (parallel)
$+m, -q, -P$	$-m, +q, +P$	$-\hbar$ (antiparallel)

In order that the conjugate semiphotons do not annihilate each other as they rotate around the axis of propagation, I have included a longitudinal oscillation that they perform as they translate along the axis of propagation [40].

A mechanical system is defined by its energy and momentum, consequently, the wave functions of the binary photon must be constrained by the energy and the momentum of the binary photon they describe. The wave functions that describe the three-dimensional paths around the center of gravity along which the leading and following semiphotons move are given in Eqns. (7a) and (7b). Eqn. (7a) describes the path of the leading semiphoton in a Cartesian coordinate system along the $\hat{x}, \hat{y}$, and $\hat{z}$ axes, respectively:

$$\Psi^{leading-position} = \begin{bmatrix} \frac{\lambda}{2\pi}\cos[\theta] \\ P\frac{\lambda}{2\pi}\sin[\theta] \\ ct + \frac{2\lambda}{(2\pi)^2}\cos^2[\theta] \end{bmatrix} \quad (7a)$$

Where, $\theta = 2\pi w$, P represents the parity of the semiphoton and is +1 for an anticlockwise rotation when looking at the source and -1 for a clockwise rotation, and w represents the phase of the binary photon, which varies between 0 and 1. Eqn. (7b) describes the path of the following semiphoton:

$$\Psi^{following-position} = \begin{bmatrix} \frac{\lambda}{2\pi}\cos[\theta] \\ -P\frac{\lambda}{2\pi}\sin[\theta] \\ ct - \frac{2\lambda}{(2\pi)^2}\cos^2[\theta] \end{bmatrix} \quad (7b)$$

The wave functions describe paths in Euclidean space and Newtonian time along which the movement of the semiphotons can be visualized (Fig. 1). The wavelength of the binary photon, which is inversely proportional to the energy of the binary photon, is equal to the length of the paths of each semiphoton projected on the plane perpendicular to the axis of propagation [33].

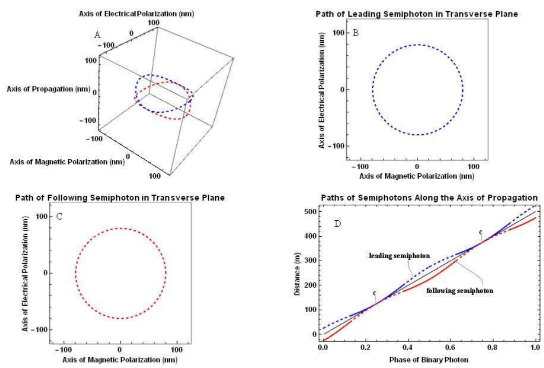

Fig. 1: The paths of the semiphotons as described by the wave functions in (A) three-dimensions, in the transverse plane (B and C), and along the axis of propagation (D) where the periods of deceleration of the semiphotons are dashed and the periods of acceleration of the semiphotons are solid.

As shown above, the wave functions of the binary photon can be pictured as paths in Euclidean space. In addition, the movement of the semiphotons in Euclidean space along the wave functions can also be pictured. Fig. 2 shows an animation[1] of the movement of the semiphotons in Euclidean space and Newtonian time that make up a binary photon with antiparallel angular momentum ($+\hbar$) and with parallel angular momentum ($-\hbar$). In essence, the wave functions are pilot waves [40] for the semiphotons.

The basis of the angular momentum of a massless quantum mechanical photon without extension is an enigma. Consequently, its angular momentum of $\pm\hbar$ is considered to be a quantum mechanical number rather than a mechanical quantity [41]. By contrast, when one considers a binary photon to be a composite particle composed of two semiphotons with opposite mass and parity (sense of rotation) that orbit around the center of gravity of the binary photon, the basis of the angular momentum is intelligible. The angular momentum of the binary is readily visualized by using the right hand rule for characterizing the angular momentum of the positive mass semiphoton and the left hand rule for characterizing the angular momentum of the negative mass semiphoton (Fig. 3).

The first two terms of each wave function describe the position of the semiphoton in the transverse plane orthogonal to the axis of propagation. The third term of each wave function describes the position of the semiphoton along the axis of propagation. For conceptual and mathematical convenience [33], the three dimensional motion of binary photons with angular momentum antiparallel or parallel to the axis of propagation can be resolved into the motion perpendicular to the axis of propagation and the motion along the axis of propagation (Fig. 4).

The wave functions that describe the sinusoidal movements of the semiphotons are solutions to the Schrödinger equation for a boson and the translational movement is a solution to the classical equations of mechanics [33]. These equations applied to the binary photon are consistent with the canonical eigenvalues of the photon. For a binary photon of total energy $E_{total} = \frac{hc}{\lambda} = \hbar\omega$, the eigenvalue for the rotational energy is $E_{rotational} = \frac{hc}{2\lambda} = \frac{\hbar\omega}{2}$ and the eigenvalue for the translational energy is $E_{translational} = \frac{hc}{2\lambda} = \frac{\hbar\omega}{2}$ [33]. The eigenvalue for the linear momentum along the axis of propagation is $\hbar k$ and the eigenvalue for the angular momentum in the plane perpendicular to the axis of propagation is $\hbar$ [33], consistent with the measured values of linear momentum [42-45], angular momentum [36], and spin [46-48]. The net angular momentum is restricted to the transverse plane of the binary photon perpendicular to the axis of propagation. The transverse plane in Euclidean space is homologous to the complex plane containing a real axis and an imaginary axis in phase space or configuration space.

The angular momentum of the binary photon is intelligible because the semiphotons with wavelength-associated mass m = $\pm\frac{\hbar\omega}{2c^2} = \frac{h}{2\lambda c}$ are not located at the center of gravity of the binary photon but at a wavelength-dependent distance $r = \frac{c}{\omega} = \frac{\lambda}{2\pi}$. Consequently, taking the masses and parities of the semiphotons into consideration, the rotational movements of the semiphotons along the trajectories described by the wave functions, are the basis of the angular momentum of the binary photon.

[1] The Mathematica® program used to produce the animations is available upon request. The animations were converted into .mp4 format using Adobe® Media Encoder using H.264 format and a Match Source-Adaptive High Bitrate.

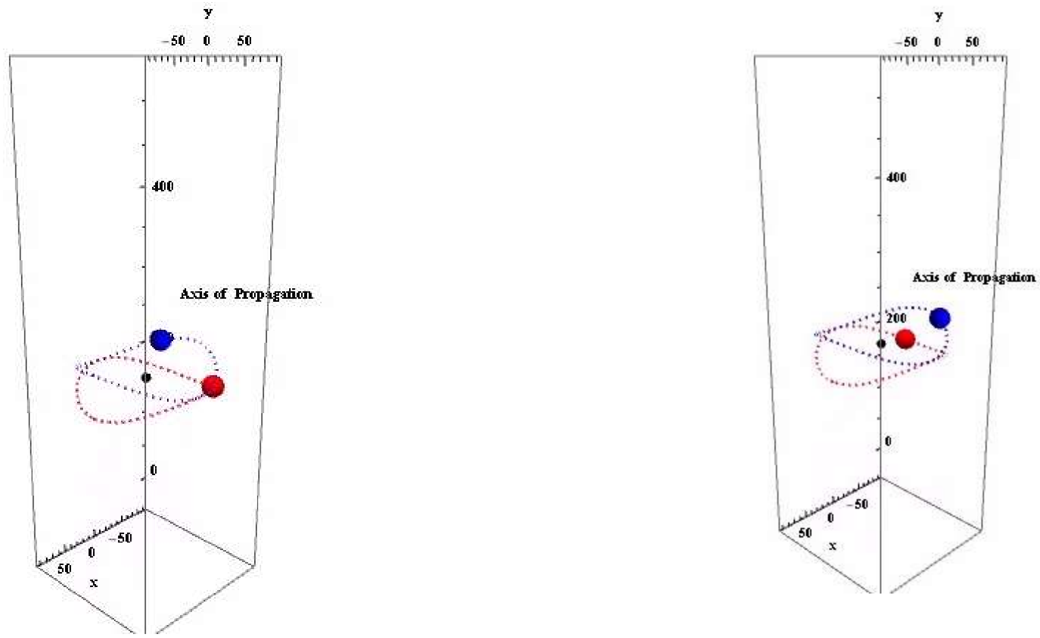

Fig. 2: The three-dimensional motions of the semiphotons that make up a 500 nm binary photon. The leading semiphoton (blue) has a positive mass and the following semiphoton (red) has a negative mass. Left: The positive mass semiphoton rotates clockwise and the negative mass semiphoton rotates anticlockwise. Thus the angular momentum ($+\hbar$) is antiparallel to direction of propagation. Right: The positive mass semiphoton rotates anticlockwise and the negative mass semiphoton rotates clockwise. Thus the angular momentum ($-\hbar$) is parallel to direction of propagation. The moving black dot represents the center of gravity of the binary photon. The axes are marked out in nanometers. The animated figures can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure%202%201.mp4 (left) and http://labs.plantbio.cornell.edu/wayne/Animations/Figure%202%204.mp4 (right).

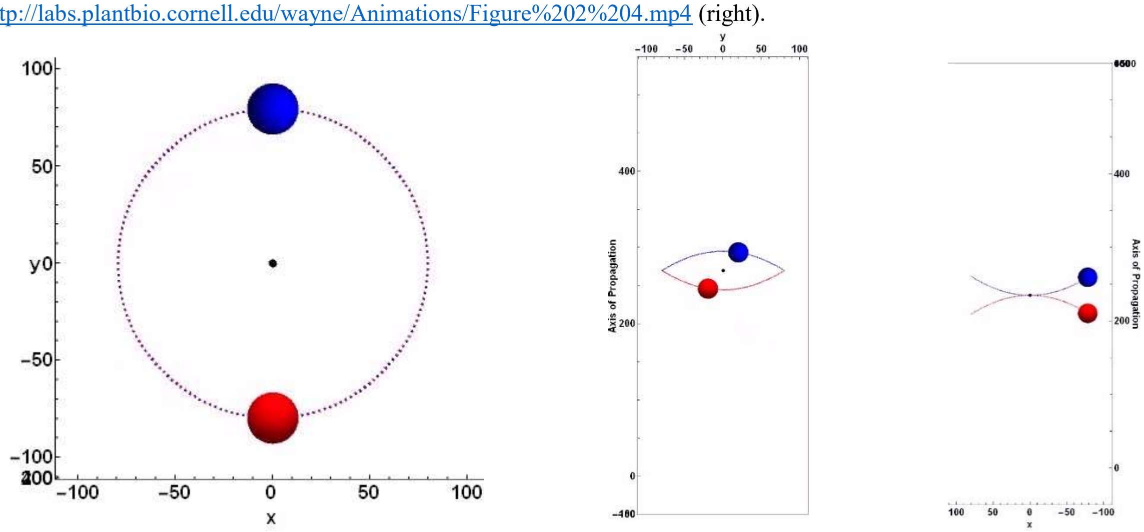

Fig. 3: The motions of the semiphotons in a 500 nm binary photon as observed in three orthogonal planes in Euclidean space. Left: The angular momentum of one cycle in the *xy* plane contributes $+\hbar$ to the total angular momentum of the binary photon with antiparallel angular momentum. Center: The angular momentum of one cycle in the *yz* plane contributes 0 to the total angular momentum. Right: The angular momentum of one cycle in the *xz* plane contributes 0 to the total angular momentum. The angular momentum of the leading semiphoton can be determined by curling the fingers of the right hand around the path of the leading semiphoton in the direction of motion. The thumb will represent the angular momentum vector. The angular momentum of the following semiphoton can be determined by curling the fingers of the left hand around the path of the following semiphoton in the direction of motion. The thumb will represent the angular momentum vector. The moving black dot represents the center of gravity of the binary photon. The axes are marked out in nanometers. The animations can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure%203%201%20XY.mp4 (left),

http://labs.plantbio.cornell.edu/wayne/Animations/Figure%203%201%20YZ.mp4 (center), and http://labs.plantbio.cornell.edu/wayne/Animations/Figure%203%201%20XZ.mp4 (right).

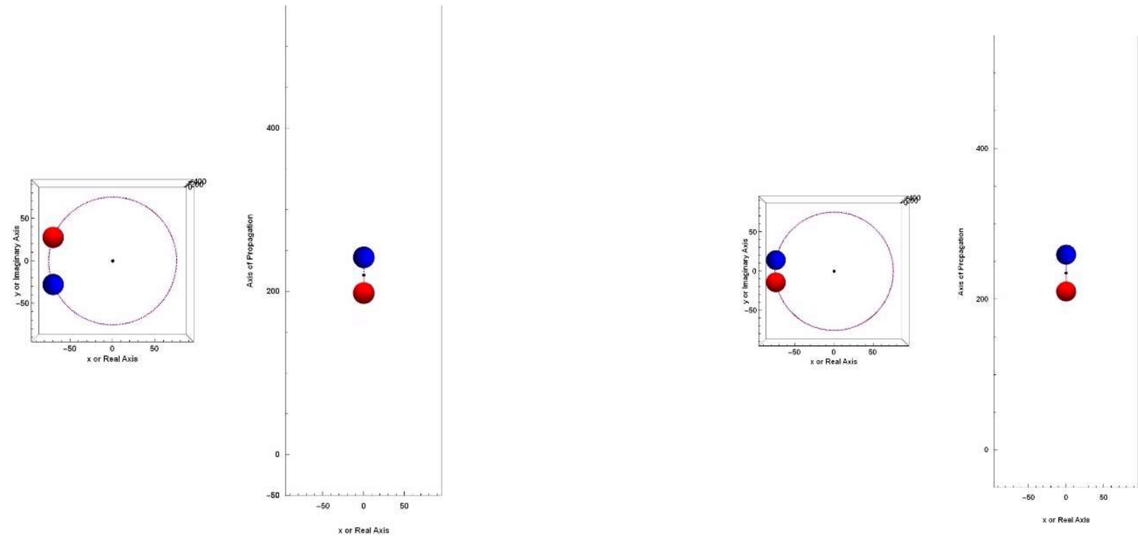

Fig. 4: Resolution of the three-dimensional motions of the semiphotons in a 500 nm binary photon perpendicular to the axis of propagation and along the axis of propagation that make up a binary photon. Left: angular momentum $+\hbar$. Right: angular momentum $-\hbar$. The black dot represents the center of gravity of the binary photon. The axes are marked out in nanometers. The animations can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure%204%201.mp4 (left) and http://labs.plantbio.cornell.edu/wayne/Animations/Figure%204%204.mp4 (right).

Since light is fundamentally the carrier of the electromagnetic force [27], we must analyze the binary photon's basis for generating electromagnetic fields. Oddly, this analysis must be built upon the foundation that light is electrically neutral. Indeed Maxwell [49] revealed the electromagnetic wave picture of light by assuming $\nabla \cdot E = 0$. In the standard model, the photon is considered to be electrically neutral by virtue of being an elementary particle with no charge. By contrast, the binary photon is considered to be electrically neutral by being a composite particle composed of two conjugate semiphotons with equal and opposite charges. The two charges generate a time-varying electric field (E, in V/m) at the center of gravity of the binary photon that depends on the positions of the semiphotons relative to the center of gravity of the binary photon. The electric field in Cartesian coordinates can be calculated using Gauss's law of electricity:

$$\vec{E}^{leading} = P \frac{\pm q}{4\pi\varepsilon_0} \frac{\vec{\Psi}^{leading-posi}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \tag{8a}$$

$$\vec{E}^{following} = -P \frac{\mp q}{4\pi\varepsilon_0} \frac{\vec{\Psi}^{following-position}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \tag{8b}$$

where q is the magnitude of the charge of the semiphoton, P is the parity of the leading semiphoton, and in Eqns. (8a) and (8b) P only applies to the $\hat{y}$ axis, and ε_0 is the electric permittivity of the vacuum. The total electric field at the center of gravity of the binary photon is given by the sum of the electric fields derived from the two semiphotons:

$$\vec{E}^{binary\ photo} = \vec{E}^{leading} + \vec{E}^{following} \tag{9}$$

The orthogonal $\hat{x}$, $\hat{y}$, and $\hat{z}$ components of the electric field have been resolved in Eqn. (10). The motions of the conjugate semiphotons along the paths described by the wave functions produce a sinusoidal transverse electric field at the center of gravity of the binary photon [26]. The axis of the electric field is defined as the axis of electric polarization. In contrast to the quantum mechanical photon, which is considered to be circularly polarized [46,50], the transverse electric field of the binary photon is linearly polarized. A longitudinal electric field is also generated at the center of gravity of the binary photon. The magnitude of the transverse electric field is greater than the magnitude of the longitudinal electric field being approximately five times greater.

$$E = \begin{bmatrix} 0 \\ P\frac{2q}{4\pi\varepsilon_0}\frac{\frac{\lambda}{2\pi}\sin[\theta]}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ \frac{4q}{4\pi\varepsilon_0}\frac{\frac{\lambda}{(2\pi)^2}\cos^2[\theta]}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \tag{10}$$

The phase relationships of the transverse and longitudinal electric fields for binary photons with antiparallel or antiparallel angular momenta are depicted in Fig. 5. Note that an equal combination of binary photons with antiparallel and parallel angular momenta that are in phase would yield exclusively a transverse electric field.

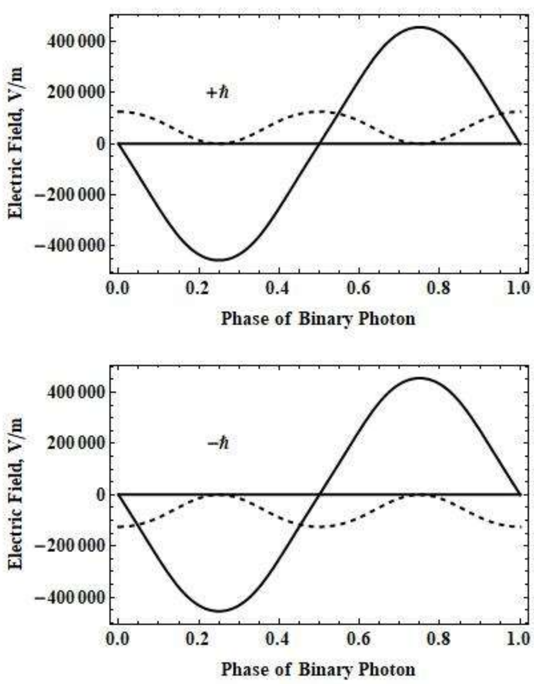

Fig. 5: The electric fields at the center of gravity of a binary photon with angular momentum (+ħ) antiparallel to the axis of propagation (top) and angular momentum (-ħ) parallel to the axis of propagation (bottom). The polarity of the transverse electric fields (solid lines) are the same while the polarity of the longitudinal electric fields are opposite. An equal combination of binary photons with antiparallel and parallel angular momenta that are in phase would yield exclusively a transverse electric field.

According to the Ampere-Maxwell law, an electric current or the time rate of change of an electric field generates a magnetic field that circulates around the current or the electric field. I consider that the curl of the magnetic field ($\nabla \times \vec{B}$, in Vs/m^3) is generated in each of the Cartesian planes as a result of the movements of the two charged semiphotons around the center of gravity of the binary photon. Consequently, I take the first temporal derivatives of the wave functions that determine the positions of the semiphotons in order to determine the velocities of the semiphotons.

The wave function that describes the velocity of the leading semiphoton is:

$$\Psi^{leading-velocity} = \begin{bmatrix} -\lambda\sin[\theta]\frac{dw}{dt} \\ \lambda\,\mathrm{P}\cos[\theta]\frac{dw}{dt} \\ c - \frac{2\lambda}{\pi}\cos[\theta]\sin[\theta]\frac{dw}{dt} \end{bmatrix} \tag{11a}$$

And the wave function that describes the velocity of the following semiphoton is:

$$\Psi^{following-velocity} = \begin{bmatrix} -\lambda\sin[\theta]\frac{dw}{dt} \\ -\lambda\,\mathrm{P}\cos[\theta]\frac{dw}{dt} \\ c + \frac{2\lambda}{\pi}\cos[\theta]\sin[\theta]\frac{dw}{dt} \end{bmatrix} \tag{11b}$$

Since $\frac{dw}{dt} = \nu$ and $\nu\lambda = c$, the velocity wave functions become:

$$\Psi^{leading-velocity} = \begin{bmatrix} -c\sin[\theta] \\ c\,P\cos[\theta] \\ c - \frac{2c}{\pi}\cos[\theta]\sin[\theta] \end{bmatrix} \tag{12a}$$

and

$$\Psi^{following-velocity} = \begin{bmatrix} -c\sin[\theta] \\ -c\,P\cos[\theta] \\ c + \frac{2c}{\pi}\cos[\theta]\sin[\theta] \end{bmatrix} \tag{12b}$$

The curl is a vector along an axis and the magnetic field is a circulation in the orthogonal plane. The curl of the magnetic field in each plane due to the charge, velocity, and position of each semiphoton can be calculated from the velocities of the semiphotons using the Ampere-Maxwell law:

$$\nabla \times \vec{B}_{zy-l} = \frac{2\mu_0}{4\pi}\frac{q\overline{\Psi}^{\,leading-velocity}\cdot\hat{x}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \tag{13a}$$

$$\nabla \times \vec{B}_{xz-l} = \frac{2\mu_0}{4\pi}\frac{Pq\overline{\Psi}^{\,leading-velocity}\cdot\hat{y}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \tag{13b}$$

$$\nabla \times \vec{B}_{yx-l} = \frac{2\mu_0}{4\pi}\frac{q\overline{\Psi}^{\,leading-velocity}\cdot\hat{z}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \tag{13c}$$

$$\nabla \times \vec{B}_{zy-f} = \frac{2\mu_0}{4\pi} \frac{q \bar{\Psi}^{following-velocity} \cdot \hat{x}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \quad (13d)$$

$$\nabla \times \vec{B}_{xz-f} = \frac{2\mu_0}{4\pi} \frac{Pq \bar{\Psi}^{following-velocity} \cdot \hat{y}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \quad (13e)$$

$$\nabla \times \vec{B}_{yx-f} = \frac{2\mu_0}{4\pi} \frac{q \bar{\Psi}^{following-velocity} \cdot \hat{z}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \quad (13f)$$

Combine the effects of the leading and following semiphotons to get the total curl of the magnetic field in each plane in a Cartesian coordinate system:

$$\nabla \times \vec{B} = \begin{bmatrix} 0\,\hat{x} \\ -\frac{\mu_0 qP}{2\pi} \frac{c\cos[\theta]\,\hat{y}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ -\frac{4\mu_0}{4\pi^2} \frac{qc\cos[\theta]\sin[\theta]\,\hat{z}}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (14)$$

The phase relationships of the curl of the magnetic fields of a binary photon with antiparallel or antiparallel angular momenta are depicted in Fig. 6. Note that an equal combination of binary photons with antiparallel and parallel angular momenta that are in phase would yield exclusively a magnetic field in the *xz* plane.

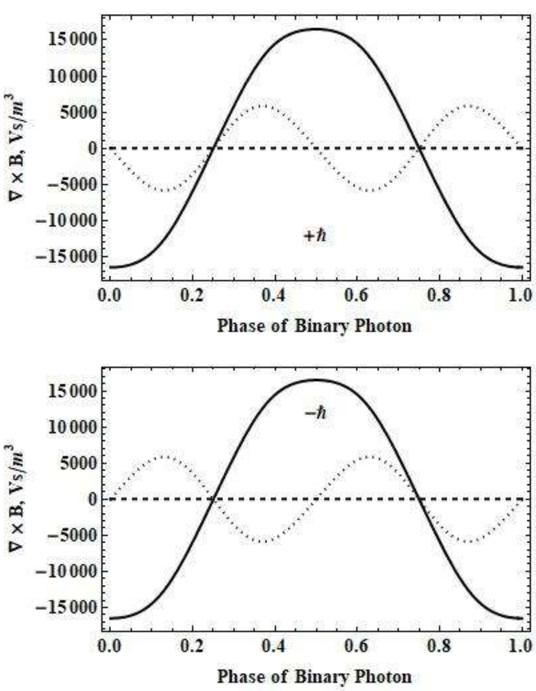

Fig. 6: The curl of the magnetic field around the center of gravity of a binary photon with angular momentum (+ħ) antiparallel to the axis of propagation (top) and angular momentum (-ħ) parallel to the axis of propagation (bottom).

The sign of the curl of the magnetic field in the *xz* plane (solid) is the same, while the signs of the curl of the magnetic field in the *xy* plane (dotted) are opposite. The curl of the magnetic field in the *yz* plane vanishes (dashed). An equal combination of binary photons with antiparallel and parallel angular momenta that are in phase would yield exclusively a magnetic field in the *xz* plane.

The electric and magnetic fields generated in the binary photon are related by Faraday's law where the temporal derivative of the magnetic field gives the negative curl of the electric field. They are also related by the Ampere-Maxwell law, where the temporal derivative of the electric field gives the curl of the magnetic field [26]. Thus the electric and magnetic fields are orthogonal and out-of-phase by a quadrature. This seems to be a *sine qua non* for a regenerative electromagnetic wave that exhibits perpetual motion. These phase relations do not exist in Maxwell's electromagnetic wave, where the electric and magnetic fields are orthogonal and in phase (Fig. 7).

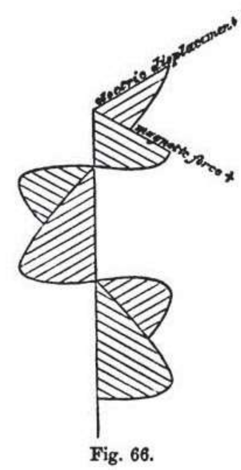

Fig. 7: The phase relations of the electric and magnetic fields according to Maxwell [48].

Henrí Poincaré [51] and Arnold Sommerfeld [52,53] realized that Maxwell's electromagnetic theory of light was inconsistent with the assumptions of Green's theorem and Kirchhoff's diffraction theory of light, which required the electric field and magnetic field to be a quadrature out-of-phase. The phase relationship of the electric and magnetic fields of the binary photon is consistent with the assumptions of Green's theorem and Kirchhoff's diffraction theory [54].

Another difference between Maxwell's electromagnetic wave theory of light and the model of the binary photon, is that the time-varying magnetic field in Maxwell's theory is planar, while the time-varying magnetic field produced by the binary photon is three-dimensional. Fig. 8 shows the electric and magnetic fields of a binary photon from the perspective of a stationary observer.

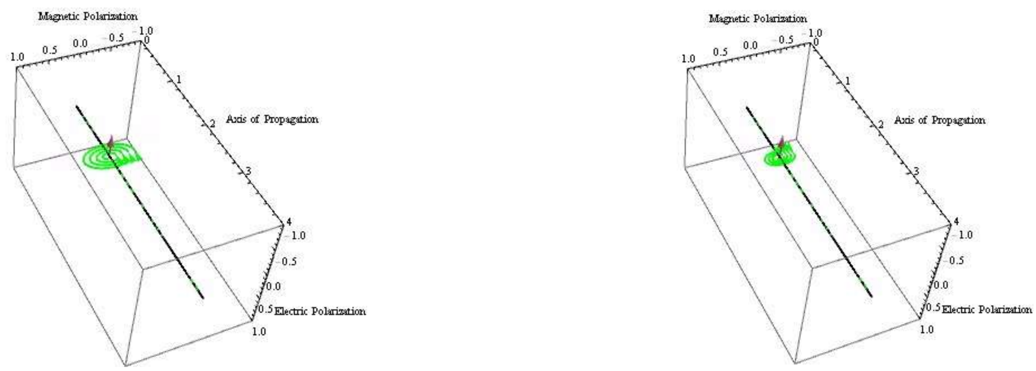

Fig. 8: The electric (pink) and magnetic (green) fields of a binary photon along the axis of propagation (black). Left: with angular momentum antiparallel to the axis of propagation from the perspective of a stationary observer. Right: with angular momentum parallel to the axis of propagation from the perspective of a stationary observer. The pink arrow indicates the sign of the electric field and the green arrows indicate the sense of the circulation of the magnetic field. The size of the vector and the diameter of the rings indicate the magnitudes of the fields. The animations can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure%208%20Stationary%20Observer1.mp4 (left) and http://labs.plantbio.cornell.edu/wayne/Animations/Figure%208%20Stationary%20Observer4.mp4 (right).

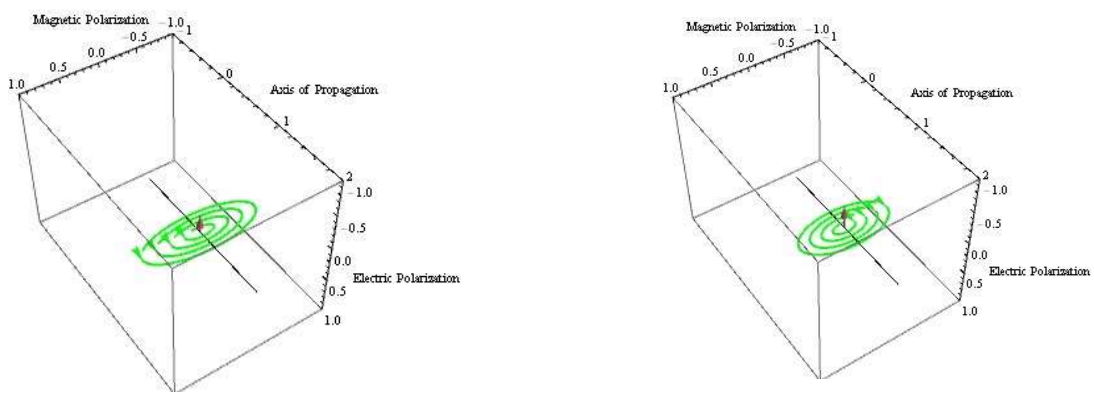

Fig. 9: The electric (pink) and magnetic (green) fields of a binary photon. Left: with angular momentum antiparallel to the axis of propagation from the perspective of an observer moving with the binary photon at the speed of light. Right: with angular momentum parallel to the axis of propagation from the perspective of an observer moving with the binary photon at the speed of light. The pink arrow indicates the sign of the electric field and the green arrows indicate the sense of the circulation of the magnetic field. The size of the vector and the diameter of the rings indicate the magnitudes of the fields.

The animations can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure%209%20Bicycle%20View1.mp4 (left) and http://labs.plantbio.cornell.edu/wayne/Animations/Figure%209%20Bicycle%20View4.mp4 (right).

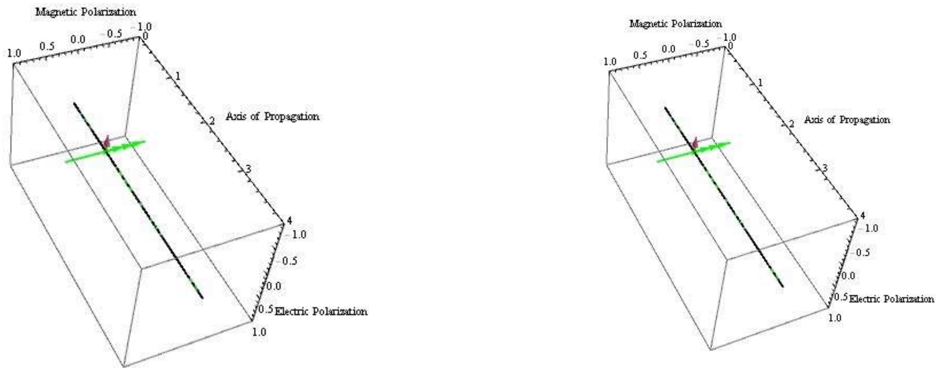

Fig. 10: Planar electric (pink) and magnetic (green) fields of a binary photon. Left: with angular momentum antiparallel to the axis of propagation from the perspective of a stationary observer. Right: with angular momentum parallel to the axis of propagation from the perspective of a stationary observer. The animations can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure%2010%20Stationary%20Observer%20Planar1.mp4 (left) and http://labs.plantbio.cornell.edu/wayne/Animations/Figure%2010%20Stationary%20Observer%20Planar4.mp4 (right).

Fig. 11: A comparison between the planar electric (pink) and geometrical- and dimensionally-reduced magnetic (green) fields of a binary photon (left) and the planar electric (pink) and magnetic fields of Maxwell's electromagnetic wave (right). The animations can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure11left.mp4 (left) and http://labs.plantbio.cornell.edu/wayne/Animations/Figure11right.mp4 (right).

Fig. 9 shows the time-varying electric and magnetic fields of a binary photon from the perspective of an observer moving the binary photon at the speed of light. This is the binary photon's answer to Einstein's most famous thought experiment [35,36]: "*If I pursue a beam of light with velocity c (velocity of light in a vacuum), I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest.*"

By reducing the quantum of light to an electrically-neutral geometric point, Einstein was unable to make a concrete physical picture of an oscillating electromagnetic field that was consistent with Maxwell's equations and showed no preferred frame of reference. In order to accommodate the principle of relativity and the principle of the constancy of the speed of light, he reckoned that time would have to become dilated so that an observer at rest with the quantum of light would see the oscillation as if it were frozen. He then relativized time and space by using the Lorentz transformation [34].

By endowing the quantum of light with equal and opposite charge and using Maxwell's equations, the model of the binary photon offers an alternative way to address the principle of relativity that demands that there be no preferred frames in reckoning the speed of light. According to the special theory of relativity, observers reckon time and space in a velocity-dependent manner, while the alternative theory states that all observers, including those in space at absolute rest, reckon time, space and the speed of light in an invariant manner but the wavelength of light observed is velocity-dependent according to the Doppler effect expanded to second order [10,11,30,55-58].

While the magnetic field of the binary photon is three dimensional, involving the *xz* and *xy* planes, we can represent it as a plane wave by removing the contribution in the *xy* plane. Fig. 10 shows planar electric and magnetic fields of a propagating binary photon viewed by a stationary observer. The two fields are a quadrature out-of-phase. Fig. 11 is an animation that shows the difference in the phase relations of the electric and magnetic fields in a binary photon and light according to Maxwell.

The model of the binary photon applies to electromagnetic radiation of all wavelengths. Since the radius and circumference of the paths in the transverse plane modeled by the wave functions depend on the wavelength, the cross section of the binary photon varies with wavelength (Fig. 12). Moreover, the floppiness of the binary photon in the axis parallel to the axis of propagation increases with wavelength (Fig. 13). Said another way, the cross-sectional area and the floppiness of the binary photon decreases with the total energy of the binary photon. The intermediate range of visible light between particle-like x-rays and wave-like infrared radiation is why light in the visible range clearly shows particulate virtues when looking at the photoelectric effect and wave virtues when looking at diffraction. Binary photons with very short wavelengths in the x-ray or gamma ray region can be approximated realistically as mathematical points while photons with very long wavelengths can be approximated realistically as plane waves. Photons in the visible range cannot be comprehensively modeled as a particle or as a wave only [59-62] but can be comprehensively modeled as a binary photon, which is a composite entity that takes up space. The binary photon is composed of a particle of matter and its conjugate antiparticle that move around their center of gravity and generate electric and magnetic waves that are out-of-phase by a quadrature.

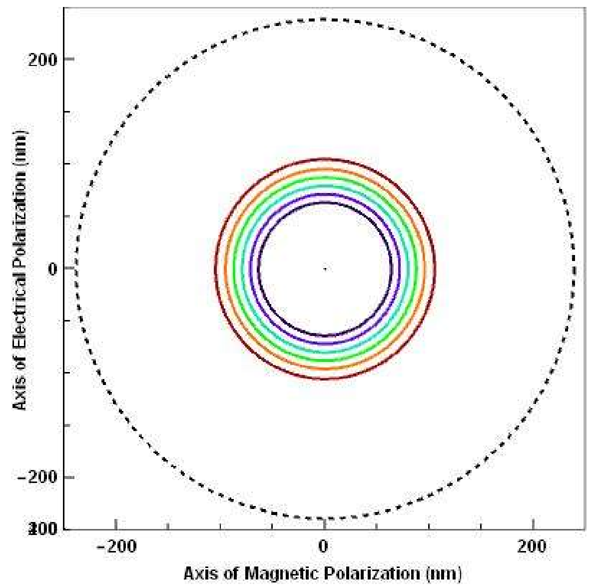

Fig. 12: The paths of semiphotons for differently colored binary photons. The paths become longer and the curvature becomes smaller as we go from x-rays, to violet, to indigo, to blue, to green, to yellow, to orange, to red, to infrared.

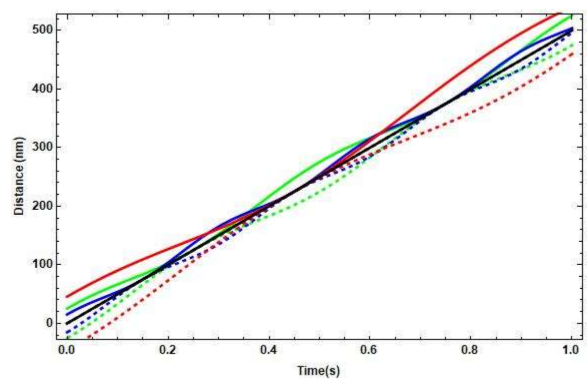

Fig. 13: The amplitude or length of the oscillation along the axis of propagation of the binary photon increases with wavelength as we go from blue, to green to red. Leading semiphoton (solid); following semiphoton (dashed).

I consider that the orbital model of the atom as opposed to the planetary model of the atom an unnecessary consequence of the quantum mechanical demand for a model in which the electrons could not be localized in time and space. This resulted in the orbital angular momentum being analyzed as $J(J+1)$, which describes an orbital instead of J, which describes an orbit. Here I consider each electron to move around the nucleus in an orbit consistent with the planetary model of the atom. With this model, the binary photon can be absorbed by an atom in such a way that the energy and angular momentum are conserved. The conservation laws determine the selection rules [63]. Conservation of angular momentum demands that atoms with electrons moving in orbits that exhibit antiparallel angular momentum will only absorb binary photons with the correct energy that exhibit antiparallel angular momentum and atoms with electrons moving in orbits that exhibit parallel angular momentum will only absorb binary photons with the correct energy that exhibit parallel angular momentum (Fig. 14). Likewise atoms that exhibit antiparallel angular momentum will only emit binary photons with antiparallel angular momentum and atoms that exhibit parallel angular momentum will only emit binary photons with parallel angular momentum (Fig. 15).

George Joos [64] wrote, "*Although the phenomena of interference appear to prove that light is of the nature of waves, we have always treated emission and absorption as though the light consisted of individual energy centres (quanta) of amount hν which could not be subdivided. This quantum-like energy transfer has been rigorously demonstrated by an enormous number of experiments. Attempts to introduce this process into the wave picture by assuming that the atom could store up the electromagnetic energy incident on it until the quantity hν is reached, lead to quite impossible accumulation times for X-rays, so that this procedure was soon abandoned. Attempts to give the quanta themselves such properties that interference phenomena would result without waves proved equally unfruitful. There remains no other course but to look upon waves and quanta as two observable aspects of a single phenomenon whose true nature cannot be described in terms of any mechanical model.*" The model of the binary photon presented here is adequate in describing absorption and emission as well as interference [26] and diffraction [56] and thus may represent the true nature of light. The mechanical nature of the binary photon offers insights into molecular spectroscopy. The correlation between the wavelength of light and the radius of the binary photon ensures that a long wavelength binary photon has a long lever arm that can cause a rotation of the absorbing body. This may be the reason why the wavelengths that effect molecular rotations are relatively long—the binary photons trade off long lever arms for less energy.

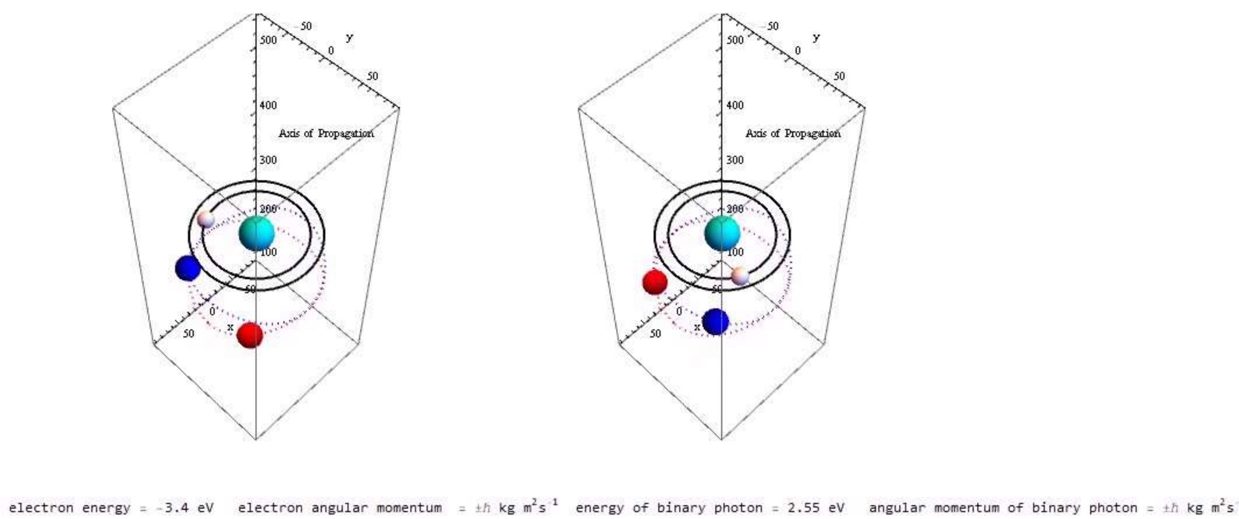

Fig. 14: The absorption of a binary photon by a Bohr atom with angular momentum antiparallel (left) and parallel (right) to the axis of propagation. The conservation of energy and conservation of angular momentum is observable. The values of the energy and angular momenta of the atom and the binary photon before and after absorption are given under the animation. The animation can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure%2014%20Absorption.mp4.

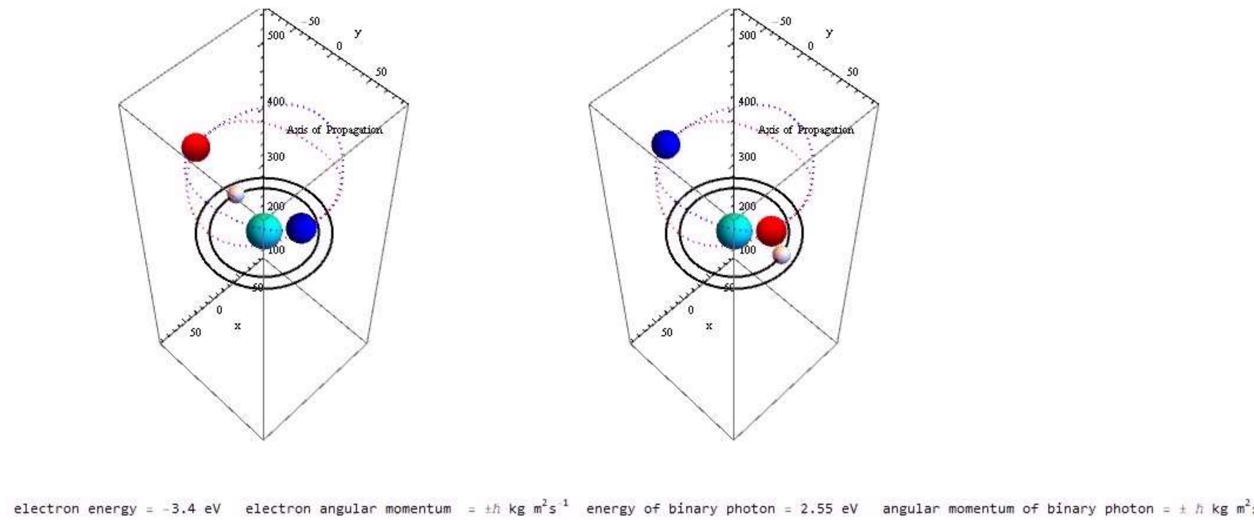

Fig. 15: The emission of a binary photon by a Bohr atom with angular momentum antiparallel (Left) and parallel (Right) to the axis of propagation. The conservation of energy and conservation of angular momentum is observable. The values of the energy and angular momenta of the atom and the binary photon before and after emission are given under the animation. The animation can be viewed at http://labs.plantbio.cornell.edu/wayne/Animations/Figure%2015%20Emission.mp4.

Since Planck's constant has the dimensions of angular momentum as well as action (energy × time), John Nicholson [65] recognized the importance of angular momentum in understanding the mechanics of atomic processes. "*If, therefore, the constant h of Planck has, as Sommerfeld has suggested, an atomic significance, it may mean that the angular momentum of an atom can only rise or fall by discrete amounts when electrons leave or return. It is readily seen that this view presents less difficulty to the mind than the more usual interpretation, which is believed to involve an atomic constitution of energy itself.*" Niels Bohr [59] built on Nicholson's insight to develop the planetary model of the atom upon which he built the theory of spectra. However, in the absorption and emission of light, Bohr emphasized energy over angular momentum, and discreteness of light over the mechanics of light. William Wilson [66] and Sommerfeld [67] extended Bohr's planetary model of the atom by giving equal weight to the conservation of both energy and angular momentum in the mechanical interaction of light and matter. The absorption and emission of a binary photon from a Bohr atom shown in figs. 14 and 15 clearly demonstrate the conservation of energy ($\hbar\omega$) and the conservation of angular momentum ($\hbar$) in the mechanical interaction of light and matter in a picturable and intelligible way. If the electrons travel in mechanically-defined orbits rather than probabilistic orbitals, then a group of randomly arranged atoms will emit binary photons with components of angular momenta that are parallel and antiparallel to the direction of propagation. If the atom and the binary photon can be defined mechanically [68,69] instead of probabilistically [70], then determining the angular momentum or spin of a binary photon would reveal a heretofore hidden variable predicted by Einstein [40,71]. Moreover, if the total energy of the binary photon be equipartitioned into rotational and translational energy, then the deflection of starlight, which is the crucial experiment underlying general relativity, is understandable as a mechanical process that takes place in Euclidean space and Newtonian time [35].

3. Conclusion

Arthur Schuster [72], who first envisioned the idea of antimatter [73], wrote over a century ago, "*There is at present no theory of optics in the sense that the elastic solid theory was accepted fifty years ago. We have abandoned that theory, and learned that the undulations of light are electromagnetic waves differing only in linear dimensions from the disturbances which are generated by oscillating electric currents or moving magnets. But so long as the character of the displacements which constitute the waves remains undefined we cannot pretend to have established a theory of light. This limitation of our knowledge, which in one sense is a retrogression from the philosophic standpoint of the founders of the undulatory theory, is not always sufficiently recognized and sometimes deliberately ignored. Those who believe in the possibility of a mechanical conception of the universe and are not willing to* *abandon the methods which from the time of Galileo and Newton have uniformly and exclusively led to success, must look with the gravest concern on a growing school of scientific thought which rests content with equations correctly representing numerical relationships between different phenomena, even though no precise meaning can be attached to the symbols used. The fact that this evasive school of philosophy has received some countenance from the writings of Heinrich Hertz renders it all the more necessary that it should be treated seriously and resisted strenuously.*

The equations which at present represent the electromagnetic theory of light have rendered excellent service, and we must look upon them as a framework into which a more complete theory must necessarily fit, but they cannot be accepted as constituting in themselves a final theory of light.

The study of Physics must be based on a knowledge of Mechanics, and the problem of light will only be solved when we have discovered the mechanical properties of the aether. While we are in ignorance on fundamental matters concerning the origin of electric and magnetic strains and stresses, it is necessary to introduce the theoretical study of light by a careful treatment of wave propagation through media the elastic properties of which are known." The electrodynamic properties of the binary photon presented here give intelligibility to the nature of light and make the mechanical, electrical, and magnetic properties given by Maxwell to the aether superfluous.

Currently, the standard theory of quantum mechanics treats elementary particles as if they have no independent existence in space and time until they are measured. In *Introduction to Quantum Mechanics*, David Griffiths [74] described: "*The orthodox position: The particle wasn't really anywhere. It was the act of measurement that forced the particle to 'take a stand' (though how and why it decided on the point C we dare not ask).* [Pascual] *Jordan said it most starkly, 'Observations not only disturb what is to be measured, they produce it…. We compel (the particle) to assume a definite position.' This view (the so-called Copenhagen interpretation), is associated with Bohr and his followers. Among physicists it has always been the most widely accepted position." One moonlit night as Einstein walked with Abraham Pais in Princeton, Einstein asked Pais, "Do you really believe the moon is not there when you are not looking at it?"* Acceptance of the Copenhagen interpretation is a choice not a certainty. Einstein never accepted it [75] as told by Philipp Frank [76] below:

Einstein: "*A new fashion has now arisen in physics. By means of ingeniously formulated theoretical experiments it is proved that physical magnitudes cannot be measured, or, to put it more precisely, that according to accepted natural laws the investigated bodies behave in such a way as to baffle all attempts at measurement. From this the conclusion is drawn that it is completely meaningless to retain these magnitudes* [position and momentum] *in the language of physics*."

Philipp Frank: "*But the fashion you speak of was invented by you in 1905*!"

Einstein: "*A good joke should not be repeated too often*."

Frank went on to say, "*then in a more serious vein he* [Einstein] *explained to me that he did not see any description of a metaphysical reality in the theory of relativity, but that he did regard an electromagnetic or gravitational field as a physical reality, in the same sense that matter had formally been considered so. The theory of relativity teaches us the connection between different descriptions of one and the same reality*."

For the champions of the Copenhagen interpretation, reality was a free creation of the imagination but the laws of physics were eternal and true. For Einstein, it was not reality that was a free creation of the imagination but the laws of physics. According to Frank [76], "*In the name of progress in physics he* [Einstein] *claims the right to create any system of formulations and laws that would be in agreement with new observations…. For Einstein the basic theoretical laws are a free creation of the imagination, the product of the activity of an inventor who is restricted in his speculation by two principles: an empirical one, that the conclusions drawn from the theory must be confirmed by experience, and a half-logical, half aesthetic principle, that the fundamental laws should be as few in number as possible and logically compatible*." Physics was moving away from explaining nature mechanically to describing nature mathematically.

In *The Character of Physical Law*, Richard Feynman [77] wrote, "*Let us start with the history of light. At first light was assumed to behave very much like a shower of particles, of corpuscles, like rain, or like bullets from a gun. Then with further research it was clear that this was not right, that the light actually behaved like waves, like water waves for instance. Then in the twentieth century, on further research, it appeared again that light actually behaved in many ways like particles—they are called photons now…As time went on there was a growing confusion about how these things really behaved—waves or particles, particles or waves? Everything looked like both.*

The growing confusion was resolved in 1925 or 1926 with the advent of the correct equations for quantum mechanics. Now we know how the electrons *and light behave. But what can I call it? If I say they behave light particles, I give the wrong impression; also if I say they behave like waves. They behave in their own inimitable way, which could be called a quantum mechanical way. They behave in a way that is nothing that you have ever seen before. Your experience with things that you have seen before is incomplete. The behavior of things on a very tiny scale is simply different. An atom does not behave like a weight hanging on a spring and oscillating. Nor does it behave like a miniature representation of the solar system with little planets going around in orbits. Nor does it appear to be somewhat like a cloud or fog of some sort surrounding the nucleus. It behaves like nothing you have seen before…*

There was a time when the newspapers said that only twelve men understood the theory of relativity. I do not believe there was ever such a time. There might have been a time when only one man did, because he was the only guy that caught on, before he wrote his paper. But after people read the paper a lot of people understood the theory of relativity in some way or other, certainly more than twelve. On the other hand, I think I can safely say that nobody understands quantum mechanics…Do not keep saying to yourself, if you can possibly avoid it, 'But how can it be like that?' because you will get 'down the drain', into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that." Today the incomprehensibility of quantum mechanics that has resulted from moving away from a mechanical explanation and towards a mathematical description has been codified by David Mermin [78] and Max Tegmark [79] in the philosophy of "*shut up and calculate*."

From its origin, there has been no consensus in quantum mechanics on the value of *Anschaulichkeit* or picturability in explaining nature [80]. On the one hand, Erwin Schrödinger [81] wrote, '*My theory was inspired by L. de Broglie and by brief but infinitely far-seeing remarks of A. Einstein (Berl. Ber. 1925, p. 9ff.) I was absolutely unaware of any genetic relationship with Heisenberg. I naturally knew about his theory, but because of the to me very difficult-appearing methods of transcendental algebra and the lack of Anschaulichkeit, I felt deterred, by it, if not to say repelled.*" On the other hand, Werner Heisenberg [82] wrote, "*The more I think about the physical portion of the Schrödinger theory, the more repulsive I find it....What Schrödinger writes about the visualizability of his theory 'is probably not quite right', in other words it's crap*." Schrödinger [81], the son of a botanist, realized that "*Physics does not consist only of atomic research, science does not consist only of physics, and life does not consist only of science. The aim of atomic research is to fit our empirical knowledge concerning it into our other thinking. All of this other thinking, so far as it concerns the outer world, is active in space and time. If it cannot be fitted into space and time, then it fails in its whole aim and one does not know what purpose it really serves.*" Perhaps quantum mechanics, as well as relativity, two theories that fundamentally depend on the nature of light, will have, in the context of Euclidean space and Newtonian time, more explanatory power and *Anschaulichkeit* in the light of the binary photon, which was founded on the possible existence of positive and negative mass.

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