A Description of the Electromagnetic Fields of a Binary Photon

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The mechanical properties of a binary photon can be described by transverse and longitudinal wave functions that give the positions and velocities of the semiphotons that make up a binary photon. The electromagnetic properties of the binary photon can be determined with the aid of Gauss's law of electricity by assuming that the two semiphotons have equal and opposite electrical charge, and consequently, they act as sources and sinks to produce electric and magnetic fields. The binary photon has a large transverse polarized electric field and a smaller longitudinal electric field. Magnetic fields are associated with the two electric fields. The associated electric and magnetic fields are a quarter of a wavelength out-of-phase, which is consistent with Faraday's law and the Ampere-Maxwell law. By assuming that light was electrically neutral due to the absence of charge, Maxwell proposed that the electric and magnetic fields produced by electrically-neutral light were orthogonal and in-phase. By contrast, the out-of-phase electric and magnetic fields found within the binary photon are a consequence of assuming that the electrical neutrality of light is due to the possession of equal and opposite charges. The strengths of the electric and magnetic fields are related to the wavelength of the binary photon. The transverse electric field (E_y) of the monochromatic binary photon is linearly polarized, the longitudinal electric field (z) is unpolarized, and the magnetic fields (B_{xz}, B_{xy}) are best represented by circulations or curls. The quantized three-dimensional electric and magnetic fields of a binary photon are able to interact with the quantized three-dimensional electric and magnetic fields of another binary photon as observed interference phenomena demand. However, complete destructive interference is only attainable if a given beam contains equal numbers of binary photons with oppositely-directed angular momenta. In retrospect, this makes sense since randomly arranged emitters will emit binary photons with opposite angular momenta with equal numbers. This suggests that the direction of angular momentum may be a hidden variable of light. The binary photon interprets the wave-particle duality of quantum mechanics in a way that makes it possible to visualize simultaneously the wave and particle properties of light as waves *and* two particles, where the electromagnetic waves are produced by two electrically-charged particles. This differs from the standard model where light is visualized as a wave *or* a particle. The visualizability of the semiphotons and the electromagnetic fields they generate within the binary photon makes Born and Heisenberg's claim that the microscopic quantum mechanical world must be fundamentally indeterminate, acausal, and unpicturable unwarranted.

"*Still, for the time being the most natural interpretation seems to me to be that the occurrence of electromagnetic fields of light is associated with singular points just like the occurrence of electrostatic fields according to the electron theory. It is not out of the question that in such a theory the entire energy of the electromagnetic field might be viewed as localized in these singularities, exactly like in the old theory of action at a distance. I more or less imagine each such singular point as being surrounded by a field of force which has essentially the character of a plane wave and whose amplitude decreases with the distance from the singular point. If many such singularities are present at separations that are small compared with the dimensions of the field of force of a singular point, then such fields of force will superpose, and their totality will yield as undulatory field of force that may differ only slightly from an undulatory field as defined by the current electromagnetic theory of light.*"

A. Einstein [1]

1. Introduction

Newton [2] and Huygens [3], the founders of the corpuscular and wave theories of light, respectively, considered optical phenomena to be the result of the action of an inseparable mixture of corpuscles *and* waves—Newton considered light to be composed of corpuscles moving through a wave-like ether while Huygens considered light to consist of waves moving through a particulate ether. The followers of these two luminaries were more unbending than the originators, believing that light was composed of *either* corpuscles *or* waves. Twentieth century physics, to a large extent strove to make the wave-particle duality they inherited intelligible.

Einstein [1] attempted to unite the particle and wave theories of light with the aid of statistical mechanics although he was aware that a complete equation for the motion of light quanta would have to contain the elementary charge (q)

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as well as the speed of light (c). Einstein [4] wrote, "*We should remember that the elementary quantum ε of electricity is an outsider in Maxwell-Lorentz electrodynamics…. The fundamental equation of optics …will have to be replaced by an equation in which the universal constant ε (probably its square) also appears in a coefficient…. I have not yet succeeded in finding a system of equations…suitable for the construction of the elementary electrical quantum and the light quanta. The variety of possibilities does not seem so great, for one to have to shrink from this task.*"

Using the founding principles of electromagnetism, Thomson [5,6] used Faraday's lines of force to describe the photon in his attempt to reconcile the two theories of light. Following the discovery of antimatter, de Broglie [7,8] tried to unite the two theories of light by considering the photon to be a composite particle composed of two spinning semiphotons consisting of a neutral particle of matter and a neutral particle of antimatter.

When all attempts to unify the wave and corpuscular theories of light failed, the idea of complementarity supplanted the classical concept of causality in modern physics. Born and Heisenberg [9] declared at the 1927 Solvay Conference [10] "*By way of summary, we wish to emphasise that while we consider the last-mentioned enquiries, which relate to a quantum mechanical treatment of the electromagnetic field, as not yet completed, we consider quantum mechanics to be a closed theory* [geschlossene Theorie]*, whose fundamental physical and mathematical assumptions are no longer susceptible of any modification…On the question of the 'validity of the law of causality' we have this opinion: as long as one takes into account only experiments that lie in the domain of our currently acquired physical and quantum mechanical experience, the assumption of indeterminism in principle, here taken as fundamental, agrees with experience. The further development of the theory of radiation will change nothing in this state of affairs, because the dualism between corpuscles and waves, which in quantum mechanics appears as part of a contradiction-free, closed theory, holds in quite a similar way for radiation. The relation between light quanta and electromagnetic waves must be just as statistical as that between de Broglie waves and electrons. The difficulties still standing at present in the way of a complete theory of radiation thus do not lie in the dualism between light quanta and waves—which is entirely intelligible—instead they appear only when one attempts to arrive at a relativistically invariant, closed formulation of the electromagnetic laws….*"

While the majority of physicists accepted Born and Heisenberg's claims, a few challenged what Schrödinger called, "*the orthodox creed*" [11-15]. According to Heisenberg [16] "*All the opponents of the Copenhagen interpretation do agree on one point. It would, in their view, be desirable to return to the reality concept of classical physics or, more generally expressed, to the ontology of materialism; that is, to the idea of an objective real world, whose smallest parts exist objectively in the same way as stones and trees, independently of whether or not we observe them.*"

As a biophysical plant cell biologist [17,18], I believe that it is just as valid to extend our knowledge of the macroscopic visible world to the invisible world, defined by the significance of Planck's constant, as it is to extend knowledge from the invisible world to the visible world. Thus I start with the assumption that the "*smallest parts exist objectively in the same way as stones and trees*" and they do so in Euclidean space and Newtonian time. With this belief, I showed [19] that the wave-particle duality of the photon could be visualized if the photon was not an elementary particle but a composite particle consisting of two semiphotons, each following the path of two wave functions in Euclidean space and Newtonian time. The wave functions give eigenvalues that characterize the observed particle-like energies and momenta of the binary photon [20-22].

I have characterized the symmetry between matter and antimatter in terms of charge, parity, and mass (CPM symmetry) instead of charge, parity, and time (CPT symmetry). In a previous analysis [19], only the mechanical properties, including the mass and sense of rotation of the semiphotons, were included. Since, the binary photon is also the carrier of the electromagnetic force, here I also include the electrical charge of the semiphotons in the analysis in order to characterize the electromagnetic properties of the binary photon. While Maxwell considered light to be electrically neutral due to the absence of charge, I consider light to be electrically neutral due to the presence of equal and opposite charges. With the inclusion of charge, a visual picture of the binary photon as a carrier of the electromagnetic force emerges. Contrary to the statement of Born and Heisenberg [9] given above, the wave-particle duality can be pictured in terms of electric fields formed by the positions of charged semiphotons and magnetic fields produced by the velocities of the charged semiphotons that move along complex wave functions through Euclidean space and Newtonian time. Such a picture is consistent with "*the validity of the law of causality*."

2. Results and Discussion

The three-dimensional wave function $\Psi(x,y,z,t)$ that characterizes the binary photon in its center of gravity frame is composed of two three-dimensional wave functions—one for each of the conjugate semiphotons:

$$\Psi(x,y,z,t) = \Psi^{leading}_{(x,y,z,t)} + \Psi^{following}_{(x,y,z,t)} \quad (1)$$

Where, the leading and the following semiphotons must be conjugate particles in terms of charge, mass, and parity. The two wave functions in Cartesian coordinates $(\hat{\boldsymbol{x}}, \hat{\boldsymbol{y}}, \hat{\boldsymbol{z}})$ are:

$$\Psi^{leading}_{(x,y,z,t)} = \begin{bmatrix} \frac{\lambda}{2\pi}\frac{\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ \frac{\lambda}{2\pi}\frac{\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ \frac{2\lambda}{(2\pi)^2}\frac{\cos^2(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (2a)$$

$$\Psi^{following}_{(x,y,z,t)} = \begin{bmatrix} \frac{\lambda}{2\pi}\frac{\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ -\frac{\lambda}{2\pi}\frac{\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ -\frac{2\lambda}{(2\pi)^2}\frac{\cos^2(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (2b)$$

Where, $r = \sqrt{x^2+y^2+z^2}$ and $\vec{r}$ is the position vector of the semiphoton with respect to the center of gravity (0,0,0). By incorporating the electric charge (q)[1] and sense of rotation or parity $(P = \pm 1)$ of the semiphotons into the wave function, we get the three-dimensional wave functions for the leading semiphoton with positive mass $(\Psi^{leading}_{(x,y,z,t,q,P)})$ and for the following semiphoton with negative mass $(\Psi^{leading}_{(x,y,z,t,q,P)})$:

$$\Psi^{leading}_{(x,y,z,t,q,P)} = \begin{bmatrix} \frac{\lambda}{2\pi}\frac{\frac{qr}{4\pi\varepsilon_o}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ P\frac{\lambda}{2\pi}\frac{\frac{qr}{4\pi\varepsilon_o}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ \frac{2\lambda}{(2\pi)^2}\frac{\frac{q}{4\pi\varepsilon_o}\cos^2(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (3a)$$

$$\Psi^{following}_{(x,y,z,t,q,P)} = \begin{bmatrix} \frac{\lambda}{2\pi}\frac{\frac{q}{4\pi\varepsilon_o}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ -P\frac{\lambda}{2\pi}\frac{\frac{q}{4\pi\varepsilon_o}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ -\frac{2\lambda}{(2\pi)^2}\frac{\frac{q}{4\pi\varepsilon_o}\cos^2(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (3b)$$

Where, ε_o is the electrical permittivity of the vacuum, and $\theta = \boldsymbol{k}\cdot\boldsymbol{z} - \omega t$, where $\boldsymbol{k}$ is the wavevector of the binary photon, $\boldsymbol{z}$ is a distance along the axis of propagation, ω is the angular frequency of the binary photon and t is Newtonian time.

I also stipulate that the accelerating charges that make up the binary photon do not radiate away energy as classical electromagnetic theory posits, but that the semiphotons remain in stationary states so that the energy remains within the confines of the binary photon, consistent with quantum theory [24][2]. This stipulation is also consistent with experience since a photon is stable from the instant it is created until the time it is absorbed. As we will see below, inside the binary photon, the electrical energy and the magnetic energy are interconverted with complete efficiency in a periodic manner.

The electric field at the center of gravity of the binary photon results from the superposition of

[1] I tentatively consider the modulus of the charge (q) of the semiphoton to be equal to the elementary charge (1.602×10^{-19} C). This assumption comes from the observation that during pair production, photons with energies of 1.022 MeV produce an electron with charge $-e$ and a positron with charge $+e$ [23]. I want to emphasize that the charge is a free parameter, and the choice made here is a limitation of the theory. While I consider the charges of the semiphotons to be the same for all binary photons, in accordance with Gauss's law of electricity, the electric fields they produce at the center of gravity vary inversely with the square of the radius of the binary photon.

[2] In an atom, the magnetic field produced by an orbiting electron has the correct orientation both inside and outside the orbit to stabilize an extended electron in the orbit through the Lorentz force. Thus the transformation of electrical energy and magnetic energy by an extended body does not result in radiating energy and the collapse of the orbit as predicted by classical electromagnetic theory but in the stabilization of the orbit [25]. I assume that the same is true for an orbiting semiphoton.

the electric fields created by the leading and following semiphotons.

$$\Psi^{electric}_{(x,y,z,t,q,P)} = \Psi^{leading}_{(x,y,z,t,q,P)} + \Psi^{following}_{(x,y,z,t,q,P)} \quad (4)$$

The components of the electric field at the center of gravity of the binary photon can be expressed in Cartesian coordinates as:

$$\Psi^{electric}_{(x,y,z,t,q,P)} = \begin{bmatrix} 0 \\ P\frac{2\lambda}{2\pi}\frac{\frac{q}{4\pi\varepsilon_O}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ \frac{4\lambda}{(2\pi)^2}\frac{\frac{q}{4\pi\varepsilon_O}\cos^2(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (5)$$

Based on the two possible signs of charge and parity (q, P) for the leading semiphoton, there are four possible classes of binary photons (Table 1). For all classes of binary photons, there is a transverse sinusoidal electric field (E_y) in the defined axis of polarization. The transverse electric field (E_x) along the orthogonal axis vanishes (Fig. 1). E_y defines the transverse electrical polarization state of the binary photon. Contrary to the standard quantum mechanical description of a photon "*as being partly in the state of polarization parallel to the axis and partly in the state of polarization perpendicular to the axis* [26]," all binary photons are linearly polarized. When polarized along the same azimuth, E_y is given by the negative sine function for Class I and Class IV binary photons and by the positive sine function for Class II and Class III binary photons. There is also a longitudinal electric field (E_z) in the binary photon. This is contrary to the standard description of electromagnetic waves in free space [1]. However, Maxwell's rejection of the longitudinal component of electromagnetic waves in free space follows from the untested assumption that the electric neutrality of an electromagnetic wave was due to zero charge density $(q = 0)$ as opposed to being due to two equal and opposite charges $(\Sigma q = 0)$.

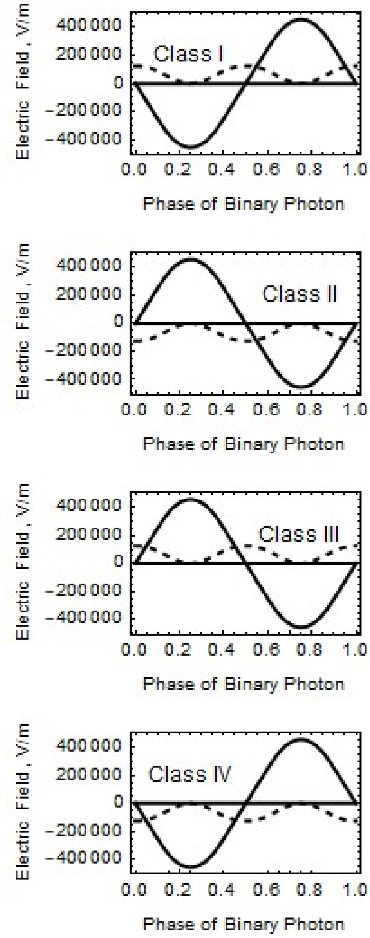

Fig. 1: The magnitudes of the transverse electric field (solid) and the longitudinal electric field (dashed) of the four classes of binary photons. The transverse and longitudinal electric fields for binary photons have the following forms: Class I (0, -sin, $\cos^2$), Class II (0, sin, -$\cos^2$), Class III (0, sin, $\cos^2$), and Class IV (0, -sin, -$\cos^2$). The wavelength is assumed to be 500 nm and the magnitude of the charge is assumed to be 1.602×10^{-19} C. All calculations were made and figures were drawn with Mathematica 11.3.

While the electric fields are obtained from the positions of the semiphotons using Coulomb's law or Gauss's law of electricity, the magnetic fields are obtained from their velocities using the Ampere-Maxwell Law.[3] The magnetic fields produced by the semiphotons are given by:

[3] Note that in a relativistic treatment of a point-like photon, in the rest frame, the magnetic field at the center of gravity would vanish. In the center of gravity of a binary photon, a magnetic field perpendicular to the *y* and *z* axes always exists.

$$\Psi^{leading}_{(x,y,z,t,q,P,v)} = \begin{bmatrix} -\frac{c}{2\pi}\frac{\frac{\mu_o qv}{4\pi}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ P\frac{c}{2\pi}\frac{\frac{\mu_o qv}{4\pi}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ -\frac{2c}{\pi}\frac{\frac{\mu_o qv}{4\pi}\cos(\theta)\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (6a)$$

$$\Psi^{following}_{(x,y,z,t,q,P,v)} = \begin{bmatrix} -\frac{c}{2\pi}\frac{\frac{\mu_o qv}{4\pi}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ -P\frac{c}{2\pi}\frac{\frac{\mu_o qv}{4\pi}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ \frac{2c}{\pi}\frac{\frac{\mu_o qv}{4\pi}\cos(\theta)\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (6b)$$

Where, μ_o is the magnetic permeability of the vacuum, v is the velocity of the semiphoton relative to the center of gravity $\frac{d\theta}{dt} = v$, and $v\lambda = c$. The magnetic field around the center of gravity of the binary photon results from the superposition of the magnetic fields created by the leading and following semiphotons:

$$\Psi^{magnetic}_{(x,y,z,t,q,P,v)} = \Psi^{leading}_{(x,y,z,t,q,P,v)} + \Psi^{following}_{(x,y,z,t,q,P,v)} \quad (7)$$

where the circulating magnetic fields in the *yz* plane, the *xz* plane, and the *xy* plane due to the electric Amperian current or the Maxwellian electric field changes in the $\hat{x}$, $\hat{y}$, and $\hat{z}$ directions, respectively, can be expressed as:

$$\Psi^{magnetic}_{(x,y,z,t,q,P)} = \begin{bmatrix} 0 \\ \frac{2c}{2\pi}P\frac{\frac{\mu_o qv}{4\pi}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \\ -\frac{4c}{\pi}\frac{\frac{\mu_o qv}{4\pi}\cos(\theta)\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3} \end{bmatrix} \quad (8)$$

For each class of binary photons, the magnitude of the curl of the magnetic field in the *xz* plane is related to the derivative of the transverse electric field along the *y* axis, and the magnitude of the curl of the magnetic field in the *xy* plane is related to the derivative of the longitudinal electric field along the *z* axis (Fig. 2). Thus the orthogonal oscillations of the fields obey Faraday's law [27] and the Ampere-Maxwell law [27]. Interestingly. The orthogonal electric and magnetic fields of the binary photon obey Faraday's law and the Ampere-Maxwell law because they are out-of-phase. The electric and magnetic fields are out-of-phase because the electrical neutrality of the binary photon results from two equal and oppositely charged semiphotons that are equidistant from the center of gravity.

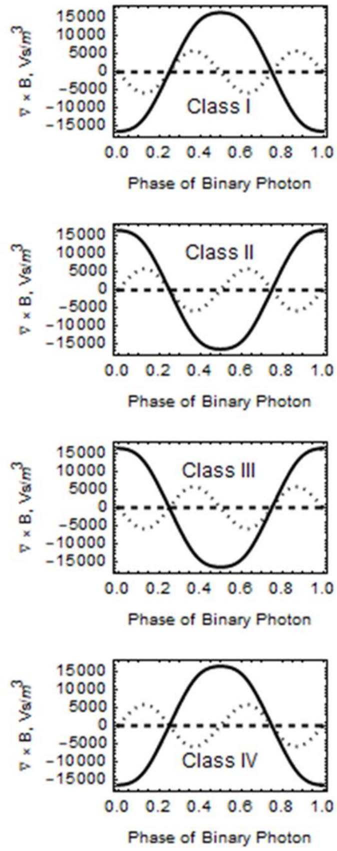

Fig. 2: The curl of the magnetic fields in the *yz* plane (dashed), the *xz* plane (solid), and the *xy* plane (dotted). While the magnetic fields are in a given plane, the vector that represents the curl of the magnetic fields is orthogonal to that plane and parallel to the changing electric field that gave rise to the magnetic fields. The vectors that represent the curl of the magnetic fields for binary photons have the following forms: Class I (0, -cos, -cos sin), Class II (0, cos, cos sin), Class III (0 cos, -cos sin), and Class IV (0, -cos, cos sin). The wavelength is assumed to be 500 nm and the magnitude of the charge is assumed to be 1.602×10^{-19} C.

By contrast, the electric and magnetic fields the compose the electromagnetic wave proposed by Maxwell (Fig. 3), while orthogonal, are in phase. This is a result of the assumption of electrical neutrality due to the absence of charge. It is not clear how Maxwell justified using Faraday's law and the Ampere-Maxwell law, which were both based on the assumption that charge existed, after assuming that no charge existed.

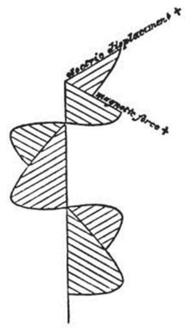

Fig. 3: Electromagnetic wave in free space where the electric field and the magnetic field are in phase as given in the first edition [27] of *A Treatise on Electricity and Magnetism* by Maxwell. This figure is given as Fig. 65 in the second edition [28] and as Fig. 67 in the third edition [29].

A comparison of the phases of the electric field and the magnetic field of the binary photon that assumes the sum of the charges vanish and the electromagnetic fields given by Maxwell, who assumed that the charge itself vanished is given in Fig. 4.

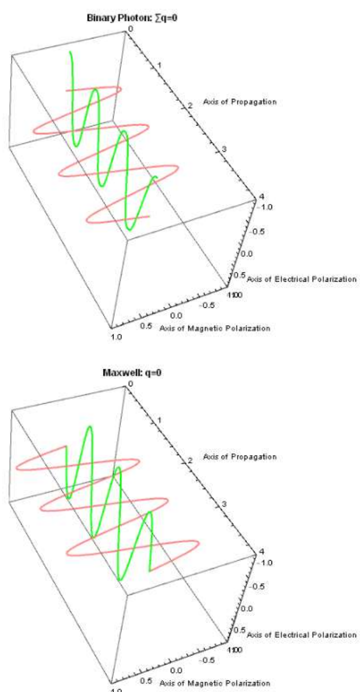

Fig. 4: A comparison of the phases of the magnitudes of the electric (pink) and magnetic (green) fields based on the assumption that $\Sigma q = 0$ (top) or $q = 0$ (bottom).

The periodic nature of the energy of the electric field and the energy of the magnetic field in the binary photon can be obtained in part by squaring the amplitudes of the respective fields. Thus we see that the instantaneous total energy of the binary photon is constant with respect to phase, while the distribution of energy varies throughout the cycle. By contrast, the instantaneous total energy according to Maxwell's electromagnetic wave equation varies from zero to a maximum with respect to phase in a manner inconsistent with the conservation of energy.

The coupled electrical and magnetic energies of a binary photon are reminiscent of an *LC* circuit and the electrical and magnetic properties of the binary photon can be characterized as if the binary photon made a resonant *LC* circuit where the angular frequency of the binary photon is related to the inductance and the capacitance by the following formula:

$$\omega^2 = \frac{1}{L_o C_o} \tag{9}$$

Where, the capacitance (C_o) represents the positions of the semi-photons and the inductance (L_o) represents the velocities of the semi-photons. The wave-like properties of the binary photon can be related to the capacitance and inductance of the binary photon through the following formula:

$$\omega^2 = \frac{1}{L_o C_o} = \left(\frac{1}{\varepsilon_o \mu_o}\right)\left(\frac{2\pi}{\lambda_o}\right)^2 \tag{10}$$

After rearranging terms we get:

$$\frac{1}{L_o C_o} = \left(\frac{2\pi}{\mu_o \lambda_o}\right)\left(\frac{2\pi}{\varepsilon_o \lambda_o}\right) \tag{11}$$

Where, the inductance and capacitance of a binary photon in the vacuum is given by:

$$L_o = \frac{\mu_o \lambda_o}{2\pi} = 2 \times 10^{-7}\ \frac{\mathrm{H}}{\mathrm{m}} \lambda_o \tag{12a}$$

$$C_o = \frac{\varepsilon_o \lambda_o}{2\pi} = 1.41 \times 10^{-12}\ \frac{\mathrm{F}}{\mathrm{m}} \lambda_o \tag{12b}$$

Where, $\mu_o = 4\pi \times 10^{-7}\ \frac{\mathrm{H}}{\mathrm{m}}$, $\varepsilon_o = 8.85 \times 10^{-12}\ \frac{\mathrm{F}}{\mathrm{m}}$, $1\ \mathrm{H} = 1\ \frac{\mathrm{Vs}}{\mathrm{A}}$ and $1\ \mathrm{F} = 1\ \frac{\mathrm{C}}{\mathrm{V}}$ in SI units. The inductance and capacitance of a 500×10^{-9} m binary photon in a vacuum is:

$$L_o = 1 \times 10^{-13}\ \mathrm{H} \tag{13a}$$

$$C_o = 7.1 \times 10^{-1} \text{ F} \quad (13b)$$

At resonance, $\omega L_o = \frac{1}{\omega C_o}$ for a binary photon. Since, the angular frequency of a 500 nm binary photon is 3.77×10^{15} s^{-1}, $\omega L_o = \frac{1}{\omega C_o} = 376\ \Omega$ (376 V/A) which is equal to the characteristic impedance of the vacuum. This is the impedance of a binary photon of any wavelength. That is, the electromagnetic properties of an otherwise empty vacuum may be an intrinsic property of the vacuum itself, or they may be created by the binary photons, which are present at any temperature greater than absolute zero.

Since the orthogonal electrical and magnetic fields of the binary photon are not in-phase as they would be if the photon were neutral as a result of containing no charge[4], the Poynting vector (S) or irradiance (I) cannot be calculated in the usual manner using the cross product of the electric field (**E**, in V/m) and the magnetic flux density (**B**, in Vs/m^2). When the Poynting vector is calculated based on Maxwell's theory, the Poynting vector fluctuates with the phase and the calculations are based on a time-average. By contrast, in the binary photon, which is based on the assumption that the electromagnetic radiation in free space is composed of equal and opposite charges, the instantaneous Poynting vector (S, W/m^2) is constant throughout the phase (φ).

$$S \cong c\left(\frac{B_{xz}^2}{\mu_o} cos^2(\varphi) + \ \varepsilon_o E_y^2 sin^2(\varphi)\right) \quad (14)$$

The Poynting vector characterizes the instantaneous mechanical pressure exerted by light on matter. The radiation friction or the resistance to the movement of matter through a radiation field or photon gas resulting from the Dopplerization of the electromagnetic fields is important for understanding the electrodynamics of moving bodies, the irreversibility of natural transformations, and the reason that the velocity of matter cannot exceed the speed of light [18,25,31-33].

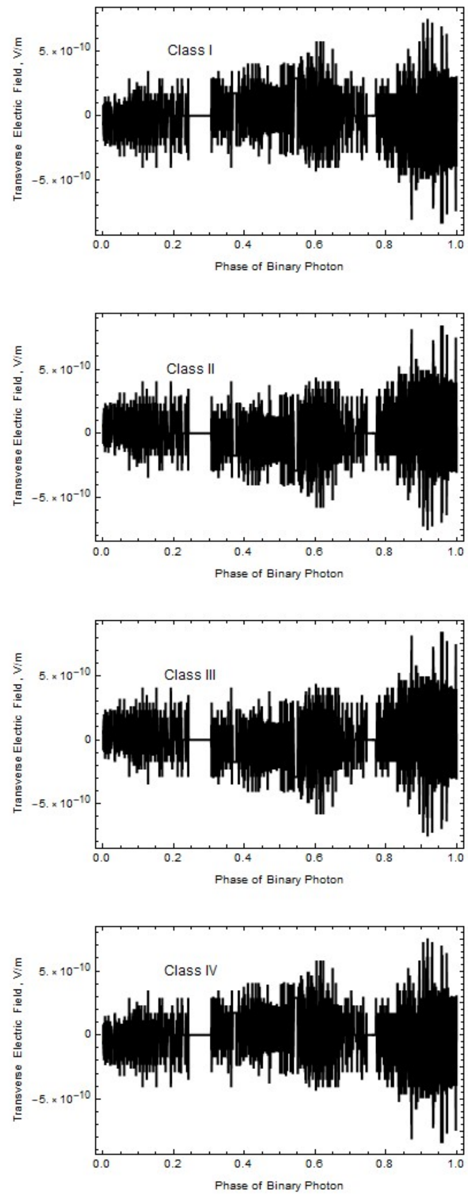

Fig. 5: The resultant transverse electric field resulting from the interference of two binary photons of the same class that are π radians out of phase. In all cases the transverse electric fields vanish to machine epsilon. The wavelength is assumed to be 500 nm.

[4] The charge of the photon has been reviewed by Okun [30].

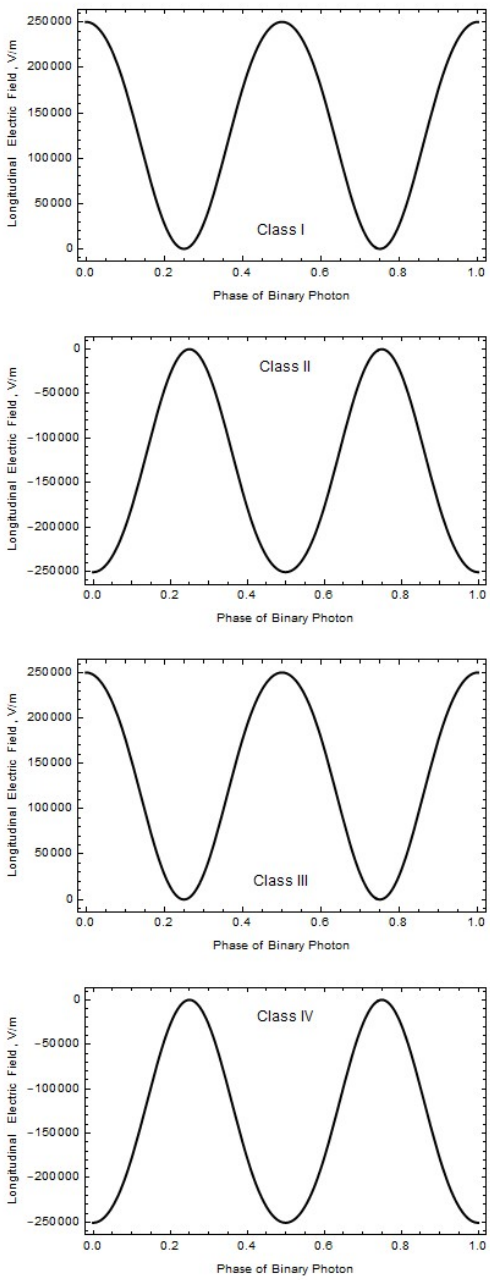

Fig. 6: The resultant longitudinal electric field resulting from the interference of two binary photons of the same class that are π radians out of phase. The transverse electric field vanishes but the longitudinal field remains. The wavelength is assumed to be 500 nm.

The interference of electromagnetic radiation has been a hallmark in characterizing light as a wave as opposed to a particle. The binary photon, which is simultaneously composed of two sub-photonic particles that generate electromagnetic fields as they follow the trajectories provided by the wave functions, can also account for interference phenomena.

Inteference results from the superposition of waves. When binary photons interfere, the interference must occur in all three dimensions of the binary photon. However, only the transverse electric field vanishes when two binary photons of the same class that are π radians out of phase interfere (Fig. 5). The longitudinal field remains (Fig. 6).

In order to achieve complete destructive interference of the electrical fields when binary photons that are π radians out of phase interfere, we must assume that a beam of light contains two classes of binary photons—binary photons of class I and class IV or binary photons of class II and class III.

When one beam contains equal numbers of class I and class IV binary photons and an interfering beam contains equal numbers of class I and class IV binary photons that are π radians out of phase, there will be complete destructive interference (Fig. 7). Likewise if one beam contains equal numbers of class II and class III binary photons and an interfering beam contains equal numbers of class II and class III binary photons that are π radians out of phase, there will also be complete destructive interference.

Complete destructive interference of the magnetic field occurs in the *xy*, *yz*, and *xz* planes when one beam contains equal numbers of class I and class IV binary photons and an interfering beam contains equal numbers of class I and class IV binary photons that are π radians out of phase (Fig. 8).

Likewise, complete destructive interference of the magnetic field occurs in the *xy*, *yz*, and *xz* planes when one beam contains equal numbers of class II and class III binary photons and an interfering beam contains equal numbers of class II and class III binary photons that are π radians out of phase (Fig. 9).

Thus the interference of two beams of binary photon gives the same results expected of the interference of two infinite plane waves. However, since the binary photon has an oscillation along the axis of vibration as well as in the transverse plane, two classes of binary photons are required to give the observed interference.

In hindsight, the observation that binary photons must exist in pairs in beams seems obvious. When light is emitted by matter that is randomly arranged, it is likely that the light will have equal numbers of photons with parallel and antiparallel angular momentum. Indeed, in order to get total destructive interference between binary photons, it is necessary to have equal numbers of class I and class IV binary photons or equal numbers of class II and class III binary photons. Each of these groupings contain binary photons with opposite angular momenta. Angular momentum may be the hidden variable that ensures if one photon has a spin of +1, its "entangled photon" will have a spin of -1.

It is possible that two classes of "entangled photons" with opposite angular momenta can be resolved by two linear polarizers separated by a quarter wave plate.

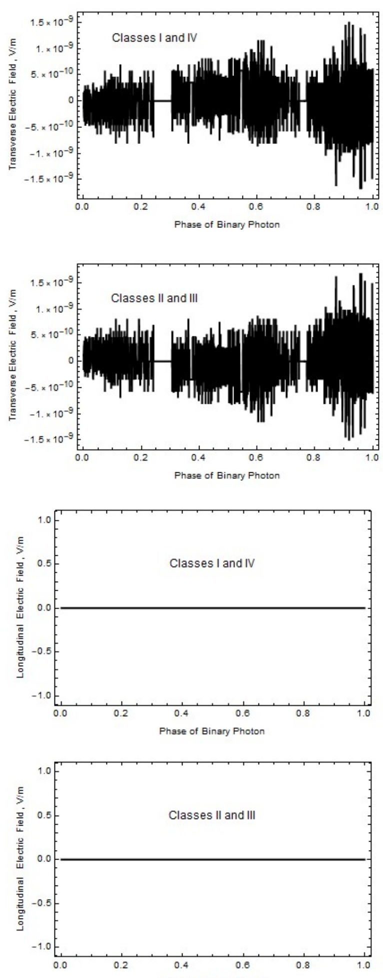

Fig. 7: Complete destructive interference of the transverse and longitudinal electric fields between binary photons that are are π radians out of phase when the beams contain equal numbers of class I and class IV binary photons or equal numbers of class II and class III binary photons. The transverse electric fields vanish to machine epsilon. The wavelength is assumed to be 500 nm.

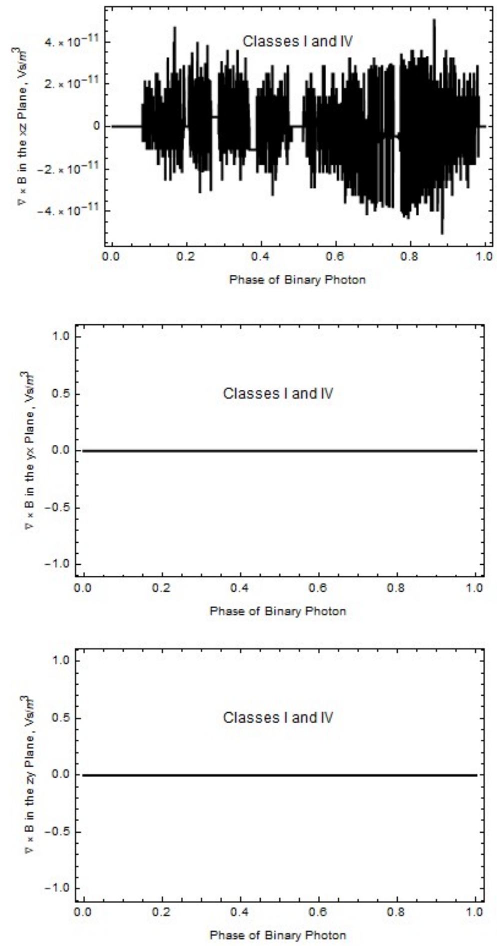

Fig. 8: Complete destructive interference of the three components of the magnetic field when the beams contain equal numbers of class I and class IV binary photons that are are π radians out of phase. The wavelength is assumed to be 500 nm.

The magnitudes of the electric field and the curl of the magnetic field depend on the wavelength. Figs. 10-13 show the magnitudes of the transverse electric field, the longitudinal electric field, the curl of the magnetic field in the *xz* plane and the curl of the magnetic field in the *xy* plane for visible light binary photons of various colors.

As Einstein [4] predicted, I have replaced "*the fundamental equation of optics*" "*by an equation in which the universal constant* ε *(probably its square) also appears in a coefficient.*" Using the amplitude coefficients given in Eqn. (3), where q is equivalent to Einstein's ε, we see that, after substituting Eqns. (5) and (8) into Eqn. (14), the intensity of the electric and magnetic fields are proportional to the square of the charge.

According to Niels Bohr [34], "*interference effects offer our only means of defining the concepts of frequency and wavelength entering into the very expressions for the energy and momentum of the photon*." The three-dimensional electric and magnetic fields of the binary photon interfere the same way that infinite plane waves interfere satisfying the hope expressed by Stark [35] at the Solvay Conference of 1927 who said, "*The interference phenomena can easily be pitted against the quantum hypothesis. However, once they are treated with more benevolence toward the quantum hypothesis, one will find an explanation for them, too—this is my hope*."

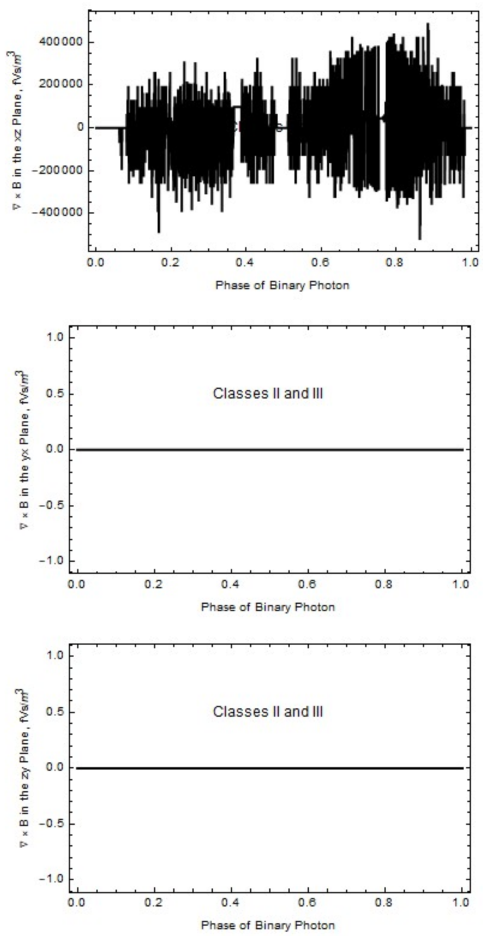

Fig. 9: Complete destructive interference of the three components of the magnetic field when the beams contain equal numbers of class II and class III binary photons that are are π radians out of phase. The wavelength is assumed to be 500 nm.

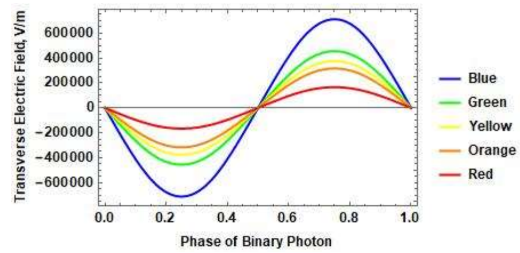

Fig. 10: The magnitude of the transverse electric field of variously-colored binary photons. Each binary photon will exert an oscillating electric force on an electron equal to eE, which is approximately 10 pN, depending on wavelength. The magnitude of the charge is assumed to be 1.602×10^{-19} C.

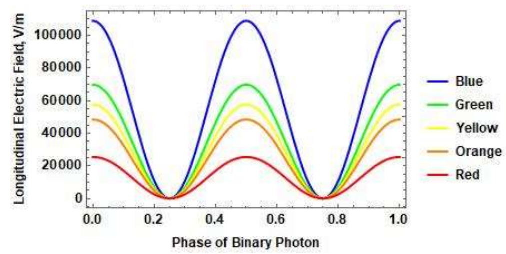

Fig. 11: The magnitude of the longitudinal electric field of variously-colored binary photons. The magnitude of the charge is assumed to be 1.602×10^{-19} C.

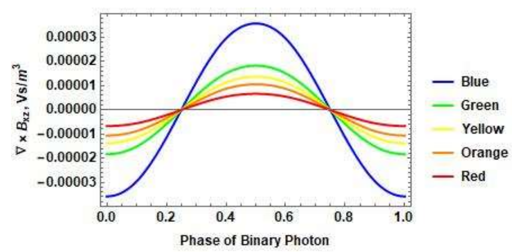

Fig. 12: The magnitude of the curl of the magnetic field in the xz plane of variously-colored binary photons. The magnitude of the charge is assumed to be 1.602×10^{-19} C.

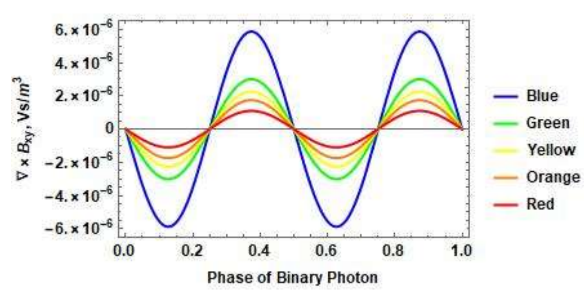

Fig. 13: The magnitude of the curl of the magnetic field in the xy plane of variously-colored binary photons. The magnitude of the charge is assumed to be 1.602×10^{-19} C.

At the same time as Stark hoped for "*benevolence toward the quantum hypothesis*" as a way to explain the wave-like and particle-like behavior of light and matter, Born and Heisenberg [9] shut the door on the possibility of explaining the behavior of light and matter based on the law of cause and effect. With the wave-particle duality taken as an article of faith, Born and Heisenberg's [9] quantum mechanics raised indeterminism from an assumption [36,37] to a principle—a principle consistent with Oswald Spengler's [38] influential pro-romanticism philosophy developed in the years following the defeat of Germany in World War I [39-42]. Lorentz [43], who realized that indeterminism was still an article of faith, yearned for a physical description of photons and electrons that were not represented by probability waves and but by "*clear and distinct images*" of real particles subject to the laws of causality when moving along trajectories in Euclidean space and Newtonian time. In the general discussion at the 1927 Solvay Conference on electrons and photons, Lorentz [43] said, "*We wish to make a representation of the phenomena, to form an image of them in our minds. Until now, we have always wanted to form these images by means of the ordinary notions of time and space. These notions are perhaps innate; in any case, they have developed from our personal experience, by our daily observations. For me, these notions are clear and I confess that I should be unable to imagine physics without these notions. The image that I wish to form of phenomena must be absolutely sharp and definite, and it seems to me that we can form such an image only in the framework of space and time.*

For me, an electron is a corpuscle that, at a given instant, is present at a definite point in space, and if I had the idea that at a following moment the corpuscle is present somewhere else, I must think of its trajectory, which is a line in space. And if the electron encounters an atom and penetrates it, and after several incidents leaves the atom, I make up a theory in which the electron preserves its individuality; that is to say, I imagine a line following which the electron passes through the atom. Obviously, such a theory may be very difficult to develop, but a priori is does not seem to me impossible…I am ready to accept other theories, on condition that one is able to re-express them in terms of clear and distinct images…Could one not keep determinism by making it an article of faith? Must one necessarily elevate indeterminism to a principle?"

Planck [44] also thought that it was "*premature*" to raise the assumption of indeterminism to the principle of indeterminism. According to Planck, "*The so-called principle of uncertainty, discovered and formulated by Heisenberg, is characteristic of quantum physics. It states that of two canonically conjugated quantities, such as position and momentum, or time and energy, only one can be measured with absolute accuracy, and that only by the sacrifice of accuracy in the other. That is to say that by increasing the accuracy with which one of them is measured you diminish the accuracy of the other, the product of the two errors being constant. Hence, if one of the two is determined with absolute accuracy, the other remains absolutely undetermined.*"

"It stands to reason that this statement makes it on principle impossible to transfer with any accuracy into the world of the senses the simultaneous values of coordinates and momenta which play the predominant part in the world of classical physics. For the strictly causal view of the world this fact raises a difficulty, which has already led some indeterminists to affirm that the law of causality in physics is definitely disproved. However, on closer consideration this conclusion, which is due to confusion of the world-picture with the world of sense, must be called at least premature. For there is at hand, for overcoming this difficulty, a means which has often done excellent service in similar cases. It is the assumption that the question as to the simultaneous values of the coordinates and of the momenta of a particle has no meaning in physics. The law of causality must not be blamed for the impossibility of answering a meaningless question. The blame must rather be laid on the assumption which have led to putting of that question, that is to say on the assumed structure of the physicist's world-picture. "

"*In conclusion we may therefore say: the law of causality is neither right nor wrong, it can be neither generally proved nor generally disproved. It is rather a heuristic principle, a sign-post (and to my mind the most valuable sign-post we possess) to guide us in the motley confusion of events and to show us the direction in which scientific research must advance in order to attain fruitful results. A**s** the law of causality immediately seizes the awakening soul of the child and causes him indefatigably to ask 'Why?' so it accompanies the investigator through his whole life and incessantly sets him new problems. For science does not mean contemplative rest in possession of sure* *knowledge, it means untiring work and steadily advancing development*."

According to the crystallographer J. D. Bernal [45], "*the* [indeterminacy] *construction put on the quantum theory is altogether arbitrary and uncalled for*." Freeing ourselves from Heisenberg's gratuitous demand that the position and momentum must be measured *simultaneously*, it is then possible to measure the position at a given instant of time and then calculate its momentum of the particle at that position from the trajectory and the initial conditions. It is also possible to measure the velocity of a particle in a given interval of time, and calculate the positions of the particle from the trajectory and the initial conditions. By viewing the wave functions for the binary photon as actual trajectories for real particles in Euclidean space and Newtonian time, we can utilize the mathematical apparatus of quantum mechanics to describe, explain, and understand the physical world in terms of the law of cause and effect. My hope is that the theory of the binary photon presented here launches a thought-provoking and unified picture of the carrier of the electromagnetic force as being composed of two conjugate particles, which are opposite in terms of charge, parity, and mass. The conjugate particles move along wave-like trajectories within the binary photon, generating electromagnetic fields. Such a picture allows one to simultaneously visualize the particle-like and wave-like behaviors of light in Euclidean space and Newtonian time without sacrificing the law of causality [46,47]. Replacing the concept of negative time with the concept of negative mass allowed the formulation of the binary photon [22].

The aim of science is to explain more and more observations with fewer and fewer laws [48]. A step forward has been made by bringing together within a capacious binary photon Faraday's and the Ampere-Maxwell laws with Schrödinger's equation for a boson to characterize the quantized carrier of the electromagnetic force.

According to K. Lee Lerner [49], "*Quantum and relativity theories strengthened philosophical concepts of complementarity, wherein phenomenon can be looked upon in mutually exclusive yet equally valid perspectives*." By taking the binary photon into consideration, we can add that the two equally valid perspectives are also mutually dependent upon each other for their reification.

3. Conclusion

The model of the binary photon is able to explain the particle-like behavior and wave-like behavior of light simultaneously in a pictorial manner. In order for the carrier of the electromagnetic force to generate time-varying electric and magnetic fields, the radius of the binary photon must be finite and nonvanishing. When $r = \frac{\lambda}{2\pi}$ goes to infinity, the electromagnetic fields tend to vanish (Figs. 10-13). The time-varying electromagnetic fields also vanish when r is zero because the charges of the two semiphotons completely cancel each other. I conclude that fundamental building block of light is the binary photon, which is not a geometrical point-like elementary particle without extension, but a composite entity that has a definite radius that depends on the wavelength of the light.

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Table 1. Four Classes of Binary Photons Based on Charge-Parity-Mass Symmetry.

Class	Leading Semiphoton M > 0	Following Semiphoton M < 0	Angular Momentum $L_z = \pm\hbar$
I	C > 0 P < 0	C < 0 P > 0	$L_z = +\hbar$
II	C < 0 P < 0	C > 0 P > 0	$L_z = +\hbar$
III	C > 0 P > 0	C < 0 P < 0	$L_z = -\hbar$
IV	C < 0 P > 0	C > 0 P < 0	$L_z = -\hbar$

The mass (*M*) of the leading semiphoton is given by $\left|\frac{\hbar\omega}{2c^2}\right| > 0$ and the mass of the following semiphoton is given by $\left|\frac{\hbar\omega}{2c^2}\right| < 0$. The charge (*C*) of the semiphoton is related to the elementary charge and is assumed to be equal to $\pm e$. The parity (*P*) is related to the quantum number m_r and is equal to ± 1, where P = 1, for anticlockwise rotation when looking at the source of the light and P = -1 for clockwise rotation when looking at the source of the light. The angular momentum of the binary photon is antiparallel to the propagation vector when $L_z = \hbar$ and parallel to the propagation vector when $L_z = -\hbar$.