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2 Nature of Light from the Perspective of a Biologist: What Is a Photon?

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The photons that compose the visible light emitted by the sun are the ultimate source of energy necessary to feed the world. The radiant energy is transformed into chemical energy in the chloroplasts of plants in the process of photosynthesis. Knowledge of the nature of the photon is thus important for a comprehensive understanding of the photosynthetic process. Such an understanding has been hampered by three assumptions that form the basis of modern physics: 1) elementary particles are mathematical points, 2) time is neither linear nor unidirectional, and 3) friction can be ignored. These constraints are untenable for a biophysical plant cell biologist; thus, I have abandoned them to construct and test a model of the photon developed from the perspective of a biophysical plant cell biologist.

> The light which makes the plants grow and which gives us warmth has the double characteristics of waves and particles, and is found to exist ultimately of photons. Having carried the analysis of the universe as far as we are able, there thus remains the proton, the electron, and the photon—these three. And, one is tempted to add, the greatest of these is the photon, for it is the life of the atom.
>
> **—Arthur Compton (1929)**

> . . . the phenomena of nature resemble the scattered leaves of the Sibylline prophecies; a word only, or a single syllable, is written on each leaf, which, when separately considered, conveys no instruction to the mind, but when, by the labour of patient investigation, every fragment is replaced in its appropriate connexion, the whole begins at once to speak a perspicuous and a harmonious language.
>
> **—Thomas Young (1807; Bence Jones 1871)**

> If you gave Stokes the Sun there was no experiment he could not not do for two-pence.
>
> **—George Gabriel Stokes' daughter**
> **Mrs. Laurence Humphry (2010)**

2.1 INTRODUCTION

Isaac Newton (1730) asked, "Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their Activity from the Particles of Light which enter their Composition?" Photosynthesis is the process by which plants and other autotrophic organisms transform the rapidly flowing radiant energy of sunlight into stable and stored chemical energy (Herschel 1833; Mayer 1845; Boltzmann 1886; Franck and Wood 1936; Franck and Herzfeld 1941; Oppenheimer 1941; Arnold and Oppenheimer 1950; Calvin 1959; Arnon 1961; BSCS 1963; Clayton 1971, 1980; Kamen 1985; Laible et al. 1994; Campbell and Norman 1998; Jagendorf 1998; Fuller 1999; Govindjee 2000, 2017; Feher 2002; Monteith and Unsworth 2008; Nobel 2009; Wayne 2009b, 2019e, 2024; Stirbet et al. 2020; Liu and van Iersel 2021; Yavari et al. 2021). Photosynthesis, the basic process that feeds the world, begins when the pigments in the antenna complex capture sunlight and transfer the energy to the pair of chlorophyll molecules that make up the reaction center of a photosystem. The chlorophyll molecules in the reaction center undergo a photochemical charge separation that initiates a sequence of oxidation-reduction reactions that generate an electrochemical potential gradient across the photosynthetic membrane. These electrochemical events facilitate the fixation of carbon dioxide and the evolution of oxygen. These life-sustaining energy conversion processes are initiated by the absorption of a particle of light now known as a photon; but what is a photon?

2.2 THE QUANTUM MECHANICAL PHOTON AND THE WAVE-PARTICLE DUALITY

Albert Einstein (1905a) described the quantum of light (*Lichtquanten*) as follows:

> it seems to me that the observations regarding "black-body radiation," photoluminescence, production of cathode rays by ultraviolet light, and other groups of phenomena associated with the production or conversion of light can be understood better if one assumes that the energy of light is discontinuously distributed in space. According to this assumption to be contemplated here, when a light ray is spreading from a point, the energy is not distributed continuously over ever-increasing spaces, but consists of a finite number of energy quanta that are localized in points in space, move without dividing, and can be absorbed or generated only as a whole.

Radiant energy quanta are currently known as photons (from φώτο, the Greek word for light), a name coined independently and with a myriad of meanings by such polymaths as Leonard T. Troland (1916, 1917), John Joly (1921),

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René Wurmser (1925a, 1925b), Frithiof Wolfers (1926), Gilbert Lewis (1926a, 1926b), and others (Kidd et al. 1989; Kragh 2014).

I would like to expand on the definition of *points in space* by quoting Euclid's description of a point as described by Freeman Dyson (1988):

> Euclid was trying to convey to his readers his idea of a geometrical point. For this purpose he gave his famous definition of a point: "A point is that which has no parts, or which has no magnitude." This definition would not be very helpful to somebody who was ignorant of geometry and wanted to understand what a point was. Euclid's notion of a point only becomes clear when one reads beyond the definition and sees how points are related to lines and planes and circles and spheres. A point has no existence by itself. It exists only as a part of the pattern of relationships which constitute the geometry of Euclid. This is what one means when one says that a point is a mathematical abstraction. The question, What is a point? Has no satisfactory answer. Euclid's definition certainly does not answer it. The right way to ask the question is: How does the concept of a point fit into the logical structure of Euclid's geometry? This question is answered when one has understood Euclid's axioms and theorems. It cannot be answered by a definition.

The question, what is a point-like photon? also has no satisfactory answer.

On the centenary of the publication of Einstein's paper entitled "On a heuristic point of view concerning the production and transformation of light," John Rigden (2005) wrote,

> What makes a physics paper revolutionary? Perhaps the most important requirement is that it contains a "big idea". Next, the big idea must contradict the accepted wisdom of its time. Third, physicists capable of judging the intrinsic merit of the big idea typically reject it until they are forced to accept it. Finally, the big idea must survive and eventually become part of the woodwork of physics. . . . Einstein's . . . paper . . . meets these criteria.

According to Murray Davis (1971), these criteria also make Einstein's paper interesting!

Einstein's mathematical point-like photon differed from Newton's light particle in that the former lacked extension, while the latter had both "bigness" and sidedness. Newton (1730) had assigned bigness to his corpuscles of light to explain the colors produced by prisms and thin plates and sidedness to explain the double refraction of light he observed in Iceland Crystal. Many of Einstein's contemporaries, including Max Planck (1920), Niels Bohr (1922), Hendrik Lorentz (1924), and Robert Millikan (1916, 1924), did not accept Einstein's model of a mathematical point-like photon since it could not explain the interference of nearby light beams (Einstein 1909c; Wheaton 1983; Stuewer 1989, 2006; Miller 1994; Holton 1999; Hecht 2003; Campos 2004; Rigden 2005; Niaz et al. 2010). In fact, by proposing that the light quantum was a point, Einstein "outplancked Planck in not only accepting quantization, but in conceiving of light quanta as actual small packets or particles of energy transferable to single electrons in toto" (Davisson 1937). Einstein's light quantum lacked the spatial extension given to the wavelength of light that is necessary to explain the interference and diffraction (Young 1807) that can be observed in soap bubbles, peacock feathers, and the beautiful iridescent blue colors found in a variety of plants, including the leaves of the spike moss, *Selaginella willdenowii*, the leaves of the fern, *Danaea nodosa*, the fruits of *Elaeocarpus angustifolius*, and the petals of the "Queen of the Night" tulip (Lee 2007; Vignolini et al. 2013).

An intuitive description and explanation of interference depends on the wave-like characteristics of light. Classically, the flux of energy or intensity of light depends on the instantaneous amplitude (A) of a monochromatic plane light wave with wavelength λ and frequency ν. The sinusoidally varying amplitude of a light wave is given by

$$A = A_o \sin\left(2\pi\left(\frac{z}{\lambda} \pm \nu t\right)\right) \tag{1}$$

where A_o is the maximum amplitude of the wave and may represent the electric field or the magnetic field. The speed ($c = \frac{z}{t}$) of the wave is equal to the product of λ and ν as given by the dispersion relation. The negative sign inside the argument represents a sinusoidal plane wave moving along the *z axis* to the right, and a positive sign represents a sinusoidal plane wave moving along the *z axis* to the left. The flux of energy or intensity (I, in W/m^2) of the light wave is proportional to the square of the time-average of the amplitude of the electric field (in V/m) and is not related to the wavelength or frequency. The intensity is given by

$$I = c\varepsilon_o \langle A \rangle^2 = \frac{c\varepsilon_o}{2} A_o^2 \tag{2}$$

where $\left[\sin^2 2\pi\left(\frac{z}{\lambda} \pm \nu t\right) = \frac{1}{2}\right]$. Interference effects result when light waves from two sources meet in a given space at the same time. The intensity of the interfering waves depends on the square of the sum of the amplitudes of two (or more) waves and *not* on the sum of the squares:

$$\begin{aligned} I = c\varepsilon_o \langle A_1 + A_2 + \cdots + A_n \rangle^2 &\neq c\varepsilon_o \langle A_1 \rangle^2 + c\varepsilon_o \langle A_2 \rangle^2 \\ &\quad + \cdots + c\varepsilon_o \langle A_n \rangle^2 \end{aligned} \tag{3}$$

Consequently, waves can both destructively and constructively interfere.

Interestingly, a one-dimensional point-like particle of polychromatic white light can be mathematically modelled by summing an infinite number of plane waves with an infinite number of wavelengths. A larger polychromatic particle of light known as a wave packet can be modelled by summing a group of plane waves with slightly different wavelengths (de Broglie 1924; Bohr 1928; Darwin 1931; Strickland 2018). Such a particle-like wave packet can be created experimentally with a pinhole and a rapid shutter (Bohm 1979).

Newton's (1730) particulate theory of light could not explain the colors of soap bubbles and peacock feathers observed by himself and by Robert Hooke (1665) and the diffraction of light described and named by Francesco Maria Grimaldi (1665). However, these phenomena could be explained at the turn of the nineteenth century by Thomas Young (1804, 1807; Anon 1804; Peacock 1855; Peacock and Leitch 1855; Scheider 1986; Kipnis 1991; Simon 2014; Ganci 2019) in terms of the interference of light waves. By the end of the nineteenth century, as a result of the successes of James Clerk Maxwell's (1865) electromagnetic wave theory and Heinrich Hertz's (1893) demonstration that electromagnetic waves obey the laws of optics, the wave theory of light (Huygens 1690), which itself had been marginalized by the particulate theory of light, was resurrected and improved, and its proponents relegated Newton's particulate theory of light to the sidelines (Stokes 1884). At the *fin de siècle*, Albert Michelson (1903) triumphantly wrote, "The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote." However, Lord Kelvin (1904) recognized that there were "nineteenth century clouds" over the wave theory of light created in part by the results of the Michelson-Morley experiment (Michelson and Morley 1887. Some of these clouds would blow over following the introduction of the quantum mechanical, mathematical point-like photon that could explain the photoelectric effect (Einstein 1905a) as well as the change of wavelength that occurs during fluorescence (Stokes 1884; Humphry 2010), while others would remain since it was not possible to describe and explain interference in terms of the mathematical point-like quantum mechanical photon.

Experiments performed in the later part of the nineteenth century by Hertz and Philipp Lenard led to the idea that there was more to the description of the energy of light than just the intensity given by wave theory. While doing research to experimentally verify Maxwell's electromagnetic wave theory that predicted the propagation of electromagnetic waves through space (Yang 2014), Hertz (1887) discovered serendipitously that the ultraviolet light produced by the spark-gap powered by an oscillating high-voltage coil that he used to transmit electromagnetic waves enhanced the ability of the receiver, which was a copper wire loop with a gap, to produce a spark (Klassen 2011). The presence of a spark in the gap of the receiver that was unconnected to the transmitter was proof that the electromagnetic waves had been transmitted from the transmitter to the receiver through space. Although Hertz hoped that he would be able to see the spark produced in the receiver better when he put it in the dark, he found that when he covered the receiver, the spark it produced was much weaker. The ultraviolet light from the transmitter sparks enhanced spark production in the receiver. This ultraviolet light-induced production of an electric spark became known as the photoelectric effect. The photoelectric effect is a physical analogue of the charge separation that takes place in the photosynthetic reaction center.

Lenard (1900, 1902), who had been an assistant of Hertz, placed the spark gap in a vacuum tube that allowed him to produce a photocurrent instead of a spark in response to ultraviolet irradiation. By moving the actinic spark light closer to the metal, Lenard showed that the magnitude of the photocurrent produced across the spark gap in the vacuum tube, which was a measure of the number of ejected photoelectrons, was a function of the ultraviolet light intensity that fell upon the metal cathode.

Lenard found that he could accelerate or retard the photoelectrons ejected from the metal by applying electrical energy in forward bias or reverse bias mode, respectively, between the negatively charged cathode from which the electrons were emitted and the positively charged anode to which the electrons traveled. He placed an electric field in the reverse bias mode so that it diminished the kinetic energy of the emitted photoelectrons. When the electric field was small, the photoelectrons had high kinetic energy, and when the electric field was large, the photoelectrons had reduced kinetic energy. At one electric field strength, the photoelectrons had zero kinetic energy. Lenard realized that photoelectrons could only be ejected from the metal atoms if their kinetic energy exceeded the binding energy. Lenard equated the binding energy with the electrical energy that would produce a photoelectron with zero kinetic energy. Lenard found that he could not cause the photoelectrons to be ejected at the threshold electrical potential and he could not cause the ejected photoelectrons to gain additional kinetic energy by increasing the intensity of the actinic light provided by the arc lamp by either moving it closer or by increasing the current that flowed through it. However, he did find that the kinetic energy of the ejected photoelectrons depended on the type of light he used. Lenard (1902) suggested that the spectral composition (i.e., frequency) of the light determined the characteristics of the photoelectrons that were ejected from the atom by ultraviolet light (Thomson 1908; Wheaton 1978, 1983)—a prediction that was confirmed by Millikan (1950) in 1912.

Looking at Lenard's (1902) experimental results, Einstein (1905a) realized that the photoelectric effect could be understood better if the energy of light was discontinuously distributed in space. Einstein wrote, "According to the conception that the exciting light consists of energy quanta of energy $\left(\frac{R}{N}\right)\beta\nu$, the production of cathode rays by light can be conceived in the following way." He continued:

> The body's surface layer is penetrated by energy quanta whose energy is converted at least partially to kinetic energy of electrons. The simplest possibility is that a light quantum transfers its entire energy to a single electron; we will assume that this can occur. However, we will not exclude the possibility that electrons absorb only a part of the energy of the light quanta. An electron provided with kinetic energy in the interior of the body will have lost a

> part of its kinetic energy by the time it reaches the surface. In addition, it will have to be assumed that in leaving the body, each electron has to do some work P (characteristic of the body).

Einstein presented a heuristic equation to describe the photoelectric effect as follows:

$$KE = \frac{R}{N}\beta\nu - P \tag{4}$$

where KE is the kinetic energy of the ejected photoelectron, P is the amount of work that must be done by the quantum of light just to overcome the attractive force between the electron and the nucleus, $\frac{R}{N}$ is the ratio of the universal gas constant to Avogadro's number and is equal to Boltzmann's constant, and β is the ratio of Planck's constant to Boltzmann's constant. Consequently, $\frac{R}{N}\beta = h$ and $\frac{R}{N}\beta\nu = h\nu$. By changing P to W to stand for the work function, the modern form of Einstein's equation for the kinetic energy ($KE = \frac{1}{2}mv^2$) of a photoelectron becomes

$$KE = h\nu - W \tag{5}$$

Einstein (1905a) wrote that

> As far as I can see, our conception does not conflict with the properties of the photoelectric effect observed by Mr. Lenard. If each energy quantum of the exciting light transmits its energy to electrons independent of all others, then the velocity distribution of the electrons, i.e., the quality of the cathode rays produced, will be independent of the intensity of the exciting light; on the other hand, under otherwise identical circumstances, the number of electrons leaving the body will be proportional to the intensity of the exciting light.

"After ten years of testing and changing and learning and sometimes blundering," Millikan (1916, 1924) provided the experimental proof using the photoelectric effect that quantitatively confirmed the validity of Einstein's equation describing "the bold, not to say the reckless, hypothesis of an electro-magnetic light corpuscle of energy hv, which energy was transferred upon absorption to an electron." The slope of the line that related the kinetic energy of the photoelectrons ejected from sodium and lithium metal to the frequency of the incident ultraviolet and visible light was equal to Planck's constant, and the product of the *x-intercept* and Planck's constant was equal to the work function (Millikan 1914, 1916, 1924, 1935). William Duane and Franklin Hunt (1915) designed an experiment that was the reverse of the photoelectric effect and showed that, consistent with equation 5, the energy of the X-rays emitted from a metal in a vacuum tube were proportional to the kinetic energy of the electrons that were used to bombard the metal. Their results supported Einstein's hypothesis concerning the proportionality between the energy of a photon and the frequency of light.

Charles D. Ellis (1921, 1926; Ellis and Skinner 1924a, 1924b) extended Millikan's experiments on the photoelectric effect to the X-ray range and showed that the slope of the graph that related the kinetic energy of photoelectrons to the frequency of incident X-rays was the same for different metals. This supported the idea that Planck's constant was a property of all photons.

These experimental confirmations of Einstein's heuristic proposal that the energy of a photon was related to its wavelength or frequency but not to its amplitude was quite a blow to the wave theory of light (Einstein 1931), although Millikan (1924) was not convinced as he expressed in his Nobel Lecture:

> the general validity of Einstein's equation is, I think, now universally conceded, and to that extent the reality of Einstein's light-quanta may be considered as experimentally established. But the conception of localized [point-like] light-quanta out of which Einstein got his equation must still be regarded as far from being established . . . It may be said then without hesitation that it is not merely the Einstein equation which is having extraordinary success at the moment, but the Einstein conception as well. But until it can account for the facts on interference and the other effects which have seemed thus far to be irreconcilable with it, we must withhold our full assent. Possibly the recent steps taken by Duane, Compton, Epstein and Ehrenfest may ultimately bear fruit in bringing even interference under the control of localized light-quanta. But as yet the path is dark.

Additional support for Einstein's point-like quantum of light came from experiments conducted by Arthur Compton using X-rays. Compton (1923) scattered X-rays from the electrons of graphite (carbon) and measured the wavelength of the scattered X-rays with an X-ray diffraction grating spectrometer. He discovered that the wavelength of the scattered X-rays was longer than the wavelength of the incident X-rays. Compton realized that if X-rays were considered to be particles with energy and linear momentum[1] and if both energy and linear momentum were conserved in a collision between a photon and an electron, as they are in collisions between massive particles, then the wavelength of the X-rays scattered from a recoiling electron would be greater than the wavelength of the incident X-rays. Compton found that the red shift in the wavelength of the scattered radiation was also consistent with the Doppler effect since the recoiling electron was actually moving away from the incident and scattered X-ray photons. The interpretation of the Compton effect was a double bonus for Einstein since Compton also found that the recoil of the electron caused by the high energy photons could only be explained by taking into consideration Einstein's (1905b) the special theory of relativity.

Chandrasekhara V. Raman (1930) provided further support for the particulate nature of light by performing experiments that were an optical analogue of the Compton effect. Raman showed that long wavelength light described by ultraviolet, visible, and infrared wavelengths were scattered by the vibrating electrons of molecules as if the light had a particulate nature. Depending on the direction of movement of the electrons, the incident light could lose or gain energy and linear momentum resulting in a lengthening or shortening of the wavelength (Wayne 2014a). Likewise, X-rays can gain energy and linear momentum from interacting with electrons moving towards them, which results in a shortening of their wavelength in a process known as the inverse Compton or the Sunyaev-Zel'dovich effect (Rybicki and Lightman 1979; Shu 1982).

For nearly a century, the widely accepted quantum mechanical model has described the photon as a point-like elementary particle or wave-packet characterized by the following four quantities: speed, energy, linear momentum, and angular momentum (Jeans 1914, 1924; Jordan 1928; Darwin 1931; Heitler 1944; Weinberg 1975; Feynman 1979; Loudon 1983; Zeilinger et al. 2005; Bialynicki-Birula 2006). The speed (c) of a photon in free space is defined as a constant equal to 2.99792458×10^8 m/s (Jaffe 1960; Livingston 1973). The speed of light is related to two other constants of nature, namely, the electrical permittivity of the vacuum ($\varepsilon_o = 8.854187817 \times 10^{-12}$ F m^{-1}) and the magnetic permeability of the vacuum ($\mu_o = 4\pi \times 10^{-7}$ H m^{-1}), by the following equation:

$$c = \frac{1}{\sqrt{\varepsilon_o \mu_o}} \tag{6}$$

The energy (E) of a photon is given by

$$E = \frac{hc}{\lambda} = \hbar ck \tag{7}$$

where h is Planck's constant ($6.62606957 \times 10^{-34}$ J s), ħ or h-bar is the reduced Planck's constant ($\hbar = \frac{h}{2\pi} = 1.055 \times 10^{-34}$ J s), λ is the wavelength of the photon, and k is the angular wave number of the photon $\left(= \frac{2\pi}{\lambda}\right)$. The wavelength of a photon is inversely proportional to its energy:

$$\lambda = \frac{hc}{E} \tag{8}$$

The proportionality constant between energy and a wavelength is hc ($= 1.99 \times 10^{-25}$ J m). The wavelength of the quantum mechanical photon represents only a number and not spatial wave-like properties. Since the frequency (ν) of the quantum mechanical photon is equal to the ratio of its speed to its wavelength as given by the dispersion relation $\left(\nu = \frac{c}{\lambda}\right)$, the energy of a photon in free space that is traveling at speed c is also given by

$$E = h\nu = \hbar\omega \tag{9}$$

where h is the proportionality constant between the energy of a photon and its frequency. The angular frequency ω equals $2\pi\nu$, and the dispersion relation is $c = \frac{\omega}{k} = \frac{2\pi\nu}{2\pi/\lambda} = \nu\lambda$. Energy is a scalar quantity that only has magnitude and is easy to work with algebraically. Equation 9 was confirmed by measuring the transformation of radiant energy into thermal energy (Nichols and Hull 1903a). Linear momentum, however, is more difficult to work with since it is a vector quantity that has both direction and magnitude. This was especially true in the early years of the fledgling field of quantum theory when linear momentum was not included in Einstein's (1905a) original concept of the quantum of light.

The linear momentum (p) of a massive body is equal to the product of the mass (m) of the body and its velocity (v). Johannes Stark (1909) took the unidirectional nature of light propagation into serious consideration and stated that the linear momentum (p) of a photon is parallel to the direction of propagation and is related to its energy (E) in the following manner:

$$p = \frac{E}{c} \tag{10}$$

where the speed of light is a constant that relates the linear momentum of a photon to its energy. Consequently,

$$p = \frac{h\nu}{c} = \frac{h}{\lambda} = \hbar k \tag{11}$$

The fact that the linear momentum of light can exert radiation pressure was already predicted by electromagnetic wave theory (Maxwell 1873; Poynting 1904) and experimentally measured (Lebedew 1901; Nichols and Hull 1901, 1903a, 1903b, 1903c). Radiation pressure can also be used to move cells, organelles, and proteins (Ashkin 1970a, 1970b, 1978, 1992, 1997, 2006, 2018; Ashkin and Dziedzic 1987, 1989; Ashkin et al. 1987, 1990). The fact that energy and linear momentum are conserved in collisions between photons and electrons not only supports the particulate nature of the photon but also suggests that the photon has some kind of mass associated with it. Since the linear momentum of a photon is inversely proportional to its wavelength, photons in the X-ray range ($\lambda = 0.01$–10 nm) have very large linear momenta. Since photons propagate at the speed of light ($v = c$), the linear momentum can be given by

$$p = mv = mc \tag{12}$$

Moreover, since $p = mc$ and $E = pc$, then

$$E = mcc \tag{13}$$

which is more commonly written as the world's most famous equation:

$$E = mc^2 \tag{14}$$

This equation states that mass and energy are transformable. It is helpful in understanding many high-energy processes. One such process is the transformation of a mass of protons into a lesser mass of helium nuclei with the attendant release of radiant energy that occurs in the core of the sun (von Weizsäcker 1937, 1938; Bethe 1939, 1967), which makes photosynthesis on earth possible.

In addition to linear momentum, each photon has angular momentum (L), a three-dimensional vector quantity that is even more difficult to work with than linear momentum and was a latecomer to quantum theory. The angular momentum of each and every photon is given by the following equation:

$$L = \frac{h}{2\pi} = \hbar \tag{15}$$

where ħ is the product of energy and time (Schuster and Nicholson 1924). The angular momentum of a photon was determined by Beth (1936) by measuring the torque exerted on a birefringent crystal by polarized light. Interestingly, the angular momentum, which like linear momentum is also a vector quantity, is unique in terms of conserved quantities in that it is the only conserved property shared by all photons, independent of their frequency and wavelength. The angular momentum[2] of a photon is related to its total energy (E) by the following relationships:

$$L = \hbar = \frac{h}{2\pi} = \frac{h\nu}{2\pi\nu} = \frac{E}{2\pi\nu} = \frac{E}{\omega} \tag{16}$$

The quantum mechanical photon is characterized by its contradictory and seemingly irreconcilable particle-like properties such as mass and linear momentum and wave-like properties such as wavelength and frequency. Max Born (1963) described particle-wave duality as follows:

> The ultimate origin of this difficulty lies in the fact (or philosophical principle) that we are compelled to use the words of common language when we wish to describe a phenomenon, not by logical or mathematical analysis, but by a picture appealing to the imagination. Common language has grown by everyday experience and can never surpass these limits. Classical physics has restricted itself to the use of concepts of this kind; by analyzing visible motions it has developed two ways of representing them by elementary processes: moving particles and waves. There is no other way of giving a pictorial description of motions—we have to apply it even in the region of atomic processes, where classical physics breaks down. Every process can be interpreted either in terms of corpuscles or in terms of waves, but on the other hand it is beyond our power to produce proof that it is actually corpuscles or waves with which we are dealing, for we cannot simultaneously determine all the other properties which are distinctive of a corpuscle or of a wave, as the case may be. We can therefore say that the wave and corpuscular descriptions are only to be regarded as complementary ways of viewing one and the same objective process, a process which only in definite limiting cases admits complete pictorial interpretation. It is just the limited feasibility of measurements that defines the boundaries between our concepts of a particle and a wave. The corpuscular description means at the bottom that we carry out the measurements with the object of getting exact information about momentum and energy relations (e.g., the Compton effect), while experiments which amount to determinations of place and time we can always picture to ourselves in terms of the wave representation.

It seems to me that when the wavelength of a photon is longer, the wave model better describes its interactions with matter; and when the wavelength of the photon is shorter, a mathematical point better describes its interactions with matter. In his Nobel Lecture, Arthur Compton (1927) offered these thoughts:

> An examination of the spectrum of the secondary X-rays shows that the primary beam has been split into two parts . . . one of the same wavelengths and the other of increased wavelength. When different primary wavelengths are used, we find always the same difference in wavelength between these two components; but the relative intensity of the two components changes. For the longer wavelengths the unmodified ray has the greater energy, while for the shorter wavelengths the modified ray is predominant. In fact when hard γ-rays are employed, it is not possible to find any radiation of the original wavelength. Thus in the wavelength of secondary radiation we have a gradually increasing departure from the classical electron theory of scattering as we go from the optical region to the region of X-rays and γ-rays. . . . According to the classical theory, an electromagnetic wave is scattered when it sets the electrons which it traverses into forced oscillations, and these oscillating electrons reradiate the energy which they receive. In order to account for the change in wavelength of the scattered rays, however, we have had to adopt a wholly different picture of the scattering process. . . . Here we do not think of the X-rays as waves but as light corpuscles, quanta, or, as we may call them, photons. Moreover, there is nothing here of the forced oscillation pictured on the classical view, but a sort of elastic collision, in which the energy and momentum are conserved. . . . Thus, we see that as a study of the scattering of radiation is extended into the very high frequencies of X-rays, the manner of scattering changes. For the lower frequencies the phenomena could be accounted for in terms of waves. For these higher frequencies we can find no interpretation of the scattering except in terms of the deflection of corpuscles or photons of radiation. Yet it is certain that the two types of radiation, light and X-rays, are essentially the same kind of thing. We are thus confronted with the dilemma of having before us a convincing evidence that radiation consists of waves, and at the same time that it consists of corpuscles. . . . Thus, by a study of X-rays as a branch of optics we have found in X-rays all of the well-known wave characteristics of light, but we have found also that we must consider these rays as moving in directed quanta. It is these changes in the laws of optics when extended to the realm of X-rays that have been in large measure responsible for the recent revision of our ideas regarding the nature of the atom and of radiation.

Neither the quantum mechanical model of a mathematical point-like photon nor the classical model of light as an infinite plane wave is sufficient on their own to explain all the observable interactions of light with matter. William

Henry Bragg (1922) described the situation in 1921 as follows:

> On Mondays, Wednesdays and Fridays, we use the wave theory; on Tuesdays, Thursdays and Saturdays we think in streams of flying quanta or corpuscles. That is after all a very proper attitude to take. We cannot state the whole truth since we have only partial statements, each covering a portion of the field. When we want to work in any one portion of the field or other, we must take out the right map. Some day we shall piece all the maps together.

In 1938, Einstein and Leopold Infeld asked,

> But what is light really? Is it a wave or a shower of photons? Once before we put a similar question when we asked: is light a wave or a shower of light corpuscles? At that time there was every reason for discarding the corpuscular theory of light and accepting the wave theory, which covered all phenomena. Now, however, the problem is much more complicated. There seems no likelihood for forming a consistent description of the phenomena of light by a choice of only one of the two languages. It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do.

In his "own obituary," Einstein (1949) wrote,

> The double nature of radiation (and of material corpuscles) is a major property of reality, which has been interpreted by quantum-mechanics in an ingenious and amazingly successful fashion. This interpretation, which is looked upon as essentially final by almost all contemporary physicists, appears to me as only a temporary way out.

Einstein saw the Copenhagen interpretation of the wave-particle duality of light as a temporary fix (i.e., a bug), whereas Niels Bohr (1934, 1958, 1963; see Jammer 1966) saw it as a fundamental aspect (i.e., a feature) of reality when he wrote,

> we are compelled to acknowledge . . . a new trait which is not describable in terms of spatiotemporal pictures. . . . [and we must envision processes] which are incompatible with the properties of mechanical models . . . and which defy the use of ordinary space-time models.

Although the irreconcilability of the wave-particle duality and the principle of complementarity have become an *idola tribus* (R. Bacon 1267; F. Bacon 1620) among almost all contemporary physicists, perhaps it is possible to take the best parts of both theories to obtain a synthetic and realistic model of a photon that can describe both gamma rays and radio waves. Such a theory should be approximated by the quantum mechanical mathematical point-like photon in the gamma ray region and by the wave theory that describes infinite plane waves in the radio wave region of the spectrum.

2.3 THE BINARY PHOTON

If ν and λ are not just numbers but rather visualizable spatiotemporal descriptions based on the units in which they are measured, then the quantum mechanical equations $\left(E = \frac{hc}{\lambda} = h\nu\right)$ that use Planck's constant to describe the energy of the photon provide the possibility of visualizing the energy of a photon as a distribution of energy in absolute time and space, where the energy of a photon is proportional to the number of cycles in a given time and inversely proportional to its length in space.

In the quantum mechanical, mathematical point-like model of the photon, there is no indication of how the photon can transfer the electromagnetic force from an emitter to an absorber (Lehnert 2006, 2008). Here, I present a model of a photon that has bigness and sidedness, as Newton (1730) would say. The extension beyond that of a mathematical point allows the carrier of the electromagnetic force to possess an electric dipole moment and a magnetic moment. I derive the finite transverse dimension of the photon from its angular momentum, linear momentum, and energy. I also describe why I think that the photon is not an elementary particle but is divisible—because it is composed of two component parts that oscillate and rotate in such a way as to generate wave-like behavior. Perhaps such wave-like behavior is what allows a single photon to interfere with itself when subject to an obstruction (Taylor 1909; Tsuchiya et al. 1985). Notable physicists such as William Bragg (1907a, 1907b, 1907c, 1911, 1933; Bragg and Madsen 1908), Louis de Broglie (1924, 1932a, 1932b, 1932c, 1933, 1934a, 1934b, 1934c, 1934d, 1939; de Broglie and Winter 1934), Pascual Jordan (1935, 1936a, 1936b, 1936c, 1937a, 1937b; Jordan and Kronig 1936), and others (Kronig 1935a, 1935b, 1935c, 1936; Scherzer 1935; Born and Nagendra Nath 1936a, 1936b; Fock 1936, 1937; Nagendra Nath 1936; Sokolow 1937; Pryce 1938; Rao 1938; Greenberg and Wightman 1955; Case 1957; Rosen and Singer 1959; Barbour et al. 1963; Ferretti 1964; Perkins 1965, 1972; Ruderfer 1965, 1971; Broido 1967; Bandyopadhyay and Ray Choudhuri 1971; Inoue et al. 1972; Sarkar et al. 1975; Clapp 1980; Dvoeglazov 1998, 1999; Varlamov 2002; Beswick and Rizzo 2008) have proffered, modified, or refuted models of a binary photon[3] composed of two semiphotons.

Some particles, such as neutral mesons that were once thought to be elementary, have turned out to be composite particles (Dirac 1933; Fermi and Yang 1949). I start with the assumption that the photon may not be an elementary particle but a binary structure consisting of two semiphotons[4]—one a particle of matter and the other an antiparticle of antimatter (Wayne 2009a). I define matter as having a positive mass and antimatter as having a negative mass (Ginzburg and Wayne 2012; Wayne 2012c, 2013b, 2015d). Negative mass is a legitimate (Luttinger 1951; Pollard and Dunning-Davies 1995; Belletête and

Paranjape 2013; Mbarek and Paranjape 2014; Paranjape 2017; Farnes 2018; Barzi 2021) although unwelcomed (Dirac 1930, 1931; Socas-Navarro 2019) concept in physics in part because it carries the historical baggage of phlogiston with it (Djerassi and Hoffmann 2001; Tingle 2014). However, the cosmologist Hermann Bondi (1957) was not deterred, and he characterized many properties of negative mass. The particle and antiparticle that make up a binary photon are conjugate in that they have equal and opposite mass (M), charge (C), and sense of rotation or parity (P). The sums of two masses or two charges that are equal in magnitude but opposite in sign are zero. Thus, a binary photon in free space is massless and charge-neutral, as is required (Okun 2006; Altschul 2008; Olive et al. 2014). Although the binary photon is electrically neutral because it is composed of two conjugate[5] semiphotons, it can form an electric dipole moment and a magnetic moment, which one could argue should be a *sine qua non* for a photon to carry the electromagnetic force. Moreover, since the senses of rotation and the signs of the masses are opposite, the angular momenta of the two particles do not cancel each other but rather add to each other such that the binary photon has angular momentum ($L = \hbar$).

By contrast, the Standard Model of Physics defines the conjugate particles of matter and antimatter as differing in charge (C), sense of rotation or parity (P), and direction in time (T), which gives CPT symmetry (Feynman 1987). According to Richard Feynman (1985), "Every particle in nature has an amplitude to move backwards in time, and therefore has an anti-particle." As a botanist, I assume that time is unidirectional since I have never seen an oak shrink back into an acorn, a sperm and egg released from a fertilized zygote, and mitosis run backwards so that two cells merge into one. I also do not know of anybody who has been able to extract sunbeams from cucumbers as Jonathan Swift (1735) described for which the scientists of the grand academy of Lagado were seeking grant money to do. Assuming that time is most accurately described as being unidirectional (Wayne 2012a, 2013b, 2015f, 2016c, 2017), I define the conjugate particles of matter and antimatter as differing in charge (C), sense of rotation or parity (P), and mass (M), which gives CPM symmetry. Matter and antimatter are antisymmetric in CPM symmetry such that $\text{CPM}_{\text{matter}} = -\text{CPM}_{\text{antimatter}}$ (Wayne 2012c, 2015d, 2016e).[6] CPM symmetry is physically distinct from CPT symmetry, but the two are mathematically similar.

To travel at the speed of light, according to de Broglie (1930), the photon in free space must be massless, even though it has energy $\left(E = \frac{hc}{\lambda}\right)$, linear momentum $p = \frac{h}{\lambda}$, and angular momentum ($L = \hbar$) that can be observably transferred to any object with which it interacts. However, given the measured energy $E = mc^2$ and linear momentum $p = mc$ of a photon, the observable photon must by necessity also have a measurable mass (Haas 1928; Ruark and Urey 1930; O'Leary 1964; Young 1976) when it interacts with either matter or antimatter. The mass transferred to the object is given by the following equation:

$$m = \pm\frac{h\nu}{c^2} \tag{17}$$

where the + sign describes the mass of a photon interacting with matter, and the − sign describes the mass of a photon interacting with antimatter. I assume that measurements made with an equal number of matter and antimatter detectors that would separately give a positive or a negative mass, respectively, when added together would give a vanishing photon mass.

Newton's second law was written only for bodies with positive mass, which was reasonable because no other substance besides matter was known. I have generalized Newton's second law to include masses that are positive and negative (Wayne 2009a). According to the generalized second law of Newton, the ratio[7] of the inertial force (***F***) to the acceleration (***a***) of a body is given by

$$m = \frac{\boldsymbol{F}}{\boldsymbol{a}} \tag{18}$$

where mass (*m*) is a scalar quantity with sign and magnitude, and force and acceleration are vector quantities with magnitude and direction in space. The vector of acceleration is parallel to the force vector for a positive mass, and the two vectors are antiparallel for a negative mass. Specifically, a positive mass will accelerate towards an attractive force, and a negative mass will accelerate away from an attractive force (Figure 2.1).

A positive mass will accelerate away from a repulsive force, and a negative mass will accelerate towards a repulsive force.

How do particles of negative and positive mass interact among themselves and with each other? At the onset, if we

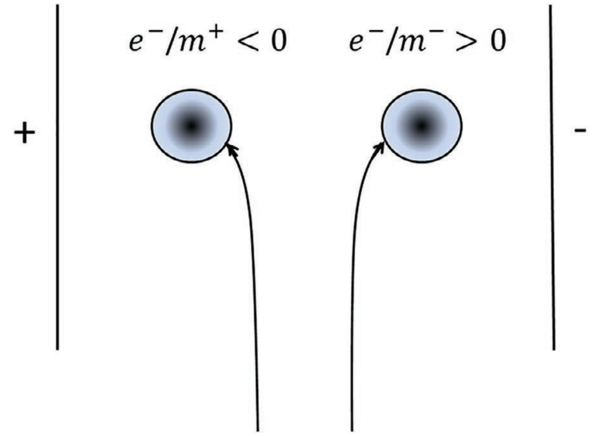

FIGURE 2.1 In an electric field, a particle, such as an electron, with a charge-to-mass (e/m) ratio less than zero, accelerates towards an attractive force and bends towards the positive plate. A negative mass electron, with a charge-to-mass ratio greater than zero, accelerates away from the positive plate.

consider the particles to have mass but not charge, then we can use a generalized version of Newton's law of gravitation to describe the causal force exerted by a positive or negative mass and a generalized version of Newton's (1687) second law to determine how any two particles, with masses of arbitrary sign, respond to the causal force and accelerate relative to each other (Wayne 2009a).

By equating the causal gravitational force ($\boldsymbol{F}_g$) to the responsive inertial force ($\boldsymbol{F}_i$), we get the following:

$$\frac{G}{r^2} m_1 \boldsymbol{m}_2 \hat{\boldsymbol{r}} = \boldsymbol{F}_g = \boldsymbol{F}_i = m_2 \boldsymbol{g} \tag{19}$$

where r is the distance between the two masses, $\hat{\boldsymbol{r}}$ is the unit vector from m_2 to m_1, G is the gravitational constant ($6.673003 \times 10^{11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$), m_1 is the mass of a large body like the earth or the sun, m_2 is the test mass, and $\boldsymbol{g}$ is the acceleration due to the gravity of the test mass relative to the large body (Figure 2.2).

The test mass accelerates towards the large body when $\boldsymbol{g} > 0$, and the test body accelerates away from the large body when $\boldsymbol{g} < 0$. When $\boldsymbol{F}_g > 0$, there are similar masses, and the gravitational force is attractive. When $\boldsymbol{F}_g < 0$, there are dissimilar masses, and the gravitational force is repulsive. The relationship between the gravitational force and the acceleration for any combination of masses can be obtained by plugging masses of various signs into the equation.

For example, when the mass of a large body such as the earth is positive, there will be an attractive force ($\boldsymbol{F}_g > 0$) between it and a positive test mass. Consequently, the positive test mass will accelerate towards the large positive mass ($\boldsymbol{g} > 0$). When the mass of a large body is positive, there will be a repulsive force ($\boldsymbol{F}_g < 0$) between it and a negative test mass. Consequently, the negative test mass will accelerate towards the large positive mass ($\boldsymbol{g} > 0$). The most recent tests on the effect of gravity on antimatter support this conjecture (ALPHA Collaboration and Charman 2013; ALPHA Collaboration and Anderson et al., 2023).

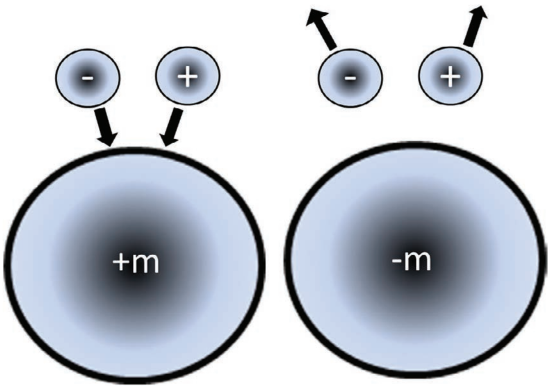

FIGURE 2.2 The direction of acceleration of positive and negative test masses relative to a large body composed of positive or negative mass. Positive and negative test masses accelerate towards a large body composed of positive mass, while positive and negative test masses accelerate away from a large body composed of negative mass.

When the mass of a large body is negative, there will be a repulsive force ($\boldsymbol{F}_g < 0$) between it and a positive test mass. Consequently, the positive test mass will accelerate away from the large negative mass ($\boldsymbol{g} < 0$). When the mass of a large body is negative, there will be an attractive force ($\boldsymbol{F}_g > 0$) between it and a negative test mass. Consequently, the negative test mass will accelerate away from the large positive mass ($\boldsymbol{g} > 0$).

The interesting part that is relevant to the binary photon is this: if the magnitudes of the masses of a negative mass particle and a positive mass particle are the same, then the positive mass particle will accelerate away from the negative mass particle ($\boldsymbol{g} < 0$), and the negative mass particle will accelerate towards the positive mass particle ($\boldsymbol{g} > 0$). Consequently, the negative mass particle will chase the positive mass particle (Figure 2.3; Bonnor and Swaminarayan 1964; Bonnor 1989; Forward 1990; Landis 1991; Price 1993).

Since $\frac{G}{r^2} m_1 m_2$ is the same for the two semiphotons but the signs of $\hat{\boldsymbol{r}}$ are opposite, the force exerted by each semiphoton on the other is equal and opposite, and the propagating binary photon obeys Newton's third law.

I suggest that the gravitational force between the two conjugate semiphotons that make up the binary photon provides the motive force that causes a photon to move. Although this is the only dynamic answer I know of to the question "what causes light to move?" it contradicts the widely held assumption that the gravitational force, which is the weakest of the four fundamental forces (e.g., strong, weak, electromagnetic, and gravitational), is unimportant when it comes to subatomic distances (Yang 1957; Dirac 1964). The proposed involvement of the gravitational force in binding the two conjugate semiphotons of the binary photon together and in propelling the binary photon through Euclidean space and Newtonian time may provide insight to explore the connection sought by Faraday (1846), Maxwell (1865), and Einstein (Pais 1982) between the gravitational and electromagnetic fields. The utilization of positive and negative mass in the analysis of the gravitational force may also be useful to those searching for a theory of everything (Charley 2023).

If the conjugate semiphotons that constitute the binary photon only had the properties of mass, then the binary

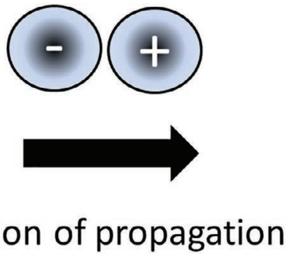

FIGURE 2.3 The propagation of conjugate particles composed of positive and negative mass. The negative mass particle chases the positive mass particle, and the positive mass particle accelerates away from the negative mass particle.

photon would accelerate to infinite velocity. Consequently, the conjugate particle and antiparticle that make up the binary photon must also have charge that could interact with the electric permittivity (ε_o) and magnetic permeability (μ_o) of the vacuum. This interaction provides the frictional force necessary to constrain the velocity of the photon to the speed of light (or the reciprocal of the square root of the product of ε_o and μ_o). The existence of charge within a photon seems reasonable since the photon is the carrier of the electromagnetic force. However, the electric field radiating from the charges of the particle and antiparticle must be equal in magnitude and opposite in sign to ensure that the charge of the binary photon is neutral overall to a distant observer (de Broglie 1934d). The direction of the electric field that radiates from a charge depends on both the sign of the charge and the sign of the mass[8] (Figure 2.4).

The gravitational force-induced movement of the charged particles causes a magnetic field according to Ampere's law and an oppositely directed electromotive force according to Faraday's and Lenz's laws that is responsible for reducing the velocity of the binary photon to the speed of light $c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}$. The prophetic Michael Faraday (1846) wrote,

> Neither accepting nor rejecting the hypothesis of an ether, or the corpuscular, or any other view that may be entertained of the nature of light; and, as far as I can see, nothing being really known of a ray of light more than of a line of magnetic or electric force, or even a line of gravitating force.

I assume that the center of gravity of the binary photon, which can be considered its rest frame, propagates at the speed of light c along the *z-axis* as a function of time (Figure 2.5).

As a result of the gravitational force on a moving charge inducing an oppositely directed electromotive force, the binary photon may have internal longitudinal motions[9] that were predicted by Wilhelm Röntgen (1896) and George FitzGerald (1896) and are consistent with Einstein's (1909a) "oscillation energy of frequency ν [that] can occur only in quanta of magnitude hz." Indeed, de Broglie (1924) wrote, "Naturally, the light quantum must have an internal binary symmetry corresponding to the symmetry of an electromagnetic wave." I have described the predicted sinusoidal oscillations with an antisymmetric normal mode using wave equations. The positions of the leading ($\phi_{leading}$) and following ($\phi_{following}$) semiphotons travelling along the z *axis* through a medium with refractive index n_i as a function

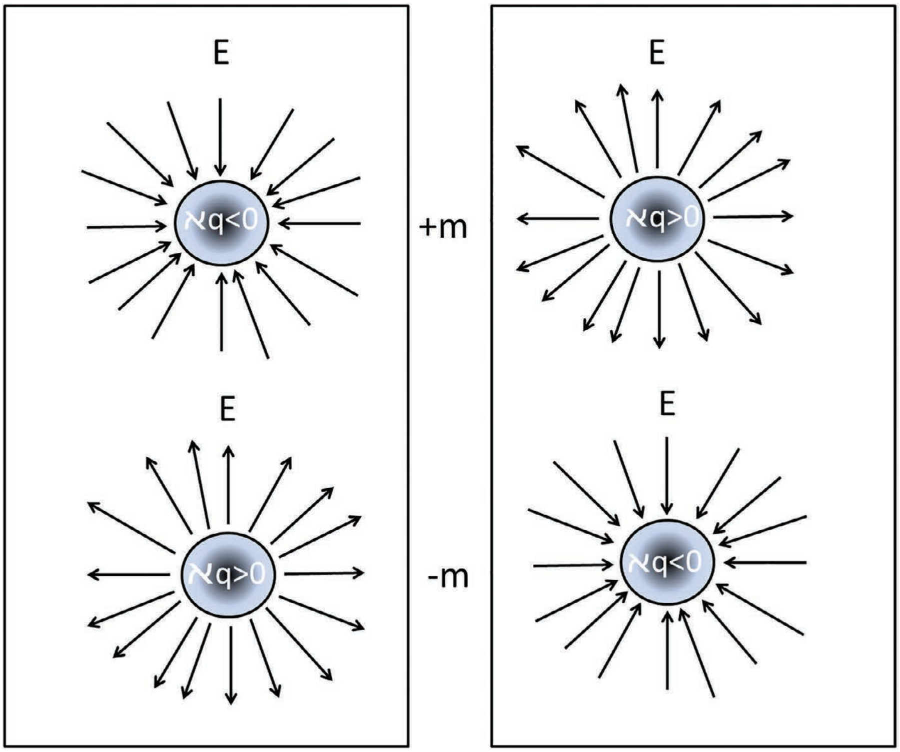

FIGURE 2.4 The electric field lines that radiate from a semiphoton. The two semiphotons on the top have a positive mass and are thus the leading semiphotons. $\aleph q > 0$ for the one on the right where the electric field lines point outwardly, and $\aleph q < 0$ for the one on the left where the electric field lines point inwardly. The two semiphotons on the bottom have a negative mass and are thus the trailing semiphotons. $\aleph q < 0$ for the one on the right where the electric field lines point inwardly, and $\aleph q > 0$ for the one on the left where the electric field lines point outwardly. The two semiphotons on the left are conjugate particles that make one type of binary photon, and the two semiphotons on the right are conjugate particles that make another type.

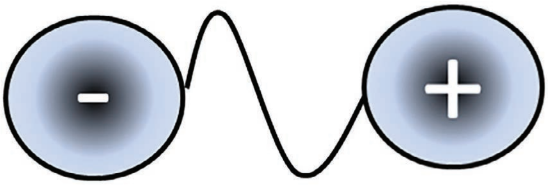

FIGURE 2.5 The positive and negative mass semiphotons oscillate towards and away from the center of gravity as the center of gravity of the binary photon propagates at the speed of light. It is easy to visualize particle-wave duality when not *one* but *two* particles oscillate and can form an oscillating wave. The laws of electromagnetism predict that as the leading particle accelerates away from the negative mass particle because of the gravitational force, the leading particle will generate a greater magnetic field that will produce an electromotive force on itself. This self-induction will put an electromagnetic brake on the leading particle so that the trailing particle can catch up to it. Before the trailing particle catches up to it, the leading particle again accelerates when the gravitational force becomes greater than the electromagnetic braking force that weakens as the leading particle slows down. The combined effects of the gravitational motive force and the frictional electromagnetic braking force result in a longitudinal wave.

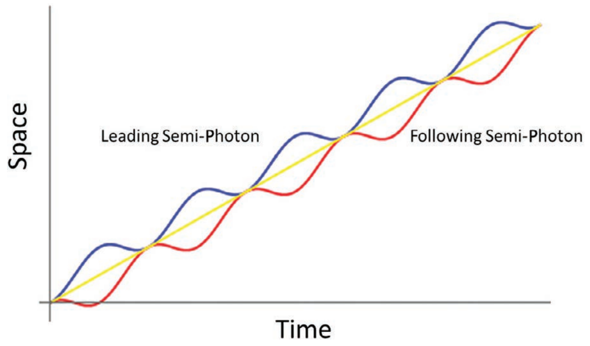

FIGURE 2.6 The longitudinal wave formed by the binary photon moving through space and time. This is a graph of equation 20.

of time is shown in Figure 2.6 and given by the following formulae:[10]

$$\begin{bmatrix}\phi_{leading}(t)\\ \phi_{following}(t)\end{bmatrix}=\begin{bmatrix}\frac{c}{n_i}t+\frac{2\lambda}{(2\pi)^2}\left(\cos^2[2\pi\nu t]\right)\\ \frac{c}{n_i}t-\frac{2\lambda}{(2\pi)^2}\left(\cos^2[2\pi\nu t]\right)\end{bmatrix}[\hat{z}] \tag{20}$$

In order for the semiphotons with mass $\left(m=\frac{\omega}{2c^2}=\frac{hc}{2\lambda c^2}\right)$ to oscillate in a sinusoidal manner with angular frequency ($\omega = 2\pi\nu$), there must be a restoring force characterized by a spring constant[11] (K in N/m). The angular frequency of the oscillator is related to the spring constant according to the following formula:

$$\omega = 2\pi\nu = \sqrt{\frac{K}{m}} \tag{21}$$

Solving for K, we find that the spring constant that provides the restoring force to the semiphoton is equal to the ratio of a constant ($2\pi^2 hc$) to the cube of the wavelength:

$$K=\frac{2\pi^2 hc}{\lambda^3} \tag{22}$$

When the wavelength is longer, the spring constant is less, and the more the binary photon approaches a floppy wave. To the contrary, when the wavelength is shorter, the spring constant is greater, and the more the binary photon approaches a “hard” mathematical point. I calculated the spring constant[12] to be 3.9×10^9 N/m for a 0.01-nm X-ray binary photon, 3921.1 N/m for a 1-nm X-ray binary photon, 6.1×10^{-5} N/m for a 400-nm visible binary photon, 3.1×10^{-5} N/m for a 500-nm visible binary photon, 1.8×10^{-5} N/m for a 600-nm visible binary photon, 14.5×10^{-20} N/m for a 3-cm microwave binary photon, and 3.9×10^{-24} N/m for a 1-m radio wavelength binary photon.[13]

The velocities of the leading ($v_{leading}$) and following ($v_{following}$) semiphotons along the direction of propagation as a function of time are obtained by differentiating equation 20 and are given by the following formulae:

$$\begin{aligned}\begin{bmatrix}v_{leading}(t)\\ v_{following}(t)\end{bmatrix}&=\begin{bmatrix}\frac{c}{n_i}-\frac{2c}{\pi}\left(\cos[2\pi\nu t]\sin[2\pi\nu t]\right)\\ \frac{c}{n_i}+\frac{2c}{\pi}\left(\cos[2\pi\nu t]\sin[2\pi\nu t]\right)\end{bmatrix}[\hat{z}]\\ &=\begin{bmatrix}\frac{c}{n_i}-\frac{c}{\pi}\left(\sin[4\pi\nu t]\right)\\ \frac{c}{n_i}+\frac{c}{\pi}\left(\sin[4\pi\nu t]\right)\end{bmatrix}[\hat{z}]\end{aligned} \tag{23}$$

Heretofore, the wave-particle duality of the quantum mechanical photon has been unintuitive. Friedrich Hund (1974) wrote, “one way of explaining quantum theory in physical terms these days consists in regarding it as a completely non-intuitive unification or two intuitive pictures, i.e., classical particles and classical waves of fields.” By considering the photon to be a binary photon composed of two conjugate particles instead of an elementary particle, it becomes possible to visualize simultaneously the wave and particle nature of the photon or what Arthur Eddington (1928) and Charles Galton Darwin, Charles Darwin’s grandson, called “wavicles.” The simultaneous visualization of the wave-like and particle-like properties was an unrealized goal of Erwin Schrödinger’s (1933) wave mechanics.

The longitudinal wave propagating along the *z axis* at the speed of light is possible to visualize if the photon is composed of two particles rather than one that oscillate with twice the frequency and half the wavelength of the light as the center of gravity translates. Consequently, in the direction of propagation, the maximum length of the binary photons that make up radio waves (1 m–100 km) and microwaves (1 mm–1 m) are predicted to be very long, and binary photons that make up gamma rays (<0.01 nm) and X-rays (0.01–10 nm) are predicted to be very short—approximating a mathematical point. The maximal length of the binary photons that make up the visible light effective in photosynthesis (Engelmann 1882) are predicted to be intermediate in length.

When one abandons the unproven assumption that the photon is a mathematical point, the possibility that a real photon has transverse extension in addition to longitudinal extension comes from an intuitive and mechanical understanding of angular momentum as a conserved mechanical property (Oberg et al. 2000) that means something more than just a number. John Nicholson (1912, 1913) interpreted Planck's constant as a "natural unit of angular momentum" when he realized that the characteristic absorption and emission spectra of atoms would be intelligible if "the angular momentum of an atom can only rise or fall by discrete amounts when electrons leave or return."

Niels Bohr (1913) applied Nicholson's idea of quantized angular momentum to Hantaro Nagaoka'a (Inamura 2016) and Ernest Rutherford's (1911) planetary model of the atom. Bohr wrote,

> In any molecular system consisting of positive nuclei and electrons in which the nuclei are at rest relative to each other and the electrons move in circular orbits, the angular momentum of every electron round the centre of its orbit will in the permanent state of the system be equal to h/2π, where h is Planck's constant.

In realizing that the planets' orbit of the sun in elliptical orbits as Newton showed required a central force, Arnold Sommerfeld (1923) suggested that electrons also orbit the nucleus in elliptical orbits. In addition, Sommerfeld argued that angular momentum, which was then known as the moment of momentum or impulse moment (Ruark and Urey 1927), must not only characterize the atomic system but also be conserved when the atom emits a photon. Sommerfeld wrote,

> in the process of emission . . ., we demanded . . . the conservation of energy. The energy that is made available by the atom should be entirely accounted for in the energy of radiation *v*, which is, according to the quantum theory of the oscillator, equal to h*v*. With the same right, we now demand the conservation of momentum and of moment of momentum [angular momentum]: if in a change of configuration of the atom, its momentum or moment of momentum alters, then these quantities are to be reproduced entirely and unweakened in the momentum and moment of momentum of the radiation.

The significance of Planck's constant as a natural unit of angular momentum was also emphasized by Linus Pauling, Sommerfeld's student. Pauling and Wilson Jr. (1935) wrote,

> h, is a new constant of nature; it is called Planck's constant . . . Its dimensions (energy × time) are those of the old dynamical quantity called action; they are such that the product of h and frequency *v* (with dimensions sec^{-1}) has the dimensions of energy. The dimensions of h are also those of angular momentum, and . . . just as h*v* is a quantum of radiant energy of frequency *v*, so is h/2π a natural unit or quantum of angular momentum.

The selection rules that successfully describe and explain the absorption and emission spectra of atoms and molecules, including chlorophyll, are based on the conservation of angular momentum (Condon and Morse 1929; Ruark and Urey 1930; White 1934; Pauling and Wilson 1935; Hund 1974; French and Taylor 1978). In the absorption process, a unit of angular momentum is gained by the absorber, and in the emission process, a unit of angular momentum is lost by the emitter. Although the unit of angular momentum carried to or carried away from the substance has a magnitude of ħ, the direction reverses, and the sign of the angular momentum may change, between absorption and emission.

What would the radius of the binary photon be in order for it to have its observed angular momentum? This question cannot be answered using current quantum mechanics (Landau and Lifshitz 1958); to answer this question, I went back to Niels Bohr's (1920) Correspondence Principle that sets a classical quantity equal to a quantum quantity. Classically, the angular momentum of a particle is equal to $mvr\Gamma$, where m is the mass of the body, v is its angular velocity, r is its radius, and Γ is a dimensionless geometric factor between 0 and 1 that equals one for a point mass at the end of a massless string of radius r. For simplicity (and no better reason), I let $\Gamma = 1$, which describes the movement of a mass at the end of a massless string. The rotational motion will be superimposed on the oscillating translational motion (Figure 2.7).

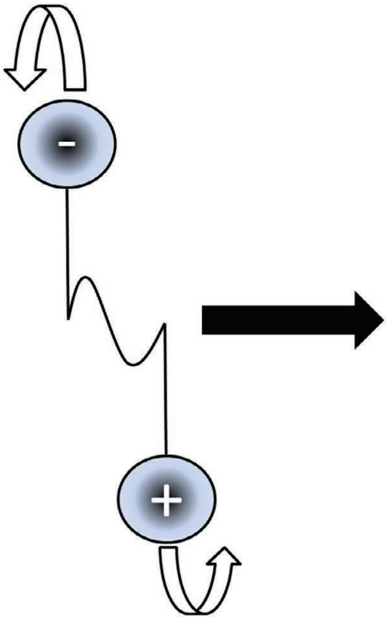

FIGURE 2.7 The rotational motion of the semiphotons is superimposed on the oscillating translational motion.

The mass of each semiphoton that composes the binary photon is one-half of the total mass of the binary photon and is given by

$$m = \frac{h\nu}{2c^2} \tag{24}$$

Using the Correspondence Principle where v is the angular velocity and r is the radius of each semiphoton that composes the binary photon, we obtain

$$L = \frac{\hbar}{2} = \frac{h}{4\pi} = mvr \tag{25}$$

for a semiphoton with angular momentum equal to $\frac{\hbar}{2}$.

We can calculate the radius of the semiphoton from equation 25 by letting $v = 2\pi\nu r$ and inserting the mass $m = \frac{h\nu}{2c^2}$ of this semiphoton to obtain (Figure 2.8)

$$\frac{h}{4\pi} = \frac{h\nu}{2c^2} 2\pi\nu r^2 \tag{26}$$

After canceling and rearranging, we get

$$r^2 = \frac{c^2}{(2\pi)^2 \nu^2} \tag{27}$$

Since according to the dispersion relation, $\frac{c^2}{\nu^2} = \lambda^2$, we get

$$r^2 = \frac{\lambda^2}{(2\pi)^2} \tag{28}$$

Furthermore, after taking the square root of both sides, we obtain

$$r = \frac{\lambda}{2\pi} \tag{29}$$

That is, the radius of the binary photon is equal to the wavelength of light divided by 2π, and the circumference ($2\pi r$) is equal to the wavelength. The radius of the binary photon is identical to the radius of the semiphoton, since for the binary photon, the angular momentum is equal to $\frac{h}{2\pi}$, and the mass is equal to $\frac{h\nu}{c^2}$. The diameter (d) of a cylinder- or needle-like or oscillating binary photon is approximately equal to one-third of its wavelength:[14]

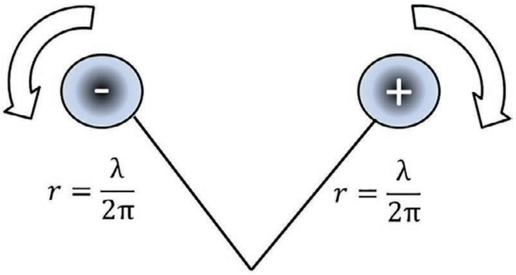

FIGURE 2.8 The radius of the binary photon can be determined from the angular momentum of the binary photon (ħ), the angular momentum of the semiphoton $\left(\frac{\hbar}{2}\right)$, the mass of the binary photon $\left(\frac{h\nu}{c^2}\right)$, and the mass of a semiphoton $\left(\frac{h\nu}{2c^2}\right)$ by using Bohr's Correspondence Principle.

$$d = 2r = \frac{\lambda}{\pi} = 0.32\lambda \tag{30}$$

This equation, which is based on the strong assumptions that the binary photon has energy, linear momentum, and angular momentum, all of which have mechanical consequences, and the arbitrary assumption concerning the geometry of the binary photon, describes the transverse extension or bigness of a binary photon with a given wavelength. Likewise, J. J. Thomson (1925) proposed that the photon was a vibrating ring-shaped Faraday "tube of force" where the circumference was equal to the wavelength of light, and the diameter of the ring was equal to $\frac{\lambda}{\pi}$. Although I hope to eventually elucidate the form of the binary photon, the arbitrariness of the geometrical assumption probably does not introduce great error since it considers the photon to be a single Newtonian corpuscle, and using similar reasoning, Zu (2008) calculated the diameter of a photon to be 0.5λ. Previously, Ludwik Silberstein (1922; Silberstein and Trivelli 1922; Mees 1922) obtained a similar diameter by modeling the interaction of photons with photographic silver grains; Bo Lehnert (2006, 2008, 2013) also derived a similar diameter by revising the assumptions of quantum electrodynamic theory. The assertion that photons have a diameter is consistent with the observed need to shift to shorter wavelengths in order to achieve a tighter focusing of laser beams (Mourou 2018).

When the wavelength of a binary photon approaches zero, so does its diameter, and the bigness of the binary photon, or perhaps its smallness, approaches the size of a mathematical point. When the wavelength of a binary photon approaches infinity, so does its diameter, and the bigness of the binary photon approaches infinity and can be described as an infinite plane wave. A binary photon of monochromatic 500-nm light has a diameter of 159.2 nm. This is why two "close" binary photons can interfere or a single binary photon can interfere with itself. The bigness of a binary photon with a wavelength of 400 nm is smaller and the bigness of a binary photon with a wavelength of 600 nm is larger than the bigness of a binary photon with a wavelength of 500 nm (Figure 2.9).

The size of a photon can be used to derive Planck's blackbody radiation law (Shanks 1956) where real space replaces phase space. Support for the predicted three-dimensional size of the binary photon, which a binary photon with a diameter of $\frac{\lambda}{\pi}$ sweeps out a length equal to λ each cycle, comes from the ability to predict the relationship between the number densities of photons of given diameters and wavelengths and the temperature of a blackbody cavity with a constant volume (Wayne 2014b[15]).

In order for the binary photon to have a non-vanishing angular momentum that is equal to $\frac{h}{2\pi}$, the two semiphotons, with masses of opposite signs, have to rotate perpendicular to the axis of propagation with opposite senses. Using the calculated radius, I incorporated the rotation of the two semiphotons that make up the binary photon into the wave equation that describes the Cartesian components of the time-varying positions (ϕ) of the two semiphotons:

$$\begin{bmatrix} \phi_{leading}(t) \\ \phi_{following}(t) \end{bmatrix} = \begin{bmatrix} \frac{\lambda}{2\pi}\cos(2\pi vt) & \frac{\lambda}{2\pi}\sin(2\pi vt) & \frac{c}{n_i}t + \frac{2\lambda}{(2\pi)^2}\left(\cos^2[2\pi vt]\right) \\ \frac{\lambda}{2\pi}\cos(2\pi vt) & -\frac{\lambda}{2\pi}\sin(2\pi vt) & \frac{c}{n_i}t - \frac{2\lambda}{(2\pi)^2}\left(\cos^2[2\pi vt]\right) \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} \tag{31}$$

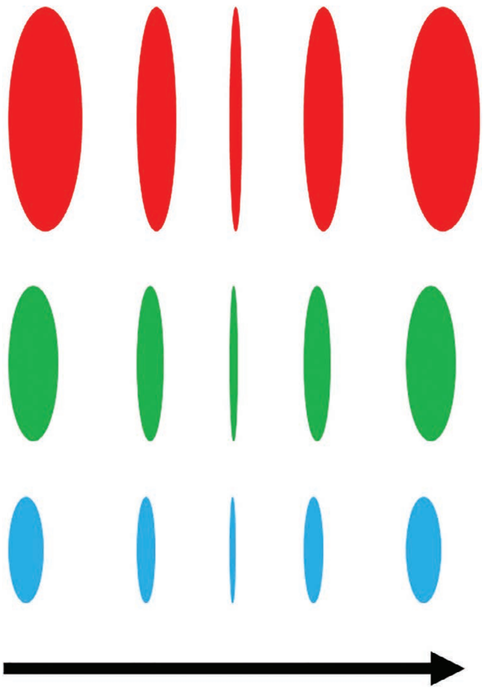

FIGURE 2.9 The predicted three-dimensional forms and relative sizes of oscillating binary photons with a wavelength of 400 nm (blue), 500 nm (green), and 600 nm (red). This is reminiscent of Newton's (1730) description: "And comparing the Fringes made in the several colour'd Lights, I found that those made in the red Light were largest, those made in the violet were least, and those made in the green were of a middle bigness."

The positions with respect to time of the two semiphotons, resolved into the rotational motion in the transverse plane and the longitudinal oscillation along the axis of propagation, are shown in Figure 2.10.

The Cartesian components of the velocities (v) of the semiphotons with respect to time are given by the following formulae:

$$\begin{bmatrix} v_{leading}(t) \\ v_{following}(t) \end{bmatrix} = \begin{bmatrix} -c\sin(2\pi vt) & c\cos(2\pi vt) & \frac{c}{n_i} - \frac{c}{\pi}\sin(2\pi vt)\cos(2\pi vt) \\ -c\sin(2\pi vt) & -c\cos(2\pi vt) & \frac{c}{n_i} + \frac{c}{\pi}\sin(2\pi vt)\cos(2\pi vt) \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} \tag{32}$$

The three-dimensional wave functions can be resolved into wave functions that describe the paths of the semiphotons in a plane transverse to the axis of propagation and the wave functions that describe the paths of the semiphotons parallel to the axis of propagation. The wave mechanical approach presented here shows that the binary photon can be visualized as an oscillating rotor propagating through Euclidean space and Newtonian time. Although quantum mechanical calculations typically agree with experience while being at odds with ordinary concepts of trajectories in space and time, the wave mechanical calculations carried out here agree with experience without conflicting with the ordinary concepts of space and time. Indeed,

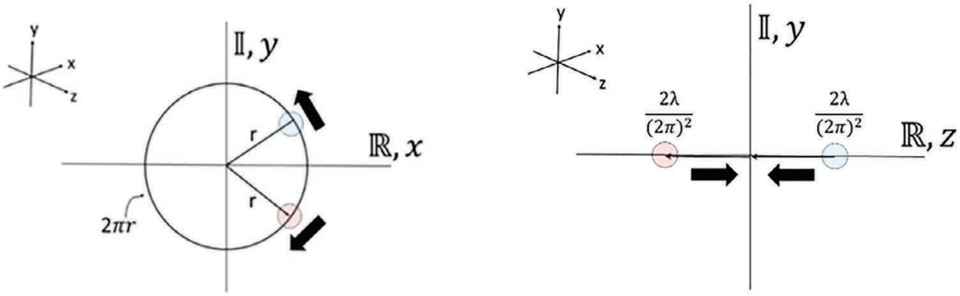

FIGURE 2.10 Views of the motion of the semiphotons of the binary photon along the transverse plane (left) and along the axis of propagation (right). In the transverse plane, the motions of the semiphotons are rotational, and along the axis of propagation, the motions are vibrational and translational. Videos of these movements can be found in Wayne (2020b).

in contrast to the claims of Heisenberg and Born, the mathematical description of the quantized binary photon presented here is consistent with the *Anschaulichkeit*, picturability, or imaged facts of classical physics sought by Einstein.

2.4 THE SCHRÖDINGER EQUATION AND THE BINARY PHOTON

Now that we have postulated equations that describe the three-dimensional motion of the semiphotons, it is possible to show that the resolved rotational motions of the semiphotons in the transverse plane are solutions to the Schrödinger equation. Schrödinger (1926) successfully solved his wave equation for fermions with spin ½, but he was unable to solve his wave equation for bosons such as the photon with spin 1. To characterize the quantum mechanical properties of the binary photon, I created a generalized Schrödinger wave equation for both fermions and bosons (Wayne 2019d). This Schrödinger wave equation characterizes the rotational motion in the plane orthogonal to the axis of propagation. This plane can be characterized as a complex plane with a Real axis that is identical to the x axis and an Imaginary axis that is identical to the y axis.

In the transverse plane, perpendicular to the axis of propagation of the binary photon, each semiphoton moves in its own ring with a constant radius centered on the axis of propagation. The radius (r) of the ring, within which each semiphoton moves, is a function of the wavelength of the binary photon ($r = \frac{\lambda}{2\pi}$) and is equal to the reciprocal of its wave number $\left(r = \frac{1}{k}\right)$. The circumference ($l$) of each ring is equal to the wavelength ($\lambda = l = 2\pi r$). Each semiphoton completes a full orbit around the ring with an angular frequency that is equal to the angular frequency (ω) of the binary photon and related to its frequency (v) and wavelength ($\omega = 2\pi v = \frac{2\pi c}{\lambda}$). Unless the binary photon is acted upon by an external force (see Faraday effect in what follows), the radius is constant and independent of time.

Consider the ring to be a one-dimensional path of length l in which a semiphoton moves. The wave function ($\mathit{\Psi}\left(l,t\right)$) that describes the movement of a semiphoton around a ring with circumference l must be continuous, finite, and single-valued in order to give rise to a time-independent standing wave or stationary state that results in a stable binary photon. As long as m_r is an integer, the complex exponential $\left(e^{im_r \frac{2\pi}{\lambda} d}\right)$ is a function that gives the same value at the same position (d) in the ring no matter how many times (m_r) the semiphoton travels completely around the ring.

As long as we are only discussing the mechanics of the binary photon, as opposed to the electromagnetic properties, we can convert a two-body problem into a one-body problem and simplify the construction of the wave function or eigenvector by combining the motion of two conjugate semiphotons that have masses and senses of rotation with opposite signs into the motion of one binary photon, with a mass that is twice the modulus of either semiphoton that moves with the same sense as the positive mass semiphoton. In a period, the combined mass binary photon is considered to travel a distance of one wavelength—the same distance that each semiphoton individually travels in a period.

The rotation of a single mass in a single two-dimensional ring is a one-dimensional problem in phase space as far as the standard Schrödinger equation is concerned. The one-dimensional Schrödinger equation for the movement of a free particle along the z-axis is given by

$$\left(-\frac{\hbar^2}{2m}\right)\frac{\partial^2 \Psi\left(z,t\right)}{\partial z^2} + \mathrm{V}\Psi\left(z,t\right) = \frac{i\hbar}{n}\frac{\partial \Psi\left(z,t\right)}{\partial t} \tag{33}$$

where ħ is the reduced Planck's constant, m is the mass of the particle, i is an imaginary number equal to $\sqrt{-1}$, V is the potential energy, and $\mathit{\Psi}\left(z,t\right)$ is the wave function with respect to space (z) and time (t). In the standard version of the Schrödinger equation for fermions, $n = 1$. I was unable to find a realistic wave function to describe the mechanical properties of the binary photon with the Schrödinger equation as long as $n = 1$. Realizing that Schrödinger created his equation for fermions, I modified the Schrödinger equation to take into account bosons by letting $n = 2$. Since the total energy ($E_{total} = \hbar\omega$) of the binary photon can be equipartitioned into transverse rotational energy and longitudinal translational and vibrational energy, I postulated separate and independent wave functions to describe the transverse motions and the longitudinal motions of the semiphotons.

The particle with the combined mass traveling around the ring can be treated as it is in quantum chemistry: as a free particle where the potential energy on the ring (V_{ring}) vanishes, and the potential energy outside the ring ($V_{outsidering}$) is infinite (Atkins 1970). When $V\mathit{\Psi}$ vanishes, the particle moving on the ring has total rotational energy $E_{rotational}$ that is equal to the kinetic energy on the ring (KE_{ring}). So defined, the operator $\left(-\frac{\hbar^2}{2m}\right)\frac{\partial^2}{\partial z^2}$ gives the total rotational energy when applied to the wave function. Using polar coordinates with a fixed radius that is determined by the wavelength of the binary photon with radius $\left(r = \frac{\lambda}{2\pi}\right)$ and circumference ($l = \lambda$), the Schrödinger equation for a boson moving in a ring becomes

$$\left(-\frac{\hbar^2}{2m_{binaryphoton},}\right)\frac{\partial^2 \Psi\left(\varphi,t\right)}{r^2 \partial \varphi^2} = \frac{i\hbar}{2}\frac{\partial \Psi\left(\varphi,t\right)}{\partial t} \tag{34}$$

where $m_{binaryphoton}$ is the mass of the binary photon. The moment of inertia (I) for a mass at the end of a massless string is given by

$$I = m_{binaryphoton} r^2 \tag{35}$$

and the moment of inertia of a semiphoton of mass ($m_{semiphoton} = \frac{\hbar\omega}{2c^2}$) is given by

$$I_{semiphoton} = m_{semiphoton} r^2 = \frac{\hbar\omega}{2c^2 k^2} \tag{36}$$

where $r = \frac{\lambda}{2\pi} = \frac{1}{k}$ is, as described, a necessary condition to ensure that the angular momentum of the binary photon is $\pm\hbar$. The sum of the moments of inertia of a binary photon composed of a semiphoton with a positive mass moving anticlockwise and a semiphoton with negative mass moving clockwise is given by

$$I_{binaryphoton} = m_{binaryphoton} r^2 = \frac{\hbar\omega}{c^2k^2} \tag{37}$$

where $m_{binaryphoton} = 2\,|\,m_{semiphoton}\,|$. The Schrödinger equation that uses polar coordinates for the rotational motion of a generalized binary photon of any wavelength in the transverse plane becomes

$$\begin{aligned}\left(-\frac{\hbar^2}{2I_{binaryphoton}}\right)\frac{\partial^2\Psi(\varphi,t)}{\partial\varphi^2} &= -\frac{i}{n}\frac{\partial\Psi(\varphi,t)}{\partial t}\\ &= \frac{i\hbar}{2}\frac{\partial\Psi(\varphi,t)}{\partial t}\end{aligned} \tag{38}$$

where $n = 2$ for a boson. I postulate that the rotational wave function $(\Psi(\varphi,t))$ and its complex conjugate $(\Psi^*(\varphi,t)$ for a combined particle of any mass representing a binary photon of any wavelength moving in a ring are

$$\Psi(\varphi,t) = Ae^{im_r\varphi}e^{-i\omega t} = A\left[\cos m_r\varphi + i\sin m_r\varphi\right]e^{-i\omega t} \tag{39}$$

$$\Psi^*(\varphi,t) = Ae^{-im_r\varphi}e^{i\omega t} = A\left[\cos m_r\varphi - i\sin m_r\varphi\right]e^{i\omega t} \tag{40}$$

where m_r is the rotational quantum number for the binary photon, A is the amplitude of the wave function and equals unity since the binary photon is described as a monochromatic wave rather than a wave packet, and ω is the rotational frequency of the combined mass binary photon, which is equal to the angular frequency of the monochromatic binary photon. $\Psi(\varphi,t)$ is the wave function for a binary photon whose combined semiphoton mass rotate anticlockwise[16] ($m_r > 0$). The complex conjugate $(\Psi^*(\varphi,t))$ of the wave function is also identical to a wave function for a binary photon whose combined semiphoton mass rotate clockwise ($m_r < 0$). The ring is two dimensional in that it exists in the *xy* plane perpendicular to the axis of propagation ($+z$) in Euclidean space. The real axis in the transverse plane is equivalent to the *x*-axis, and the imaginary axis is equivalent to the *y*-axis. With this picture, ordinary space is equivalent to configuration space, and the imaginary number does not represent an unreal quantity but an orthogonal quantity in a two-dimensional complex plane that cannot be summed algebraically with a real quantity. The real and imaginary values must be summed as components of a vector. This two-dimensional representation in Euclidean space and Newtonian time is mathematically equivalent to the less picturable representation in one-dimensional phase space and imaginary time.

Now we must check if the proposed wave function is a solution to the Schrödinger equation for a boson byplacing equation 39 into equation 34:

$$\left(-\frac{\hbar^2c^2k^2}{2\hbar\omega}\right)\frac{\partial^2 e^{im_r\varphi}e^{-i\omega t}}{\partial\varphi^2} = \frac{i\hbar}{2}\frac{\partial e^{im_r\varphi}e^{-i\omega t}}{\partial t} \tag{41}$$

After differentiating equation 41, we get

$$\left(-\frac{\hbar^2c^2k^2}{2\hbar\omega}\right)i^2m_r^2e^{im_r\varphi}e^{-i\omega t} = \frac{i^2\hbar\omega}{2}e^{im_r\varphi}e^{-i\omega t} \tag{42}$$

After simplifying equation 42, we get

$$m_r^2 = 1 \tag{43}$$

The wave function for the rotational energy in the transverse plane of the binary photon is a solution to the Schrödinger equation for a boson only if $m_r = \pm 1$. m_r is a dimensionless quantum number equivalent to the bosonic spin quantum number in standard quantum mechanics. In standard quantum mechanics, the intrinsic spin is a quantum number that does not represent a mechanical motion because motion cannot take place within a mathematical point, but here, the spin represents the sense of the rotational motion intrinsic to the binary photon. To find the energy eigenvalue for the intrinsic rotational motion of the binary photon in the transverse plane, we must separate the rotational wave function into its spatial and temporal parts that describe movement in absolute Euclidean space (φ) and Newtonian time (t):

$$\Psi(\varphi,t) = \psi(\varphi)T(t) \tag{44}$$

To find the eigenvalues for a binary photon, we substitute $\Psi(\varphi,t) = \psi(\varphi)T(t)$ into the Schrödinger equation for a boson:

$$\left(\frac{-\hbar^2}{2I_{binaryphoton}}\right)\frac{\partial^2\left[\psi(\varphi)T(t)\right]}{\partial\varphi^2} = \frac{i\hbar}{2}\frac{\partial\left[\psi(\varphi)T(t)\right]}{\partial t} \tag{45}$$

We then treat the variables inside the partial derivatives that are not part of the partial derivative as constants:

$$\left(\frac{-\hbar^2}{2I_{binaryphoton}}\right)T(t)\frac{\partial^2\left[\psi(\varphi)\right]}{\partial\varphi^2} = \frac{i\hbar}{2}\psi(\varphi)\frac{\partial\left[T(t)\right]}{\partial t} \tag{46}$$

We then divide by $\psi(\varphi)T(t)$:

$$\begin{aligned}&\left(\frac{-\hbar^2}{2I_{binaryphoton}}\right)\frac{T(t)}{\psi(\varphi)T(t)}\frac{\partial^2\left[\psi(\varphi)\right]}{\partial\varphi^2}\\ &= \frac{i\hbar}{2}\frac{\psi(\varphi)}{\psi(\varphi)T(t)}\frac{\partial\left[T(t)\right]}{\partial t}\end{aligned} \tag{47}$$

We then cancel like terms to obtain a fully separated equation where one term is only a function of Euclidean space

(φ) and the other term is only a function of Newtonian time (t).

$$\left(\frac{-\hbar^2}{2I_{binaryphoton}}\right)\frac{1}{\psi(\varphi)}\frac{\partial^2\left[\psi(\varphi)\right]}{\partial\varphi^2}=\frac{i\hbar}{2}\frac{1}{T(t)}\frac{\partial\left[T(t)\right]}{\partial t} \tag{48}$$

$E_{rotational}$, the separation constant, is the eigenvalue for the total rotational energy of the binary photon. After separating the variables, the partial differential equation becomes two ordinary differential equations that give $E_{rotational}$:

$$E_{rotational}=\left(\frac{-\hbar^2}{2I_{binaryphoton}}\right)\frac{1}{\psi(\varphi)}\frac{d^2\left[\psi(\varphi)\right]}{d\varphi^2} \tag{49}$$

and

$$E_{rotational}=\frac{i\hbar}{2}\frac{1}{T(t)}\frac{d\left[T(t)\right]}{dt} \tag{50}$$

Equation 49 is the time-independent Schrödinger equation, which gives the curvature of $\psi(\varphi)$ in the transverse plane. The curvature of the trajectory in the transverse plane of the semiphotons described by the wave function is picturable in that when the rotational energy of a binary photon is greater, the curvature of $\psi(\varphi)$ in the transverse plane is greater. The wave function of highly energetic binary photons will have a great curvature and will make a tight circle in the transverse plane that appears particle-like, while the wave function of low energy binary photons will have a small curvature in the transverse plane and will make a wide circle that appears plane wave-like.

Next, we solve equation 49 to obtain the eigenvalue of the rotational energy of the binary photon:

$$\begin{aligned}E_{rotational}&=\left(-\frac{\hbar^2c^2k^2}{2\omega}\right)\frac{1}{\psi(\varphi)}\frac{d^2\left[e^{im_r\varphi}\right]}{d\varphi^2}\\&=\left(-\frac{\hbar^2c^2k^2}{2\omega}\right)\frac{i^2m_r^2}{\psi(\varphi)}\left[e^{im_r\varphi}\right]=\frac{\hbar\omega}{2}\end{aligned} \tag{51}$$

When the wave function operated upon by the Schrödinger equation for a boson is either $\Psi(\varphi,t)=Ae^{im_r\varphi}e^{-i\omega t}$ or $\Psi^*(\varphi,t)=Ae^{-im_r\varphi}e^{i\omega t}$, the observable eigenvalue of the rotational energy equals $\frac{\hbar\omega}{2}$. The value of the transverse rotational energy of the binary photon is independent of the sense of rotation and is equal to one-half of the total energy of the binary photon ($E_{total}=\hbar\omega$).

By definition, the product of $\Psi(\varphi,t)$ and $\Psi^*(\varphi,t)$ equals unity, which allows one to calculate not only the expectation values for the rotational energy $\langle E_{rotational}\rangle$ of the monochromatic binary photon using the Hamiltonian operator but also the angular momentum of a monochromatic binary photon using the angular momentum operator. The expectation value of the rotational energy is given by

$$\left\langle E_{rotational}\right\rangle=\Psi^*(\varphi,t)\left(-\frac{\hbar^2c^2k^2}{2\hbar\omega}\right)\frac{\partial^2\Psi(\varphi,t)}{\partial\varphi^2} \tag{52}$$

$$\left\langle E_{rotational}\right\rangle=e^{-im_r\varphi}e^{i\omega t}\left(-\frac{\hbar^2c^2k^2}{2\hbar\omega}\right)i^2m_r^2e^{im_r\varphi}e^{-i\omega t} \tag{53}$$

Since $e^{-im_r\varphi}e^{i\omega t}e^{im_r\varphi}e^{-i\omega t}=1$ and $m_r^2=1$, the expectation value[17] for the rotational energy of the monochromatic binary photon is

$$\langle E_{rotational}\rangle=\frac{\hbar\omega}{2} \tag{54}$$

The expectation value for the rotational energy is equal to the eigenvalue for the rotational energy, which is one-half of the value of the total energy of the binary photon ($E_{total}=\hbar\omega$).

A body with rotational energy has angular momentum, and *vice versa*. Using the angular momentum operator, we can solve for the expectation value for the angular momentum $\langle L_z\rangle$ either parallel or antiparallel to the propagation vector:

$$\langle L_z\rangle=\Psi^*(\varphi,t)\frac{\hbar}{i}\frac{\partial\Psi(\varphi,t)}{\partial\varphi} \tag{55}$$

$$\langle L_z\rangle=e^{-im_r\varphi}e^{i\omega t}\frac{\hbar}{i}\frac{\partial e^{im_r\varphi}e^{-i\omega t}}{\partial\varphi} \tag{56}$$

$$\langle L_z\rangle=e^{-im_r\varphi}e^{i\omega t}\left(\frac{im_r\hbar}{i}\right)e^{im_r\varphi}e^{-i\omega t} \tag{57}$$

Since $e^{-im_r\varphi}e^{i\omega t}e^{im_r\varphi}e^{-i\omega t}=1$ and $m_r=\pm1$, the expectation value for the angular momentum of the binary photon is

$$L_z=\frac{im_r\hbar}{i}=m_r\hbar=\pm\hbar \tag{58}$$

which is independent of the wave properties of the binary photon. Depending on the sign of m_r, $\langle L_z\rangle$ is equal to $\pm\hbar$. When $\langle L_z\rangle>0$, the angular momentum vector is parallel to the propagation vector, and when $\langle L_z\rangle<0$, the angular momentum vector is antiparallel to the propagation vector.[18] Thus m_r is numerically equivalent to the spin quantum number in standard quantum mechanics.

In principle, the individual positions of the positive mass semiphoton and the negative mass semiphoton that carry the rotational energy can be determined by using symmetry in the following manner: replace the position of the combined mass binary photon with the positive mass semiphoton; then, the negative mass semiphoton can be located by finding the image of the positive mass semiphoton reflected by a plane mirror placed on the xz plane at the origin of the y-axis. When considering the two conjugate semiphotons separately, the time-averaged center of gravity of the binary photon remains constant and can be considered the rest frame of the binary photon.

The standing wave functions or eigenvectors for the rotational motion of monochromatic binary photons are degenerate in terms of their rotational energy but resolvable in terms of their angular momenta:

$$\psi_{m_r}(\varphi) = \left\{ \begin{matrix} A\left[\cos(\varphi) + i\sin(\varphi)\right] & m_r = +1 \\ A\left[\cos(\varphi) - i\sin(\varphi)\right] & m_r = -1 \end{matrix} \right\} \tag{59}$$

Using the postulated wave function and the Schrödinger equation for a boson, the eigenvalue for the rotational energy of the binary photon around the axis of propagation accounts for only half of its total energy. The other half of the total energy is accounted for by the longitudinal translational and vibrational energy (Wayne 2019d).

Although the longitudinal vibrations are necessary to prevent the rotating semiphotons from colliding and annihilating one another, the longitudinal vibrational energy vanishes due to the opposite signs of the masses and the velocities of the semiphotons (Wayne 2019d). By contrast, the translational energy ($E_{translational}$) of a binary photon of mass $\left(\frac{h\nu}{c^2}\right)$ propagating at velocity c and interacting with matter or antimatter does not vanish. The classical equation for translational energy is used for a binary photon propagating at the speed of light c (Wayne 2019d):

$$E_{translational} = \frac{1}{2}mv^2 = \frac{1}{2}mc^2 = \frac{1}{2}\left(\pm\frac{h\nu}{c^2}\right)c^2 = \pm\frac{h\nu}{2} \tag{60}$$

Additionally, since the vibrational energy ($E_{vibrational}$) of the oscillating rotor vanishes as the binary photon translates, the total energy (E_{total}) of the binary photon interacting with matter or antimatter is given by the sum of the rotational ($E_{rotational} = \frac{1}{2}mr^2\omega^2$) and the translational energies $\left(E_{translational} = \frac{1}{2}mc^2\right)$. Furthermore, since $r^2 = \frac{1}{k^2}$ and $\omega^2 = k^2c^2$,

$$\begin{aligned} E_{total} &= \frac{m}{2}\left(r^2\omega^2 + c^2\right) = \frac{m}{2}\left(\frac{1}{k^2}k^2c^2 + c^2\right) \\ &= \frac{m}{2}\left(c^2 + c^2\right) = mc^2 = \pm h\nu \end{aligned} \tag{61}$$

which is the measured energy of the photon (Nichols and Hull 1903a).

Interestingly, as shown in equation 60, the classical equation for the translational energy of a body gives half of the value that Einstein's mass-energy equation would give, suggesting that Einstein's mass-energy equation for an elementary particle gives the sum of the rotational and translational energies; but since a mathematical point cannot rotate, the rotational energy is interpreted in terms of relativistic space-time.

The binary photon is reminiscent of two vibrating rings or strings moving through an observable Euclidean space and Newtonian time. The binary photon has been described as a three-dimensional version of string theory. Actual string theory, according to Michio Kaku (1994), expounds that "the laws of nature become simpler and more elegant when expressed in higher dimensions." Kaku writes,

> String theory is such a promising candidate for physics because it gives a simple origin of the symmetries found in particle physics as well as general relativity. . . . The heterotic string consists of a closed string that has two types of vibrations, clockwise and counterclockwise, which are treated differently. The clockwise vibrations live in a ten-dimensional space. The counterclockwise live in a 26-dimensional space, of which 16 dimensions have been compactified. . . . The heterotic string owes its name to the fact that the clockwise and the counterclockwise vibrations live in two different dimensions but are combined to produce a single superstring theory. That is why it is named after the Greek word for heterosis, which means 'hybrid vigor.'

The biophysical approach to nature assumes that a form-function relationship must exist. Although this is not necessarily true (Niklas and Spatz 2012), the biophysicist in me thinks that the structure of the binary photon has hybrid vigor in performing the function of electromagnetic energy transfer from the sun to the chloroplast through Euclidean space and Newtonian time.

2.5 THE ELECTRIC AND MAGNETIC FIELDS OF THE BINARY PHOTON

The rotational motions of the semiphotons are evocative of Maxwell's (1861) mechanical interpretation of the luminous ether composed of particles and vortices. However, since the model of the binary photon assumes CPM symmetry where isolated charges in the vacuum do not exist, the particles and vortexes must be part of the binary photon itself.

Since photons are the carrier of the electromagnetic force (Fermi 1932), it is only natural that they generate electric and magnetic fields described by Faraday's, Ampere's, and Lenz' laws (Jackson 1999). Einstein (1909a) 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[19] 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.

Since the two semiphotons carry equal and opposite charges, the binary photon is electrically neutral with respect to infinity. However, internal electric and magnetic fields can exist between the two semiphotons, and it is the internal electromagnetic field that interacts with electrons. Coulomb's law predicts that the semiphotons each generate a time-varying, three-dimensional electric field inside the binary photon. A positively charged semiphoton will generate an electric field that points away from the source and towards the center of gravity of the binary photon, while a negatively charged semiphoton will generate an electric field[20] that points towards the source and away from the center of gravity of the binary photon. The center of gravity of the binary photon will most effectively interact with electrons, unless the wavelength of the binary photon is in the radio wave range, where it will most likely interact with baryons in the atom and exert a gravitational pushing force (Abbot 1898; Wayne 2016a).

By incorporating into the wave functions Gauss's or Coulomb's laws that include the electric charge $(\pm q)$[21] or Ampere's law that includes the charge and velocity of the semiphoton and its sense of rotation or parity $(P = \pm 1)$, we get three-dimensional wave functions for the leading semiphoton with positive mass $\left(\Psi^{leading}_{(x,y,z,t,q,P)}\right)$ and for the following semiphoton with negative mass $\left(\Psi^{leading}_{(x,y,z,t,q,P)}\right)$. The wave functions (Ψ) that characterize the electric fields of the leading and following semiphotons are (Wayne 2018)

$$\Psi^{leading}_{(x,y,z,t,q,P)} = \begin{bmatrix} \dfrac{\lambda}{2\pi}\dfrac{\dfrac{q}{4\pi\varepsilon_o}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{x} \\ P\dfrac{\lambda}{2\pi}\dfrac{\dfrac{q}{4\pi\varepsilon_o}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{y} \\ \dfrac{2\lambda}{(2\pi)^2}\dfrac{\dfrac{q}{4\pi\varepsilon_o}\cos^2(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{z} \end{bmatrix} \tag{62}$$

$$\Psi^{following}_{(x,y,z,t,q,P)} = \begin{bmatrix} \dfrac{\lambda}{2\pi}\dfrac{\dfrac{q}{4\pi\varepsilon_o}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{x} \\ P\dfrac{\lambda}{2\pi}\dfrac{\dfrac{q}{4\pi\varepsilon_o}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\quad\hat{y} \\ -\dfrac{2\lambda}{(2\pi)^2}\dfrac{\dfrac{q}{4\pi\varepsilon_o}\cos^2(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{z} \end{bmatrix} \tag{63}$$

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

The electric field at the center of gravity (0,0,0) of the binary photon results from the superposition of the electric fields created by the leading and following semiphotons. The electric field vectors inside the binary photon constructively interfere to give a linearly polarized wave equivalent to Faraday's (1846) "line of electric force."

$$\Psi^{electric}_{(x,y,z,t,q,P)} = \Psi^{leading}_{(x,y,z,t,q,P)} + \Psi^{following}_{(x,y,z,t,q,P)} \tag{64}$$

The components of the electric field at the center of gravity of the binary photon can be expressed as a vector (Figure 2.11) in Cartesian coordinates as

$$\Psi^{electric}_{(x,y,z,t,q,P)} = \begin{bmatrix} 0 \quad \hat{x} \\ P\dfrac{2\lambda}{2\pi}\dfrac{\dfrac{q}{4\pi\varepsilon_o}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{y} \\ \dfrac{4\lambda}{(2\pi)^2}\dfrac{\dfrac{q}{4\pi\varepsilon_o}\cos^2(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{z} \end{bmatrix} \tag{65}$$

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 2.1; Wayne 2018). Nevertheless, for all classes of binary photons, there is a transverse sinusoidal electric field (E_y), which defines the axis of polarization, and the transverse electric field (E_x) along the orthogonal axis vanishes. Contrary to the standard quantum mechanical description of a circularly polarized photon "as being partly in the state of polarization parallel to the axis and partly in the state of polarization perpendicular to the axis" (Dirac 1958), binary photons are exclusively linearly polarized (Wayne 2020b).

The azimuth of polarization of the electric field of the binary photon depends on the azimuth of the line between the two particles of the binary photon when they are maximally separated, and the dipole moment is greatest. Consistent with the wave theory of light, the electric fields of two binary photons constructively or destructively interfere in a manner that depends on the phase of the three spatial components of each binary photon. Because of the choice of charge and parity, each linearly polarized binary photon has at least two isomers—one with a parallel magnetic moment and one with an antiparallel magnetic moment (see what follows). It is possible that entanglement (Ismail et al. 2014) is related to the racemic mixture of binary photons.

There is also a smaller longitudinal electric field (E_z) in the binary photon (Wayne 2018). This is contrary to the standard description of electromagnetic waves in free space. However, Maxwell's rejection of the longitudinal component of electromagnetic waves in free space follows

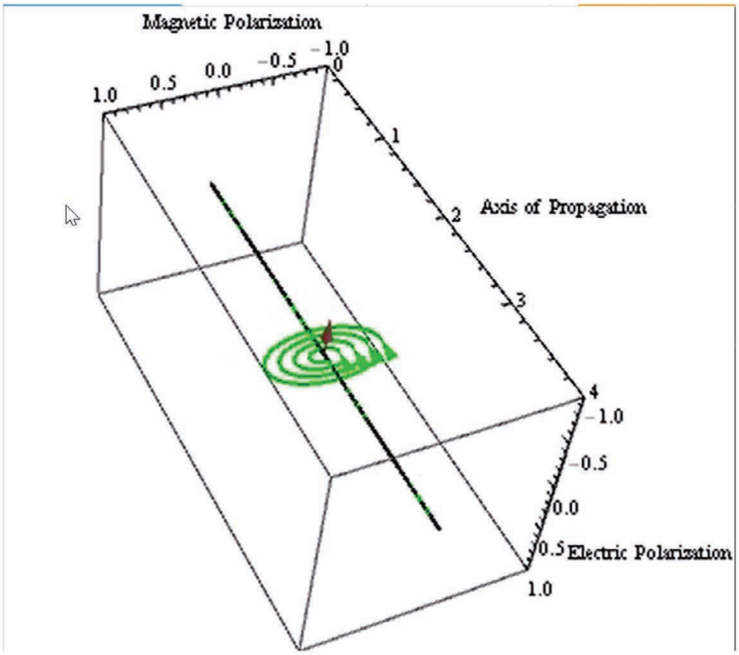

FIGURE 2.11 The electric and magnetic fields of a binary photon. The electric field (pink vector) is linearly polarized. The magnetic field lines (green) are circularly polarized, orthogonal to the electric field, and a quadrature out of phase with the electric field. Videos of the electric and magnetic fields of propagating binary photons can be seen in Wayne (2020b).

TABLE 2.1

The Four Possible Classes of Binary Photons

Class	Symmetry	Leading Semiphoton	Following Semiphoton	Angular Momentum (L)	Magnetic Moment (μ)
I	M	+m	-m	antiparallel	antiparallel
	C	$q > 0$	$q < 0$		
	P	CW	ACW		
II	M	+m	-m	antiparallel	parallel
	C	$q < 0$	$q > 0$		
	P	CW	ACW		
III	M	+m	-m	parallel	parallel
	C	$q > 0$	$q < 0$		
	P	ACW	CW		
IV	M	+m	-m	parallel	antiparallel
	C	$q < 0$	$q > 0$		
	P	ACW	CW		

Abbreviations: Mass (M), Charge (C), Parity (P), Clockwise (CW), and anticlockwise (ACW).
Parallel and antiparallel are relative to the propagation vector.

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 $\left(\Sigma q = 0\right)$ as postulated here.

The positions of the rotating semiphotons in the transverse plane determine the polarization of the electric field, whereas the velocities (v) of the rotating semiphotons determine the polarization of the magnetic field. The three-dimensional form of the magnetic field lines of the binary photon depends on the time-varying three-dimensional velocities, which can be determined relative to the principal unit tangent vectors of the two moving charges. Because the products of the charge and the velocity of each conjugate semiphoton have the same sign, the magnetic field lines that they generate add together. The superposition of the magnetic fields is maximal in the *x-z plane*. The magnetic field oscillates perpendicular to the electric field and is greatest when the electric dipole moment is weakest and weakest when the electric dipole moment is greatest (Figure 2.11). The magnetic field of the binary photon is a three-dimensional extension of Maxwell's (1873) planar magnetic wave that was predicted by Evans and Vigier (1994).

The curl of the magnetic field $\left(\Psi^{magnetic}_{(x,y,z,t,q,P,v)}\right)$ of the binary photon is obtained by combining the wave functions of the semiphotons with the Ampere-Maxwell law.[22] The curls of the magnetic fields produced by the semiphotons are given by[23]

$$\Psi^{leading}_{(x,y,z,t,q,P,v)} = \begin{bmatrix} -\dfrac{c}{2\pi}\dfrac{\frac{\mu_o qv}{4\pi}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{x} \\[2ex] P\dfrac{c}{2\pi}\dfrac{\frac{\mu_o qv}{4\pi}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{y} \\[2ex] -\dfrac{2c}{\pi}\dfrac{\frac{\mu_o \mathrm{qv}}{4\pi}\cos(\theta)\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{z} \end{bmatrix} \tag{66}$$

$$\Psi^{following}_{(x,y,z,t,q,P,v)} = \begin{bmatrix} -\dfrac{c}{2\pi}\dfrac{\frac{\mu_o qv}{4\pi}\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{x} \\[2ex] P\dfrac{c}{2\pi}\dfrac{\frac{\mu_o qv}{4\pi}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{y} \\[2ex] \dfrac{2c}{\pi}\dfrac{\frac{\mu_o qv}{4\pi}\cos(\theta)\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{z} \end{bmatrix} \tag{67}$$

where μ_o is the magnetic permeability of the vacuum, $v\lambda = c$, and $v = \frac{d\theta}{dt}$ is the angular velocity of the semiphoton relative to one of the axes. The curl of 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:

$$\Psi^{magnetic}_{(x,y,z,t,q,P,v)} = \Psi^{leading}_{(x,y,z,t,q,P,v)} + \Psi^{following}_{(x,y,z,t,q,P,v)} \tag{68}$$

When the curl of the magnetic field points in the $\hat{x}$ direction, the circulating magnetic field lines are in the *yz* plane. When the curl of the magnetic field points in the $\hat{y}$ direction, the circulating magnetic field lines are in the *xz* plane. When the curl of the magnetic field points in the $\hat{z}$ direction, the circulating magnetic field lines are in the *xy* plane. The circulating magnetic field lines in the *yz*, *xz*, and *xy* planes are due to the electric Amperian current or the Maxwellian electric field changes in the $\hat{x}$, $\hat{y}$, and $\hat{z}$ directions, respectively. That is, using the right-hand rule, the curl of the magnetic field is indicated by the thumb, when the fingers curl along the magnetic field lines. The curls of the magnetic fields can be expressed as

$$\Psi^{magnetic}_{(x,y,z,t,q,P)} = \begin{bmatrix} 0 \quad \hat{x} \\[2ex] \dfrac{2c}{2\pi}P\dfrac{\frac{\mu_o qv}{4\pi}\cos(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{y} \\[2ex] \dfrac{4c}{\pi}\dfrac{\frac{\mu_o qv}{4\pi}\cos(\theta)\sin(\theta)}{\left(\sqrt{x^2+y^2+z^2}\right)^3}\hat{z} \end{bmatrix} \tag{69}$$

The magnetic field lines in the *xy* plane are orthogonal to the electric field along the *y* axis, and the magnetic field lines in the *xz* plane are orthogonal to the electric field along the *z* axis. Additionally, 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. Thus, the orthogonal oscillations of the electric and magnetic fields obey Faraday's law and the Ampere-Maxwell law (Figure 2.11; Maxwell 1873). Because the orthogonal electric and magnetic fields are out of phase, the orthogonal electric and magnetic fields of the binary photon obey Faraday's law and the Ampere-Maxwell law without the transformation being instantaneous as it must be in Maxwell's model of light, in which the electric and magnetic fields are in phase. The electric and magnetic fields are out of phase in the binary photon because the electrical neutrality of the binary photon results from two equal and oppositely charged semiphotons that are equidistant from the center of gravity as opposed to Maxwell's assumption that the absence of charge means that the divergence of the electric field vanishes ($\nabla E = 0 \neq \frac{\rho}{\varepsilon_o}$, where ρ is the charge density).

I am currently trying to map the electric and magnetic fields of 916 MHz photons in a standing wave formed in Lecher (1890) wires. By analyzing the phase relationship of the electric and magnetic fields in the standing waves using the Fresnel equations (Wayne 2019a), I should be able to infer the phase relationship of the electric and magnetic fields in the traveling waves.

Röntgen (1896) found that X-rays were not deflected by a magnet, and he used the fact that cathode rays but not X-rays could be bent by a magnetic field to distinguish the newly discovered X-rays from cathode rays. This distinction was also used by George P. Thomson (1928, 1938) to confirm that the diffraction pattern he saw was due to electrons and not X-rays. Does the fact that the deflection of X-rays was not detected mean that X-rays do not have a magnetic moment? Should the results be extrapolated to mean that photons do not have a magnetic moment? It could be argued *a priori* that as the carrier of the electromagnetic force, the photon should have a magnetic moment. If light were composed of binary photons with both parallel and antiparallel magnetic moments, then the light would not bend in a magnetic field.

Based on their analysis of a gamma photon produced by the annihilation of an electron and a positron, Sahin and Saglam (2009) derived a formula to calculate the magnetic moment of a photon. Although the photon is usually supposed to lack a magnetic moment (Jackson 1999; Karpa and Weitz 2006; Altschul 2008), this may be an unjustified and unintended consequence of the assumption that the photon is a massless ($m = \frac{\hbar\omega}{c^2} = 0$) mathematical point. Using the model of the binary photon, I predict that all photons have a magnetic moment, and the formula I derive in what follows is identical to that derived by Sahin and Saglam (2009).

According to the model of the binary photon, the magnetic moment (μ) of a semiphoton with charge (q) and mass $\left(\frac{\hbar\omega}{2c^2}\right)$ is related to its angular momentum $\left(\frac{\hbar}{2}\right)$ by the following equation:

$$\mu = \frac{q}{2m}L = \frac{q\hbar}{2m}\frac{}{2} = \frac{q\hbar 2c^2}{4\omega} = \frac{qc^2}{2\omega} \tag{70}$$

Since the conjugate particles that make up a binary photon have opposite charge (q) and opposite spinning frequency (ω), then $\frac{qc^2}{2\omega} = \frac{qc^2}{2\omega}$ for the leading and trailing semiphotons, respectively. Thus, the magnetic moment for the binary photon does not vanish, but it is twice as great as the magnetic moment of each individual particle. The magnetic moment (μ) of the binary photon is equal to

$$\mu = \pm\left|\frac{qc\lambda}{2\pi}\right| = \pm\left|\frac{qc^2}{\omega}\right| \tag{71}$$

The orientation of the magnetic moment depends on the composition of the binary photon (Table 2.1). When the leading semiphoton with positive mass has a positive charge and a clockwise spin (the trailing semiphoton would have a negative mass, a negative charge, and an anticlockwise spin), the magnetic moment is antiparallel to the vector of propagation (Class I). When the leading semiphoton with positive mass has a negative charge and a clockwise spin (the trailing semiphoton would have a negative mass, a positive charge, and an anticlockwise spin), the magnetic moment is parallel to the vector of propagation (Class II).

Classes I and II binary photons have an angular momentum that is antiparallel to the axis of propagation. Symmetry predicts that there may also be two other binary photons with an angular momentum that is parallel to the axis of propagation (Classes III and IV). However, it is not impossible that for binary photons that travel at the speed of light, nature favors one isomer over the other as it does in the case of neutrinos and antineutrinos. All neutrinos have left-handed helicity with spin antiparallel to the propagation axis, and all antineutrinos have right-handed helicity with spin parallel to the propagation axis (Lee 1957; Lee and Yang 1957; Goldhaber et al. 1958; Griffiths 1987; Solomey 1997; Bilenky 2013).

Equation 71 predicts that the magnetic moment of a binary photon is proportional to the wavelength and inversely proportional to the angular frequency. The magnetic moment of a binary photon with a wavelength on 0.01 nm is 7.61×10^{-23} A m^2, the magnetic moment of a binary photon with a wavelength on 400 nm is 1.45×10^{-21} A m^2, the magnetic moment of a binary photon with a wavelength on 500 nm is 1.81×10^{-21} A m^2, the magnetic moment of a binary photon with a wavelength on 600 nm is 2.17×10^{-21} A m^2, and the magnetic moment of a binary photon with a wavelength on 1 m is 8.62×10^{-14} A m^2.

The predicted proportional relationship between the magnitude of the magnetic moment and the wavelength indicates that long wavelength binary photons are more likely to be bent by a magnetic field than X-rays. However, symmetry predicts that a beam of natural light with both parallel and antiparallel magnetic moments will be broadened by a magnetic field, while a beam with only one orientation of the magnetic moment will be bent (Figure 2.12).

Perhaps the X-rays observed by Röntgen were broadened but not bent. Experimental tests of the magnetic moment of light could reify or falsify the model of the binary photon.

In the Standard Model of Physics, symmetry includes real particles of matter, real particles of antimatter, and the virtual particles that pop in and out of the vacuum (Lee 1988). To balance the positive energy of matter and antimatter, the

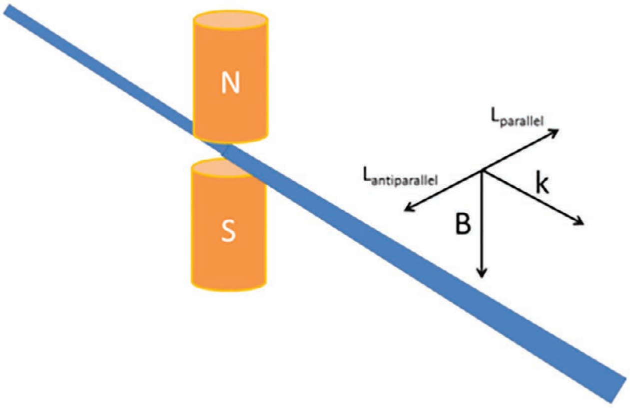

FIGURE 2.12 Predicted effect of a magnetic field on binary photons. If the binary photon has a magnetic moment ($\vec{\mu}$), then a magnetic field ($\vec{B}$) will induce a torque ($\vec{\tau}$) on it, according to the following formula: $\vec{\tau} = \vec{\mu} \times \vec{B}$. The torque exerted on the binary photon will depend on the orientation of the magnetic moment. As a result of the magnetic field, I predict that there will be a broadening of the beam in the plane orthogonal to the magnetic field lines and the axis of propagation. This proposed experiment is similar to the experiment performed by Gerlach and Stern (1922a, 1922b, 1922c) when they discovered the spins of silver ions (Castelvecchi 2022).

vacuum was endowed by Dirac (1930) with an infinite number of particles with negative energy that could give rise to virtual particles (Feynman 1949a, 1949b, 1987). "A *virtual particle*," according to David Kaiser (2005),

> is one that has borrowed energy from the vacuum, briefly shimmering into existence literally from nothing. Virtual particles must pay back the borrowed energy quickly, popping out of existence again, on a time scale set by Werner Heisenberg's uncertainty principle.

The uncertainty principle, according to quantum field theory, allows photons to develop internal structures that give rise to fermion-antifermion pairs for a short period of time that carry the same quantum numbers as the photon itself (Przybycień 2003; Lehnert 2008). Perhaps each binary photon propagating through an empty and vacuous vacuum is *actually* composed of a fermion-antifermion pair that conserves the energy, linear momentum, and angular momentum of the binary photon and can be produced when the binary photon experiences an electric field that is great enough to split it. If so, then the binary photon serves as "a unification between the charges (and thus of the forces) by . . . a single entity, of which the various charges are components in the sense that they can be transformed one into the other" (Salam 1979).

Indeed, pair production is known to occur when a photon with a very short wavelength enters the strong electric field of an atom (Figure 2.13).

During pair production, a photon (γ) with energy of 1.02 MeV undergoes an internal conversion to form an electron (e^-), which is a particle, and a positron (e^+), which is an antiparticle (Curie and Joliot 1933; Rose and Uhlenbeck 1935; Leone and Robotti 2010). Pair production in general results when a photon with sufficient energy ($\geq 2mc^2$) is transformed into a particle (mc^2) and its antiparticle (mc^2), and both are measured by detectors made of matter to have mass m. Conversely, when an antiparticle such as a positron collides with a particle such as an electron, they annihilate each other and are transformed into high energy photons in a process known as pair annihilation.

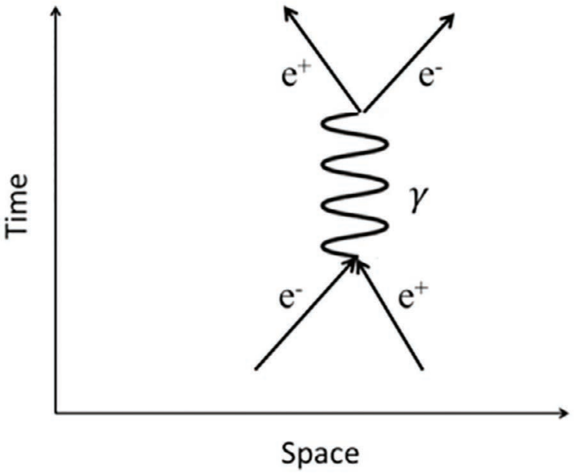

FIGURE 2.13 Feynman diagram of the annihilation of an electron (e^-) and positron (e^+) to form a gamma ray photon (γ) and the production or creation of an electron and a positron from a gamma ray photon.

It is worth reminding the reader that positrons are not "other-worldly." For example, bananas emit one positron every 75 minutes (Tanedo 2009), and positron emission tomography (PET) has been used to investigate photosynthate translocation to storage organs, such as root crops or fruits (Kawachi et al. 2006; Jahnke et al. 2009; Yamazaki et al. 2015; Hidaka et al. 2019; Kurita et al. 2020; Mincke et al. 2021; Antonecchia et al. 2022).

Eugene Wigner (1967) assumed that elementary particles were symmetrical in terms of right and left. Lee and Yang (1956) questioned the assumption that parity was a conserved quantity, and Wu et al. (1957) and Garwin et al. (1957) showed that parity was not a conserved quantity.

It turns out that the product of the signs of charge (C), parity (P), and time (T) is a conserved quantity (Lee 1988). Wayne (2012c) suggested that the sign of mass (M) might be a more realistic indicator than the sign of time, and it is CPM, not CPT, that is conserved. CPM theory allows all symmetries to be satisfied in three-dimensional Euclidean space and unidirectional Newtonian time with real particles of matter, real particles of antimatter, and a vacuum that has been swept clean of everything except its electric permittivity and magnet permeability.

The photon, according to the Standard Model of Physics, is a gauge boson that carries electromagnetic force (Glashow 1979; Salam 1979; Weinberg 1979). The binary photon could be considered to be a boson with spin ±1 composed of two conjugate fermions with spin ±½ (de Broglie 1934d; Wayne 2019d).

I claim that the photon cannot be a mathematical point with no parts since the presence of two rotating particles ensures that the binary photon is longer and wider than a mathematical point and can be divided into parts. The extension and twoness of the binary photon allows the formation of an electric dipole moment ($\pm|q\lambda|$) and a magnetic moment ($\pm\left|\frac{q\lambda c}{2\pi}\right|$), two characteristics that I presume are a *sine qua non* for the carrier of electromagnetic force. The model of the binary photon follows Franks Lloyd Wright's (1953) dictum "Form and Function Are One," which was inspired by his love of design and experience with the natural world.

Robert Hooke (1665) learned long ago that a mathematical point is an idealization that is not found in nature. He wrote in his *Micrographia*,

> As in Geometry, the most natural way of beginning is from a Mathematical point; so is the same method in Observations and Natural history the most genuine, simple, and instructive. . . . And in Physical Enquiries, we must endevour to follow Nature in the more plain and easier ways she treads in the most simple and uncompounded bodies,

> to trace her steps, and to be acquainted with her manner of walking there, before we venture ourselves into the multitude of meanders she has in bodies of a more complicated nature; lest, being unable to distinguish and judge our way, we quickly lose both Nature our guide, and our selves too, and are left to wander in the labyrinth of groundless opinions; wanting both judgment, that light, and experience, that clew, which should direct our proceedings. We will begin these our Inquiries therefore with the Observations of Bodies of the most simple nature first, and so gradually proceed to those of a more compounded one. In prosecution of which method, we shall begin with a Physical point; of which the Point of a Needle is commonly reckon'd for one; and is indeed, for the most part, made so sharp, that the naked eye cannot distinguish and parts of it. . . . But, if viewed with a very good Microscope, we may find that the top of a Needle . . . appears a broad, blunt, and very irregular end.

Indeed, Einstein (in Campos 2004) wrote to Hendrik Lorentz in 1909 stating that "I am not at all of the opinion that one should think of light as being composed of mutually independent quanta localized in relatively small spaces."

The binary photon is composed of two oppositely charged semiphotons that move with a three-dimensional wave-like motion that generates a linearly polarized sinusoidal electric field and an orthogonal circularly polarized sinusoidal field that is a quadrature out of phase with the electric field (Figure 2.11). It is understandable how such a carrier of radiant energy can raise the energy of an electron in the reaction center of chlorophyll, and it thus moves away from a positively charged nucleus in chlorophyll and towards the positively charged nucleus of the acceptor.

The wave-particle duality of light also becomes comprehensible since the two semiphotons that make up the binary photon rotate around the propagation axis in a way that generates sinusoidal wave-like electric and magnetic fields. As we will see later, the wave-like motion of the binary photon compared to the motion of a quantum-mechanical, mathematical point-like photon gives intelligibility to Heisenberg's uncertainty principle.

Just as a plant systematist has to weigh the advantages and disadvantages of lumping two taxa into one taxon or splitting one taxon into two, so must the biophysical plant biologist weigh the value and limitations of the binary photon and the quantum mechanical, mathematical point-like photon as the carrier of the electromagnetic force that separates charge in the reaction center that results in the evolution of oxygen and the fixation of carbon dioxide, two key events that make the contemplation of the photon possible.

2.6 THE UNCERTAINTY PRINCIPLE AND THE BINARY PHOTON

The uncertainty principle originated when Werner Heisenberg (1927) realized the difficulty that one would have trying to use just one photon to determine the position and momentum of a subatomic particle such as an electron at an instant in time without disturbing it. Pierre-Simon Laplace (1814) wrote,

> We ought then to regard the present state of the universe as the effect of its anterior state and as the cause of the one which is to follow. Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it an intelligence sufficiently vast to submit these data to analysis it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes.

Knowledge of the position and momentum of an electron would allow a Laplacian superbeing to predict all future movements of the electron with deterministic physical laws. This assumption gave some to doubt the existence of free will. However, the fundamental nature of chance and statistics given by the uncertainty principle of quantum mechanics would not allow such determinism in Euclidean space and Newtonian time (Jordan 1927; Heisenberg 1933, 1974; Jaki 1966, 1989; Frayn 2000). Quantizing Ernst Haeckel's (1905) ideas that atoms have free will, Ralph Lillie (1927), Eddington (1928), Bohr (1934), Compton (1935), Dingle (1937), Schrödinger (1945), Heitler (1963), Hawking and Mlodinow (2010), and Heisenberg's son Martin Heisenberg (2009) have discussed the relationship between physical indeterminism and the belief in free will and the freedom of the human mind. To me, free will is a fact (Wayne 2010c), and the determinacy found in the binary photon suggests that the source of free will must be sought outside of quantum mechanics.

In principle, because of diffraction, the electron can be best localized with a microscope by using the shortest wavelength of the illuminating gamma rays. Likewise, the linear momentum of the moving electron can be determined by measuring the Doppler shift of the scattered gamma rays as described by the Compton effect. But to get the most accurate measure of the electron's linear momentum, longer wavelength gamma rays that give the greatest Doppler shift $\left(\frac{\Delta\lambda}{\lambda}\right)$ for a given electron velocity should be used. As $\lambda \rightarrow 0$, the localization of the electron gets better, but the measurement of its linear momentum becomes less accurate, and as $\lambda \rightarrow \infty$, the localization of the electron becomes less accurate, but the measurement of its linear momentum becomes more accurate. Thus, with a monochromatic photon, it is impossible to accurately measure both the position and linear momentum of an electron at the same time (Bohr 1928; Heisenberg 1930; Darwin 1931; Hawking 1999). Heisenberg (1927) realized that the mutually incompatible requirement for longer and shorter wavelengths is a general principle that results in an incomplete knowledge of the electron in principle. Since position and linear momentum were two canonically linked variables in quantum mechanics, he suggested that there was a fundamental limit to knowledge. Heisenberg (1927) wrote that

> At the instant of the determination of its position—i.e., the instant at which the light quantum is diffracted by the electron—the electron discontinuously changes its impulse. That change will be more pronounced, the smaller the wavelength of the light used, i.e. the more precise the position determination is to be.

To describe the reciprocal relationship between the canonical variables of quantum mechanics that result in incomplete knowledge, Heisenberg introduced the principle of *Umbestimmtheit*, which could stand for the principle of indeterminacy, indefiniteness, or uncertainty in the following forms (Ruark and Urey 1930; Pauling and Wilson 1935; Mott and Sneddon 1948):

$$\Delta p \Delta z \sim h \tag{70}$$

and

$$\Delta p \Delta z = \hbar \tag{71}$$

Subsequently, the uncertainty relation has been presented in alternative but not equivalent forms such as

$$\Delta p \Delta z \geq \frac{\hbar}{2} \tag{72}$$

where the relationship is derived from the mathematical structure of quantum theory, and Δ represents the uncertainty due to the standard deviation (Kennard 1927; Richtmyer and Kennard 1942, 1947; Richtmyer et al. 1955, 1969; Brehm and Mullin 1989; Griffiths 2005; Serway et al. 2005), and

$$\Delta p \Delta z = h \tag{73}$$

where Δ represents the uncertainty due to the wave nature of light (Slater and Frank 1933; Slater 1951; Brehm and Mullin 1989; Serway et al. 2005). Which is the correct form of the uncertainty principle is still an open question (Prevedel et al. 2011).

The uncertainty principle, which replaced the principle of causality, undergirds the principle of complementarity touted by Bohr's (1934) Copenhagen School that treats quantum mechanics as a complete theory and emphasizes the particle-like *or* wave-like properties of light and the necessity of chance. By contrast, the binary photon is a melting pot for particle(s)-like *and* (as opposed to *or*) wave-like properties that welcomes causality. The unity in diversity displayed in the binary photon provides a way of describing the heretofore hidden variables (Bohm 1952a, 1952b; Bohm and Vigier 1954) within the photon that would seem to cause a mathematical point-like photon to scatter in a probabilistic manner. The positions and velocities of the semiphotons within the binary photon are described by continuous wave functions and are thus determined if one knows the initial conditions. De Broglie (1957) wrote,

> It is possible that looking into the future to a deeper level of physical reality we will be able to interpret the laws of probability and quantum physics as being the statistical results of the development of completely determined values of variables which are at present hidden from us.

The binary photon provides a challenge to the fundamental nature of the principle of uncertainty, the principle that has led to the counterintuitive elevation of chance and the promotion of paradoxical interpretations of reality supported by the maxim "shut up and calculate" (Mermin 1989, 2004; Tegmark 2007). Indeed, Eddington (1928) wrote that "if we could understand it [$qp - pq = \frac{ih}{2\pi}$, the root of the uncertainty principle] we should not think it so fundamental."

The time-varying position and extension of the binary photon may provide the hidden variables that allow a complete description of the process. A precisely defined state of the linear momentum[24] and the position of the binary photon can be calculated in principle from equations 31 and 32 and the initial conditions.

The linear momentum of the two semiphotons adds because the signs of the mass and velocity are both opposites. The variation in the velocity of the two semiphotons is equal to $\left(\Delta \frac{2c}{\pi}\right)$, the modulus of the mass is equal to $\left(\frac{hc}{\lambda c^2}\right)$, and the variation in the linear momentum is equal to $\left(\Delta \frac{2h}{\lambda\pi}\right)$. The product of the linear momentum and the variation in length ($\Delta z = \Delta \frac{\lambda}{\pi^2}$) along the axis of propagation results in an equation comparable to the uncertainty relation:

$$\left(\Delta \frac{\lambda}{\pi^2}\right)\left(\Delta \frac{2h}{\lambda\pi}\right) = \frac{2h}{\pi^3} \tag{74}$$

where the magnitude $\frac{2h}{\pi^3}$ is intermediate between the magnitudes of $\frac{\hbar}{2}$ and h.

Since equation 74 represents the maximum longitudinal length of the binary photon, it gives the maximal uncertainty. Since the minimal longitudinal length of the binary photon approaches zero, the uncertainty in the product of the position and linear momentum resulting from a collision with a binary photon is given by

$$\left(\Delta \frac{\lambda}{\pi^2}\right)\left(\Delta \frac{2h}{\lambda\pi}\right) \sim \frac{2h}{\pi^3} = 0.0645h \cong \frac{h}{4\pi} = 0.0796h \tag{75}$$

where $\frac{2h}{\pi^3}$ differs from $\frac{h}{4\pi}$ by about 23%. Therefore, the internal motions of the binary photon will lead to uncertainties in determining the position and the linear momentum of a body, and the magnitude of this uncertainty is close to the uncertainty predicted by Heisenberg (1927) based on his thought experiment.

Could a knowledge of the phase of the binary photon, which is in principle knowable by using differential equations and initial positions, tell us how far the center of gravity of an incident photon will be when its leading edge collides with an electron (McQuarrie et al. 2010)? Could the phase of the binary photon, which is in principle knowable by using differential equations and initial positions, determine whether a photon is reflected from or transmitted through an interface (Feynman 1985)? Could the phase of the two semiphotons be the hidden variables proposed by Max Born (1926), which have been long-searched for and often outright dismissed (von Neumann 1932; Bohm 1957; Belinfante 1973; Pinch 1977; Peat 1997)? Such an interpretation would provide support for the idea that Heisenberg's (1927) uncertainty principle is not a foundational principle that "once and for all establishes the invalidity of the law of causality."

Max Planck realized that requiring the simultaneous measurement of position and linear momentum was not only impossible but also an unnecessary requirement. Planck (1932) wrote that

> on closer consideration this conclusion, which is due to confusion of the world-picture [subjective reality] with the world of sense [measurement], 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 assumptions which have led to putting of that question, that is to say on the assumed structure of the physicist's world-picture.

Planck concluded by saying,

> 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.

The unnecessary requirement of the simultaneous measurement of position and linear momentum that led to the chasm between reality at the macroscopic level and the formal theory of quantum mechanics led Schrödinger (in Heisenberg 1927) to describe "quantum mechanics as a formal theory of frightening, even revulsive un-intuitiveness and abstraction."

The calculable and predictive but paradoxical nature of quantum mechanics may, in part, have resulted from considering the photon as a mathematical point-like elementary particle subject to statistical laws that hide important "real world" parameters instead of a pair of particles, with theoretically knowable time-varying momenta and position, and electric and magnetic fields that interact causally with matter. Thus, even though the act of observation would have an effect on atomic and subatomic particles (Park 1992), the cause-and-effect relation could be knowable in principle. Perhaps this is what Einstein meant when he wrote to Born (2005) on December 4, 1926 the following:

> Quantum mechanics is certainly imposing. But an inner voice tells me that it is not yet the real thing. The theory says a lot, but does not really bring us any closer to the secret of the 'old one'. I, at any rate, am convinced that He is not playing at dice.

The next sections discuss experimental tests of the binary photon.

2.7 A TEST OF THE BINARY PHOTON: CONSERVATION OF LINEAR MOMENTUM

In physical optics, the Snel-Descartes law of refraction is typically derived using a dispersion relation that assumes that the frequency (ν) is invariant across a vacuum-dielectric interface and that the wavelength (λ) decreases (Slayter 1970; Johnsen 2012). Since the linear momentum of a photon is inversely proportional to its wavelength, this treatment predicts that the linear momentum of a photon increases as it propagates from a vacuum to a medium with refractive index n_i and then decreases to the original value when it exits the medium. According to Hermann Minkowski (1908), the linear momentum of the photon, which is also known as the canonical momentum, increases from $\frac{h}{\lambda}$ to $n_i \frac{h}{\lambda}$ as the photon enters the medium with refractive index n_i and falls from $n_i \frac{h}{\lambda}$ to $\frac{h}{\lambda}$ as the photon exits the medium. This clearly contradicts the law of conservation of linear momentum, which has otherwise stood the test of time.

Halberg et al. (2020) tested if the wavelength actually does change when a photon enters a dielectric medium from the vacuum by replacing air with water and determining the position of the first order diffraction fringes. When the air is replaced by water, the distance between the fringes contracts in a way that is consistent with Abbe's equation of diffraction. However, the color of the spots does not change (Figure 2.14).

Halberg et al. (2020) inserted, in the water, a blue filter that would pass the shortened wavelength predicted by Minkowski as the photons pass through water or a 632.8±2 nm interference filter that would only pass the original wavelength. No light passed and the diffraction spots disappeared when the filter that passes the wavelength predicted by Minkowski was inserted, whereas the diffraction spots were unaffected by the 632.8 nm interference filter. Clearly the canonical Minkowski momentum is not relevant to the linear momentum of light.

Max Abraham (1909, 1910) thought that the linear momentum of light, which he called kinetic momentum, would decrease as it propagated through a dielectric medium with refractive index n_i since the velocity of the photon slows down. According to Abraham, the

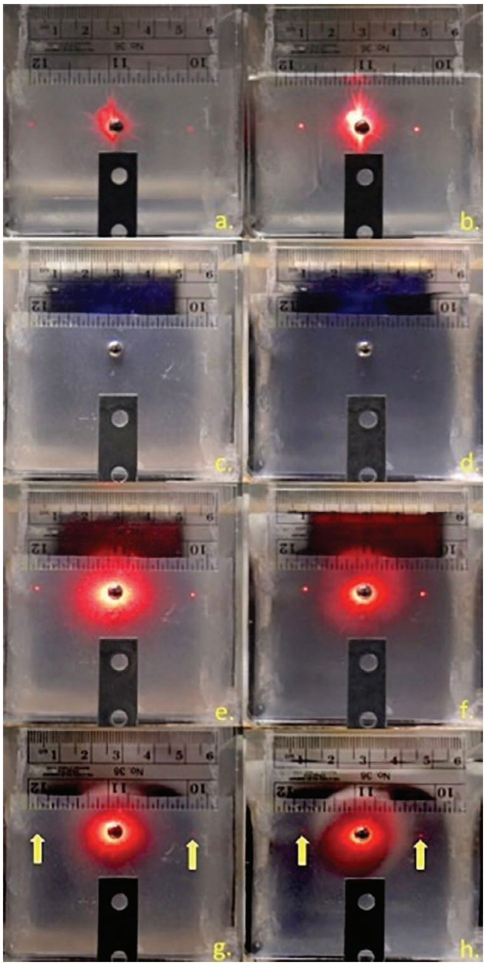

FIGURE 2.14 Photographs of the diffraction pattern produced in air and water without a filter (a and b, respectively), with a Kodak Wratten # 47 blue filter (c and d, respectively), with a Kodak Wratten # 29 red filter (e and f, respectively), and with a 632.8 nm laser line interference filter (g and h, respectively). Arrows indicate the positions of the faint spots observed with the interference filter.

linear momentum of the photon would decrease from $\frac{h}{\lambda}$ to $\frac{h}{n_i\lambda}$ as the photon entered the dielectric medium and increase from $\frac{h}{n_i\lambda}$ to $\frac{h}{\lambda}$ as the photon exited the medium. This also clearly contradicts the law of conservation of linear momentum.

How can we resolve the paradox? According to Halberg et al. (2020), the binary photon is a rotating oscillator with constant energy, linear momentum, and angular momentum, as well as a constant wavelength and frequency when it comes to the rotation of the semiphotons in the transverse plane. This energy, linear momentum, and angular momentum are intrinsic to the binary photon as a result of the constant wavelength and frequency of the rotating semiphotons in the transverse plane. It is these properties that are conserved.

The rotating oscillator produces an oscillating transverse electric field and a circular oscillating magnetic field that are a quarter of a wavelength out of phase with each other as the binary photon propagates at the speed of light due the balance of the accelerating gravitational force and the decelerating electromagnetic force.

Because the intrinsic rotary oscillator propagates at a velocity that is inversely proportional to the refractive index in a dielectric, the wavelength of the electric and magnetic fields that the rotary oscillator produces decreases, and the frequency of these fields increase. Halberg et al. (2020) proposed that the wavelength and frequency of the electromagnetic fields are not an intrinsic conserved property but a contingent property, and they should not be used to calculate the energy and linear momentum. The contingent wavelength and frequency are reversible and depend on the refractive index of the medium.

The decreased length of the contingent wavelength gives rise to the "illusional" Minkowski linear momentum, and the decreased velocity gives rise to the "illusional" Abraham linear momentum. The geometrical mean of these two "illusional" contingent linear momenta is equal to the intrinsic linear momentum, which we consider to be the real linear momentum:

$$\sqrt{\left(n_i\frac{h}{\lambda}\right)\left(\frac{h}{\lambda n_i}\right)}=\frac{h}{\lambda} \tag{76}$$

Unlike the standard photon, the model of the binary photon has the degrees of freedom to incorporate more than one definition of linear momentum. According to Halberg et al. (2020), the Minkowski linear momentum considers the center-to-center distance between corpuscular binary photons along the axis of propagation, while the Abraham linear momentum takes into consideration the ratio of the velocity of the binary photons in a dielectric medium compared to the speed of light in a vacuum. Both illusional linear momenta can be described simultaneously in terms of corpuscles or waves and represent the linear binary photon density (Figure 2.15).

Rudolf Peierls (1991) noted that attempts to resolve the Abraham-Minkowski controversy have resulted in "an extensive and confusing literature," and Vitaly Ginzburg (1970) calls the Abraham-Minkowski controversy one of the "perpetual problems" in physics.

However, the extensive, confusing, and perpetual problem is resolved by the binary photon that posits that these two infamous linear momenta are "illusional" in terms of mechanics, and it is only the intrinsic linear momentum that is physical and mechanical. The intrinsic linear momentum is defined by the circumference of the path along which the semiphotons move in the transverse plane and the translational movement controlled by the balance between the accelerating gravitational force between the two semiphotons and the decelerating electromagnetic force exerted between the semiphotons and the vacuum. The model of

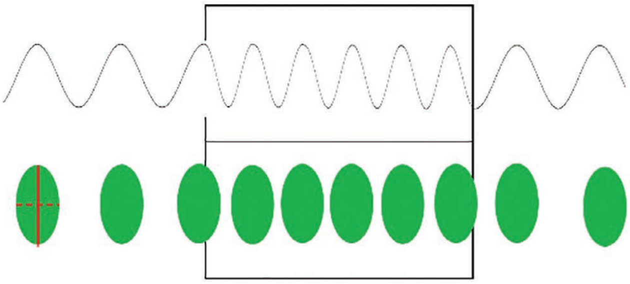

FIGURE 2.15 A corpuscular representation of the binary photon shows that as the binary photons enter and leave a refractive medium ($n > 1$), the intrinsic wavelength (λ) that is represented by the major circumference of the oblate binary photons (—) is invariant. The maximal length $\left(\frac{\lambda}{\pi^2}\right)$ along the axis of propagation (—) is also intrinsic and invariant. The center-center distance between binary photons along the axis of propagation (—) represents the contingent wavelength that is refractive index dependent. The contingent wavelength is equal to the intrinsic wavelength when $n = 1$. The refractive index-dependent change in the contingent wavelength is shown in a wave representation of the binary photon at the top of the figure. The corpuscle represents the three-dimensional space in which the two semiphotons rotate and oscillate as the binary photon propagates.

the binary photon provides a way to visualize the intrinsic linear momentum that is conserved and the contingent and "illusional" Minkowski and Abraham linear momenta.

2.8 A TEST OF THE BINARY PHOTON: DIFFRACTION

Kirchhoff's (1883, 1891) diffraction equation exactly describes observed optical phenomena, and it has been used for over a century to design optical instruments. Curiously, the derivation of Kirchhoff's equation from the Helmholtz equation requires that the Dirichlet and Neumann boundary conditions are satisfied simultaneously for an arbitrary surface. According to Poincaré (1892) and Sommerfeld (1964, 2004), this should be impossible if light is an electromagnetic wave as described by Maxwell where the magnetic and electrical fields are in phase. Given Maxwell's theory of light as an electromagnetic wave, the Dirichlet and Neumann boundary conditions could be satisfied only if light vanished identically in the image space, which is clearly contrary to experience.

Hans Bethe (1944), a student of Sommerfeld's, satisfied the boundary conditions by postulating the existence of a magnetic monopole that circulates around the aperture as if it caused a magnetic dipole. Although this solution is mathematically rigorous, it has no physical meaning unless magnetic monopoles exist at the aperture. Miller (1991) solved the problem by treating a spherical point source as a dipolar source. Both of these solutions have one thing in common—they bring twoness to the solution.

The binary photon naturally satisfies the Dirichlet and Neumann boundary conditions since it is composed of electrical and magnetic fields that are out-of-phase by a quarter of a wavelength. Consequently, one field satisfies the Dirichlet boundary condition, while the other field simultaneously and in ordinary space satisfies the Neumann boundary condition, and the paradox is solved (Wayne 2019b, 2019c).

According to geometrical optics, the image formed by a perfect aberration-free lens is a point-by-point representation of the object (Wayne 2019b). In theory, obtaining a point-by-point image of an object requires the photon to be a symmetrical, zero-dimensional, mathematical point. Otherwise, the photons themselves would blur the boundaries of each point. Moreover, since no lens is perfect, diffraction as described by the Kirchhoff equation occurs and inflates the image. If the mechanism of diffraction is independent of the direction of the diffracted light, then the amount of inflation due to diffraction should be independent of the direction. Consequently, a spherical object should produce a spherical image.

However, Cole et al. (2011) have shown that a spherical object produces a prolate ellipsoid as an image:

$$\text{Lateral resolution} = \frac{0.51\lambda_{exc}}{NA} \tag{77}$$

$$\text{Axial resolution} = \frac{0.88\lambda_{exc}}{n - \sqrt{n^2 - NA^2}} \tag{78}$$

where the geometry of the image depends on the wavelength of the excitation light (λ_{exc}), the numerical aperture of the objective lens (NA), the refractive index of the mounting medium (n), and unexplained coefficients that probably come from the analysis of diffraction made by Linfoot and Wolf (1956), who used the first-order Bessel function of the first kind as an approximation to derive the equation for lateral resolution, and the sinc function, which is equivalent to the first-order Bessel function of the zeroth kind as an approximation for the axial resolution.

Using confocal scanning microscopy, Lovier et al. (2020) showed that prolate ellipsoidal images (Figure 2.16) of sub-resolution fluorescent microspheres are not described by equations (77) and (78) but are better described by Equations (79) and (80):

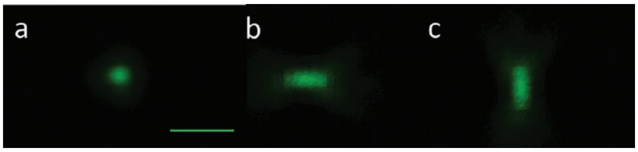

FIGURE 2.16 Maximal projection images of a 175 nm in diameter microsphere created by a confocal laser scanning microscope using a 63 × (NA 1.44) oil-immersion objective lens. (a) *xy* plane, (b), *yz* plane, and (c) *xz* plane. Scale bar = 1 μm.

$$\text{Lateral resolution} = \frac{0.61\lambda_{em}}{NA} \qquad (79)$$

$$\text{Axial resolution} = \frac{0.61\pi n\lambda_{em}}{NA^2} \qquad (80)$$

where the geometry of the image depends on the wavelength of the emitted light (λ_{em}), the numerical aperture of the objective lens (NA), the refractive index of the mounting medium (n), the length-to-width ratio (π) of a propagating binary photon, and a single coefficient that is derived using only the first-order Bessel function of the first kind (Figure 2.17).

The use of one Bessel function, which yields homogeneous diffraction equations, is an indication of the commonsense expectation that the diffraction mechanism is the same at any observed angle.

Thus, the lateral and axial resolution equations that are based on Rayleigh's criterion and derived from the Kirchhoff diffraction equation whose assumptions are met by the binary photon are not only better describers and predictors but also better explainers of the quantitative spatial aspects of the images. The accuracy of the equations that are based on the model of the binary photon in predicting the geometry of the images of the fluorescent microspheres support the claim that binary photons, which exhibit wave-particle duality as a consequence of the motions of two oppositely charged particles that give rise to wave-like electromagnetic fields, may be the fundamental and irreducible component of light.

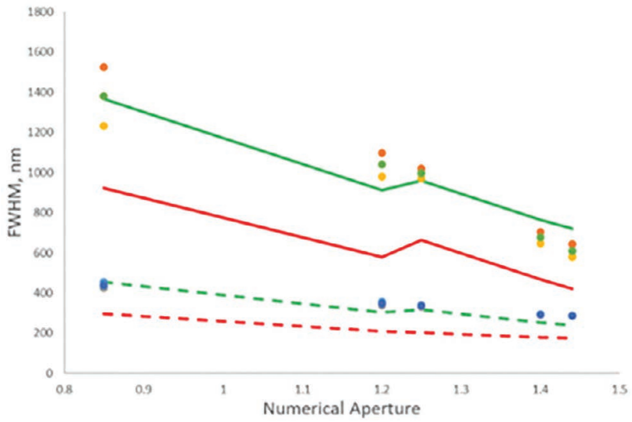

FIGURE 2.17 Measurements of lateral and axial lengths of the image of fluorescent microspheres, where the different colored dots represent different methods of measuring. The red lines represent the predictions from the standard equations, and the green lines represent the predictions from the equations based on the binary photon. The dashed lines indicate lateral resolution, and the solid lines represent axial resolution. The equations are

$$\text{Lateral resolution} = \frac{0.51\lambda_{exc}}{NA} \quad (\text{red dashed line})$$

$$\text{Axial resolution} = \frac{0.88\lambda_{exc}}{n-\sqrt{n^2-NA^2}} \quad (\text{red solid line})$$

$$\text{Lateral resolution} = \frac{0.61\lambda_{em}}{NA} \quad (\text{green dashed line})$$

$$\text{Axial resolution} = \frac{0.61\pi n\lambda_{em}}{NA^2} \quad (\text{green solid line})$$

2.9 A TEST OF THE BINARY PHOTON: THE FARADAY EFFECT

Michael Faraday (1846) discovered that the azimuth of linearly polarized light could be rotated by a magnetic field as it propagated through a piece of "heavy glass." Since the effect could not be observed in air, Faraday assumed that the magnetic field acted on the glass and that the glass influenced the magnetic properties of light itself. According to the standard theory, the magnetic field causes the glass, which has a single refractive index in the absence of a magnetic field, to become optically active because of the Lorentz force acting on the electrons in the glass. As a result, the glass develops one refractive index for right circularly polarized (RCP) light and another refractive index for left circularly polarized (LCP) light. This results in the rotation of the azimuth of polarization. Although the discovery of the Faraday effect was important evidence for the electromagnetic theory of light, the magnetic property of light itself that responds to the changes in the refractive index remains enigmatic.

Christopher Faraday et al. (2020) suggested that if light be described as being composed of equal and opposite moving charges within each binary photon, then the magnetic field could act on light itself. As a result of the electromagnetic properties of the binary photon, the force exerted on the binary photons by the applied magnetic field used to demonstrate the Faraday effect would result in the transformation of binary photons with a single intrinsic

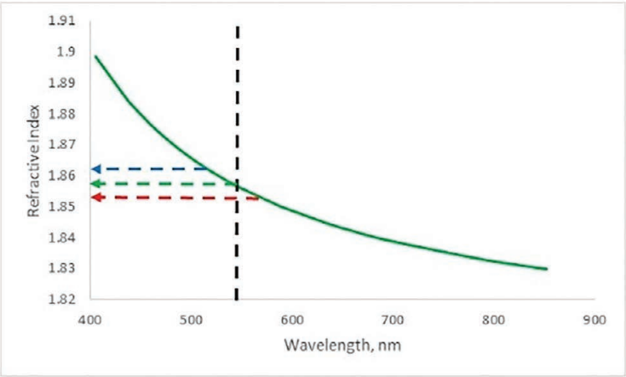

FIGURE 2.18 The relationship between the wavelength and refractive index (n_λ) of SF-57 glass. If the wavelength of half the binary photons that make up the linearly polarized light were blue-shifted and the wavelength of the other half of the binary photons that make up the linearly polarized light were red-shifted, then the azimuth of the linearly polarized light would be rotated.

wavelength into binary photons with two different intrinsic wavelengths. Because of the dispersion of glass, the binary photons with two different intrinsic wavelengths would no longer experience the same refractive index as they propagated through the "heavy glass" because by necessity, the glass required to show the Faraday effect with a relatively short geometrical path length must have high dispersion (Figure 2.18).

As a result of the high dispersion, the transformed binary photons with the shorter intrinsic wavelength would experience a higher refractive index, and the transformed binary photons with the longer intrinsic wavelength would experience a lower refractive index. Consequently, as they propagated through the glass, the shorter intrinsic wavelength binary photons would be retarded relative to the longer intrinsic wavelength binary photons, and the azimuth of polarization would be rotated.

The mechanism resulting in the simultaneous shortening and lengthening of a population of binary photons occurs this way: a clockwise current flowing through the solenoid produces a magnetic flux density that runs S → N antiparallel to the direction of propagation. The magnetic flux density exerts a Lorentz force on the moving charges of the semiphotons, which causes them to either accelerate centripetally or centrifugally (Figure 2.19).

A centripetal acceleration transforms the binary photon into a binary photon with a shorter circumference in the transverse plane and a shorter intrinsic wavelength, while a centrifugal acceleration transforms the binary photon into a binary photon with a longer circumference in the transverse plane and a longer intrinsic wavelength.

In any given binary photon, the two semiphotons accelerate in the same direction so that the Lorentz force results in an increase or decrease in the intrinsic wavelength of the binary photon. As a consequence of the high dispersion of "heavy glass," the long wavelength Classes I and IV binary photons experience a lower refractive index propagating through the "heavy glass" than the short wavelength Classes II and III binary photons when the magnetic field is antiparallel to the direction of light propagation. Since the azimuth of polarization is rotated anticlockwise in response to a magnetic field in the experiments described, we can infer that the Classes I and IV binary photons make up the right-handed circularly polarized (RCP) light, and the Classes II and III binary photons make up the left-handed circularly polarized (LCP) light.

The model of the binary photon and its response to a magnetic field describe and explain the magnetic properties of light proposed by Faraday and the requirement for high dispersion glass to observe the Faraday effect. The electromagnetic properties of the binary photon have the required number of degrees of freedom to account for other magneto-optical phenomena (Kerr 1877, 1878; Thompson 1901; Rikken and van Tiggelen 1996; 't Hooft and van der Mark 1996; van Tiggelen and Rikken 2002; Weinberger 2008), including the Zeeman effect (Zeeman 1903).

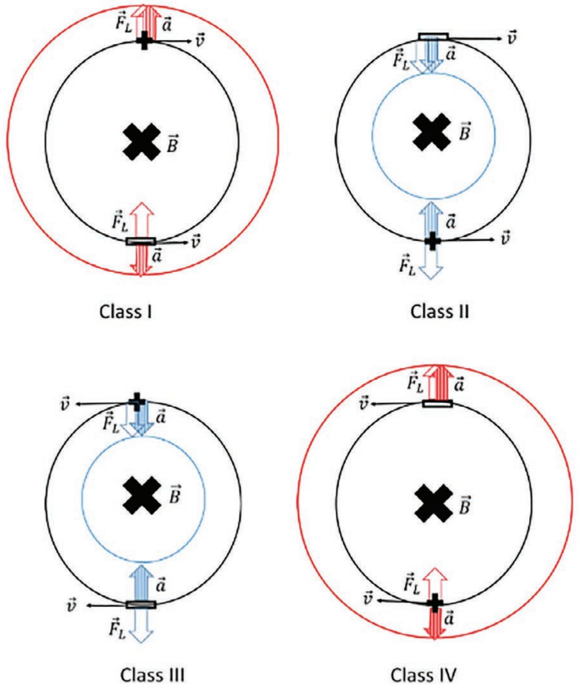

FIGURE 2.19 Schematic of the effect of a magnetic flux density ($\vec{B}$) directed into the paper (×) on the circumference of four classes of binary photons propagating towards the reader. A clockwise current flowing through the solenoid produces a magnetic flux density that runs S → N antiparallel to the direction of propagation. The leading semiphoton, which always has a positive mass (M), is shown on the top of the projection of its path (black circle) on the transverse plane, and the following semiphoton, which always has a negative mass, is shown on the bottom of the projection of its path (black circle) on the transverse plane for each class of binary photon. The electric charge (C) is shown as a black + or – on the positive mass semiphoton and as a white + or – on the negative mass semiphoton. The direction of the velocity vector $\left(\vec{v}\right)$ of the semiphotons is determined by the sign of the parity (P), which is +1 for anticlockwise motion and −1 for clockwise motion. The Lorentz force $\left(\vec{F}_L = \aleph q\vec{r} \times \vec{B}\right)$ exerted on the leading and following semiphotons in each class of binary photon is shown by empty red or blue arrows. The radial acceleration $\left(\vec{a} = \vec{F}_L / m\right)$ on the leading and following semiphotons is shown by stripped red or blue arrows. For the leading semiphotons, the acceleration is always parallel to $\vec{F}_L$, and for the following semiphotons, the acceleration is always antiparallel to $\vec{F}_L$. In Classes I and IV binary photons, the Lorentz force on the positive mass leading semiphoton is centrifugal, which results in a centrifugal acceleration, and the Lorentz force on the negative mass following semiphoton is centripetal, which also results in a centrifugal acceleration. The two centrifugal accelerations result in an increase in the circumference (red circle) of the binary photon, which is equivalent to an increase in wavelength. In Classes II and III binary photons, $\vec{F}_L$ on the leading semiphoton is centripetal, which results in a centripetal acceleration, and $\vec{F}_L$ on the following semiphoton is centrifugal, which also results in a centripetal acceleration. The two centripetal accelerations result in a decrease in the circumference (blue circle) of the binary photon, which is equivalent to a decrease in wavelength.

2.10 A TEST OF THE BINARY PHOTON: THE DEFLECTION OF STARLIGHT

I put the model of the binary photon to a test by describing and explaining the observed magnitude of the gravitational deflection of starlight—the *experimentum crucis* in favor of the general theory of relativity (Wayne 2020a)—in terms of the binary photon (Wayne 2012b, 2012d, 2020b).

By assuming that gravity was not a Newtonian force that influenced massive objects directly but that mass influenced the movement of mathematical point-like objects by warping an interdependent space-time through which they moved, Einstein (1916, 1920) predicted that starlight would be bent by the sun twice as much as was predicted by Johann von Soldner by using the Newtonian model that gravity is a force that interacts with massive particles and that light itself was a particle with translational motion only (Jaki 1978).

Following the horrors of World War I, there was a favorable eclipse that allowed the deflection of starlight to be measured in the heavens (Figure 2.20).

Dyson et al. (1920) found that "the results of the expeditions to Sobral and Principe can leave little doubt that a deflection of light takes place in the neighbourhood of the sun and that is of the amount demanded by EINSTEIN'S generalized theory of relativity." Following the observation of the signs in the heavens, Einstein became an instant celebrity. According to Subramanya Chandrasekhar (1983), Rutherford told him on May 29, 1919,

> The war had just ended, and the complacency of the Victorian and Edwardian times had been shattered. The people felt that all their values and all their ideals had lost their bearings. Now, suddenly, they learnt that an astronomical prediction by a German scientist had been confirmed . . . by British astronomers. Astronomy had always appealed to public imagination; and an astronomical discovery, transcending worldly strife, struck a responsive chord. The meeting of the Royal Society, at which the results of the British expeditions were reported, was headlined in all the British papers: and the typhoon of publicity crossed the Atlantic. From that point on, the American press played Einstein to the maximum.

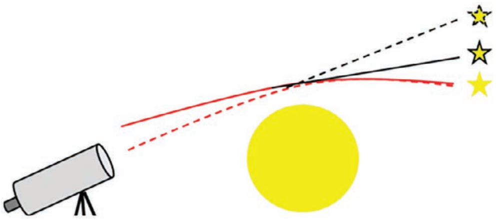

FIGURE 2.20 The deflection of starlight. As a result of the gravitational attraction of the sun, starlight composed of photons is deflected (dashed red line) as it passes close to the sun. The star is assumed to exist in a direction parallel to the telescope axis. As a result of gravity, the source of the starlight (star without outline) appears to be displaced away from the sun (star with dashed outline). The observed "double" deflection is predicted equally well by 1) the general theory of relativity and 2) the binary photon theory. If the binary photon did not have rotational motion, then the translational energy would be twice as large, and the starlight would be bent half as much (solid red line). Since the starlight would be deflected half as much, the star would appear to be closer to the sun (star with solid outline).

The *New York Times* (1919) reported that

> if those English scientists are right in feeling that the theory is strongly supported, we may be forced to conclude after all that our world is in just a topsy-turvy condition, and that we must learn the theory of relativity to understand it.

Unfortunately, they also reported that

> As all common folk are suavely informed by the President of the Royal Society that Dr. Einstein's deductions from the behavior of light observed during an eclipse cannot be put in language comprehensible to them, they are under no obligation to worry their heads, already tired by contemplation of so many other hard problems.

How did Einstein, the iconoclast that overturned Newton, become an icon himself and *Time* magazine's *Person of the Century* (Golden 1999)? According to Pais (1994), in the wake of the horrors of World War I, Einstein "carried a message of a new world order in the universe," and Einstein knew how to use language. Everyone knows what "space" and "warp" mean, but hardly anyone understands what "warped space" is. Einstein himself said to a Dutch newspaper in 1921, "It is the mystery of the non-understanding that appeals to them."

The general theory of relativity that posited that a relative and interdependent space-time directed the movement of a mathematical point such as light quantum became accepted by the scientific community. In appreciation, Einstein (1923) won the Nobel Prize in Physics for 1921 "for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect" and gave his lecture on the fundamental ideas and problems of the theory of relativity.

Is it possible that space is Euclidean and time is Newtonian (Wayne 2016c) and that the hidden properties revealed in the binary photon could explain the double deflection? Since the binary photon has angular momentum and radial extension, it must have rotational motion, which means that it must have rotational energy. If the binary photon had infinite translational energy, then it would not be deflected by the sun, and if it had vanishing translational energy, then it would fall into the sun. However, if the total energy of a binary photon ($E = h\nu$) is equipartitioned between the translational energy and the rotational energy, as described by equation 61, then the binary photon would have one-half of the expected translational energy. Consequently, the deflection of starlight would be twice as great as that which von Soldner predicted for a particle that has translational energy only (Wayne 2012b). The deflection of starlight composed of binary photons would also be equal to that predicted by Einstein (1916, 1920).

That is, the binary photon model of a rotating oscillator, which assumes that the binary photon rotates as it translates through absolute space and time gives the same prediction as Einstein's general theory of relativity. This means that the interpretation of the *experimentum crucis* that gave support for the relative and interdependent nature of space-time proffered by the general theory of relativity depends on the model of the photon. If the photon is a mathematical point whose energy cannot be partitioned into translational and rotational energy, then space and time must be relative and interdependent. However, if the photon is a binary compound with extension and its total energy is equipartitioned between its translational energy and its rotational energy, then space must be Euclidean, and time must be Newtonian.

In the same paper in which I offered this interpretation of the deflection of starlight, I also offered a quantitatively accurate interpretation of the gravitational red shift. According to the general theory of relativity, the warping of space-time results in a reddening of the photons emitted by a star. According to the binary photon theory, the reddening results because the binary photon loses energy as it does work against the gravitational binding energy of a star. If the star is so massive, then the reddening will be so extreme that the massive star would appear black in Euclidean space and Newtonian time (Wayne 2012b). This is the origin of black holes according to the binary photon theory that assumes that space is Euclidean and that time is Newtonian.

According to the theory of general relativity, the atomic clocks of the global positioning system that emit photons of a given frequency must be adjusted to take into consideration the warping of space-time by the earth. According to the binary photon theory, the decrease in the frequency or "clock ticks" of the binary photons moving away from the earth and the increase in the frequency or "clock ticks" of the binary photons moving towards the earth result from the loss or gain in the energy of the binary photon due to the work done as it propagates against or along the gradient in gravitational binding energy (Wayne 2012b). The other successes of Einstein's theories of relativity are also understandable and explainable in terms of Euclidean space and Newtonian time (Wayne 2015a).

According to Einstein (1923), the speed of light is a fundamental universal constant that relates relative space to an interdependent relative time, and "to harmonize the relativity principle with the light principle, the assumption that an absolute time (agreeing for all inertial frames) exists, had to be abandoned." That is, the speed of light is a universal absolute that relegates space and time to relative geometrical quantities. The following equation expresses the relationship between absolute and relative quantities:

$$ds^2 = dx^2 + dy^2 + dz^2 - c^2 dt^2 \tag{81}$$

where *ds* is a line element or world line in a Minkowski four-dimensional space-time. According to the theory of relativity, the square of the line element (ds^2) and the square of the speed of light (c^2) are constant for all observers, while the square of the distance in space ($dx^2 + dy^2 + dz^2$) and the square of the duration of time (dt^2) are relative quantities that depend on the velocity of the observer or the mass of an object—both of which warp space-time.

I asked myself if there could there be a heretofore hidden property of light itself that is relative when it moves through absolute space and time. Could Einstein have discounted such a property of light when he concentrated on its speed? The answer is, yes! The spatial extension of the binary photon allows one to see the fundamental nature of the wave-like properties of the binary photon that are subject to the Doppler effect expanded to the second order. The Doppler effect was discovered by Gregor Mendel's physics teacher, Christian Doppler (Baksalary and Styan 2009; Wayne 2013a), and I expanded it to the second order.

Doppler (1842) guessed that the color of binary stars might be caused by their movement towards or away from an observer (Andrade 1959; Hujer 1963; Gill 1965; Toman 1984; Schuster 2005). Following the introduction of the rapidly moving steam locomotive, Christophorus Buijs Ballot (1845) tested Doppler's wave theory acoustically by placing musicians on a railroad train that traveled 40 mph past musically trained observers. The stationary observers perceived the notes played by the horn players to be a half-note sharper when the train approached and a half-note flatter when the train receded. Three years later, John Scott Russell (1848) noticed that when he was on a moving train, the pitch of the whistle of a stationary train was higher when the train moved towards it and lower when the train moved away. Further support for the Doppler effect came when Hermann Vogel (1876) quantified the increase and decrease of the pitch of a train whistle as the train approached or receded by matching the tone on a violin.

Following the rise of chemical spectroscopy (Roscoe 1869; Kirchhoff and Bunsen 1860), Ernst Mach (1860, 1873) and Hippolyte Fizeau (1870) proposed that the radial velocity of objects could be ascertained by observing the Doppler-shift in the spectral lines that identified each chemical. The value of the Doppler effect on determining the velocity of objects was confirmed in the heavens (Huggins 1868; Slipher 1913) and in the laboratory (Bélopolsky 1901; Stark 1906; Galitzin and Wilip 1907). The cited acoustic and optical phenomena demonstrated the first-order Doppler effect. I have derived the Doppler effect expanded to the second order by starting with Maxwell's second-order wave equations (Wayne 2010b, 2016d):

$$\frac{\partial^2 \Psi}{\partial t^2} = c^2 \nabla^2 \Psi \tag{82}$$

Einstein tried to reformulate Maxwell's wave equation so that it would consider two inertial frames moving relative to each other, but he was unsuccessful (Wertheimer 1959). Consequently, Einstein concluded that Maxwell's wave equation, as it was written with its single explicit velocity (c), was a fundamental law of physics valid in all inertial frames and that the speed of light was invariant. I have reformulated Maxwell's wave equation so that it takes into consideration the changes in the spatial and temporal characteristics of electromagnetic waves observed when there is relative motion between the inertial frame that includes the source and the inertial frame that includes the observer. My reformulation of Maxwell's wave equation is based on the primacy of the Doppler effect expanded to the second order, which is experienced by all waves (Wayne 2010b, 2016d). Since for any solution to the second-order wave equation in the form of $\Psi = \Psi_o e^{2\pi i\left(\frac{1}{\lambda}z - vt\right)}$, ($\frac{1}{\lambda}$), and ($z$) or ($v$) and ($t$) are complementary pairs ($\frac{z}{\lambda}$ and vt), it is only a matter of taste between which members of the pairs ($\frac{1}{\lambda}$, v) or (z, t) one assumes to depend on the relative velocity of the source and observer and which members of the pairs one assumes to be invariant. Einstein chose z and t to be velocity-dependent and $\frac{1}{\lambda}$ and v to be invariant in all inertial frames, and I chose $\frac{1}{\lambda}$ and v to be velocity-dependent and z and t to be invariant in all inertial frames. The Doppler-based relativistic wave equation is given in what follows in two equivalent forms—the first emphasizing symmetry and the second, which is equation 82 multiplied by $\frac{c\sqrt{\mathrm{c-v\cos\theta}}}{c\sqrt{\mathrm{c-v\cos\theta}}} = 1$, emphasizing the similarity with the Lorentz transformation:

$$\frac{\partial^2\Psi}{\partial t^2} = cc'\frac{\sqrt{\mathrm{c - v\cos\theta}}}{\sqrt{\mathrm{c + v\cos\theta}}}\nabla^2\Psi \tag{83}$$

$$\frac{\partial^2\Psi}{\partial t^2} = cc'\frac{1-\frac{v}{c}\cos\theta}{\sqrt{1-\frac{v^2\cos^2\theta}{c^2}}}\nabla^2\Psi \tag{84}$$

The magnitude of the relative velocity of the source and observer is given by v; θ is the angle subtending the velocity vector originating at the source and the wave vector originating at the source and pointing towards the observer; c is the speed of light through the vacuum and is equal to $\frac{1}{\sqrt{\varepsilon_o\mu_o}}$; and c is the product of the frequency (v_{source}) of the source in its inertial frame and the wavelength ($\lambda_{observer}$) observed in any inertial frame. When the source and the observer are receding from each other, $\theta = \pi$ radians, and when the source and the observer are approaching each other, $\theta = 0$ radians. The following equation is a general plane wave solution to the second-order relativistic wave equation given previously:

$$\Psi = \Psi_o e^{2\pi i\left(\frac{z}{\lambda_{observer}} - v_{source}\frac{1-\frac{v}{c}\cos\theta}{\sqrt{1-\frac{v^2\cos^2\theta}{c^2}}}t\right)} \tag{85}$$

Solving the relativistic wave equation for the speed of wave c results in the following relativistic dispersion relation:

$$c = \lambda_{observer}v_{source}\frac{1+\frac{v}{c}\cos\theta}{\sqrt{1-\frac{v^2\cos^2\theta}{c^2}}} = 2.99 \times 10^8\,m/s \tag{86}$$

indicating that the speed of light (c) is equal to 2.99×10^8 m/s and is independent of the velocity of the observer. When v vanishes, the source and the observer are in the same inertial frame, and the relativistic dispersion relation reduces to the standard dispersion relation $c = \lambda_{source}v_{source}$. After replacing v_{source} with $\frac{c}{\lambda_{source}}$, equation 86 transforms into a simple, perspicuous, and lucid relativistic equation that describes the new relativistic Doppler effect:

$$\lambda_{observer} = \lambda_{source}\frac{1-\frac{v}{c}\cos\theta}{\sqrt{1-\frac{v^2\cos^2\theta}{c^2}}} \tag{87}$$

and the effect of relative velocity on the wavelength of the observed light.

The Doppler effect expanded to second order differs from the first-order Doppler effect in that the denominator in the first-order Doppler effect is unity. Consequently, as a result of the first-order Doppler effect, at any relative velocity, the *average* wavelength of light observed by or colliding with an observer or object from the front and back is unchanged and predicted to be (Page 1918)

$$\lambda_{observer} = \lambda_{source}\frac{1}{2}\left[\left(1-\frac{v}{c}\right)+\left(1+\frac{v}{c}\right)\right] = \lambda_{source} \tag{88}$$

By contrast, when the Doppler effect is expanded to second order, at any relative velocity, the *average* wavelength of light observed by or colliding with an observer or object from the front and back will change and will be given by

$$\begin{aligned}\lambda_{observer} &= \lambda_{source}\frac{1}{2}\left[\left(\frac{1-\frac{v\cos\theta}{c}}{\sqrt{1-\frac{v^2\cos^2\theta}{c^2}}}\right)+\left(\frac{1+\frac{v\cos\theta}{c}}{\sqrt{1-\frac{v^2\cos^2\theta}{c^2}}}\right)\right]\\ &= \frac{\lambda_{source}}{\sqrt{1-\frac{v^2\cos^2\theta}{c^2}}}\end{aligned} \tag{89}$$

The equation, which describes the new relativistic Doppler effect, differs from Einstein's relativistic Doppler effect equation by having a cosine term in both the numerator and the denominator. The cosine term describes the dependence of the first- and second-order velocity-dependent spatial properties of electromagnetic waves on the component of the velocity relative to the propagation vector. Unlike Einstein's relativistic Doppler effect, where the term in the denominator describes the relativity of time independent of the propagation vector, the new relativistic Doppler effect shown here does not predict a transverse Doppler effect when $\theta = \frac{\pi}{2}$ since at this angle, $\cos\theta = 0$. This is a testable difference between the special theory of relativity and the theory of the binary photon. The Doppler effect expanded to the second order will cause a velocity-dependent change in the observed length ($L_{observer}$) of the binary photon according to the following equation:

$$L_{observer} = \lambda_{source} \frac{1 - \frac{v}{c}\cos\theta}{\sqrt{1 - \frac{v^2\cos^2\theta}{c^2}}} \tag{90}$$

and a velocity-dependent change in its observed cross-sectional area ($A_{observer}$) according to the following equation:

$$A_{observer} = \pi r^2 = \pi \frac{\lambda_{source}^2}{(2\pi)^2}\left[\frac{1 - \frac{v}{c}\cos\theta}{\sqrt{1 - \frac{v^2\cos^2\theta}{c^2}}}\right]^2$$

$$= \frac{\lambda_{source}^2}{4\pi}\left[\frac{1 - \frac{v}{c}\cos\theta}{\sqrt{1 - \frac{v^2\cos^2\theta}{c^2}}}\right]^2 \tag{91}$$

I assume that the velocity-induced change in the cross-sectional area of the binary photon is a result of the equipartition of energy between the longitudinal motion and the rotational motion. Indeed, the fact that the entropy (S) of a photon is $3.60k$, where k is Boltzmann's constant, indicates that a photon has approximately 36 microstates (Ω) among which to share the entropy (Wayne 2015d):

$$S = k\ln\Omega \tag{92}$$

It is difficult to see how the quantum mechanical, mathematical point-like photon can accommodate 36 microstates.

Red- and blue-shifted binary photons are shown in Figure 2.21.

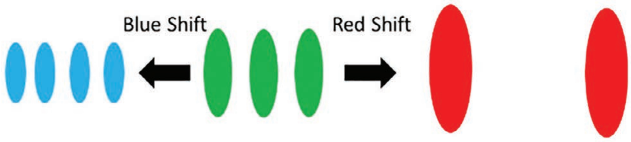

FIGURE 2.21 Red-shifted and blue-shifted binary photons. The Doppler effect will cause a velocity-dependent change in the length and cross-sectional area of the oscillating binary photon.

Curiously, even though the Doppler effect is readily perceived when there is relative motion, whether one is looking at the water waves produced by a swimming swan, the water waves striking a cattail, the sound waves produced by the siren on a fire truck, or the light coming from a distant galaxy, standard theories rarely, if ever, include the Doppler effect as a primary consideration in the study and description of relative motion. The analyses done by my colleagues and me (Wayne 2010a, 2010b, 2012a, 2013c, 2015c, 2015e; Maers and Wayne 2011; Maers et al. 2013) are unique in that we incorporate the relativistic Doppler effect *ab initio*. When expanded to second order, the inclusion of the Doppler effect makes it possible to unify many aspects of mechanics, electrodynamics, and optics that are usually treated separately. Indeed, the Doppler effect expanded to second order combined with absolute time also provides alternative derivations of results familiar from the special theory of relativity that describes the relativity of simultaneity and why charged particles cannot exceed the vacuum speed of light. It also describes the optics of moving bodies and the mass equivalent of energy and allows the combination of Newton's second law with the second law of thermodynamics to produce a fundamental, relativistic, and irreversible law of motion, which is something that Tom Stoppard (1993) realized should be possible.

Einstein lived at a time when fast-moving coal-powered trains and telegraphic communication made time seem as if it were relative (Galison 2003). Imagine someone living at that time who was one thousand miles away telling you that their train or a telegram was going to arrive at 12 o'clock noon. Which 12 o'clock noon, the noon of the person telling you or the noon of the person waiting for the train or the telegram? The confusion led to the creation of standard time (Blaise 2000). Before the creation of standard time in 1884, there was local time or solar time where each community considered 12 o'clock noon to be the time that the sun was highest in the sky at that location.

In his book *Relativity: The Special and the General Theory*, Einstein (1920) used a train analogy developed by David Comstock (1910) to describe the foundations of the

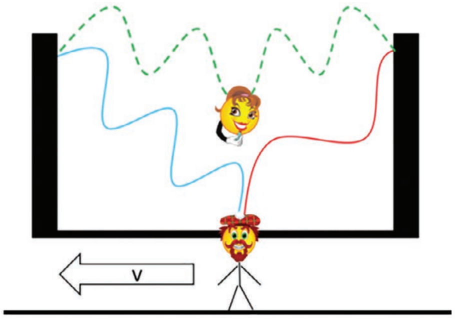

FIGURE 2.22 The observer in the railroad car midway between the lights sees two identical lights come on simultaneously, while the observer on the platform, midway between the two lights and moving backwards relative to the railroad car, sees the light from the back come on before the light from the front.

special theory of relativity to a general audience in a non-mathematical manner.

Einstein (1920) demonstrated that time is relative by comparing the observations of a person on "a very long train travelling along the rails with the constant velocity v" with the observations made by a person on a "railway embankment." He asked the reader to picture an observer in a railroad car midway between light sources at the back of the railroad car and at the front of the railroad car (Figure 2.22).

This observer would see the lights come on simultaneously. By contrast, an observer standing on the railway embankment, who is moving backwards at velocity v relative to the train, would see the light at the back of the railroad car come on before the light at the front of the railroad car comes on. Since there was only one simultaneous event observed by the person on the train but two non-simultaneous events observed by the person on the embankment, Einstein concluded that time was relative, and the perceived time depended on the relative velocity of the observer.

Working at a time when transformations between local times and standard time were being made by engineers and telegraph operators, Einstein was immersed in the relativity of time. Combined with the fact that he considered light to be a mathematical point where wavelength and frequency were just numbers that represented momentum and energy, Einstein considered the relativity of time to be a more reasonable explanation than the relativity of wavelength and frequency (i.e., color) due to the Doppler effect. By contrast, I am immersed in a time of Doppler radar, Doppler weather, Doppler ultrasound, and Doppler MRI (Doviak and Zrnić 1993; Maulik 1997; Baksalary and Styan 2009), and as a child of the 1960s, how could I not appreciate the train metaphor in terms of the Doppler effect and the relativity of color?

Although there is a lack of clarity as to whether color is described by wavelength or by frequency (Johnsen 2012), the color of light can be described equally well in terms of wavelength and frequency (Wayne 2014c). According to the Doppler theory (Wayne 2010b), if the person in the railroad car midway between the lights at the back and front of the railway car sees the lights come on simultaneously, then he or she would see them to be the same color. By contrast, the person on the embankment would see the light at the back of the train as bluer and the light at the front of the train as redder as a result of the Doppler effect expanded to the second order and the relative motion between the train and the person on the railway embankment. Although the velocities of the blue-shifted and red-shifted light are the same and equal to c, the speed of light in free space, the amplitude, energy, or probability of finding a photon (Born 1954; Bloch 1976) described by the blue-shifted wave arrives at the observer before the amplitude, energy, or probability of seeing a photon described by the red-shifted wave arrives at the observer. Consequently, the person on the platform would not observe the two lights coming on simultaneously, but because of the difference in the wavelengths that results from the Doppler effect, the person on the railway embankment would observe the blue-shifted light from the back before observing the red-shifted light from the front.

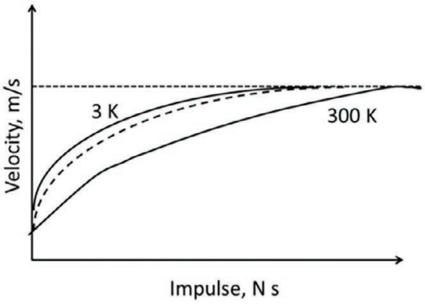

FIGURE 2.23 Particles cannot exceed the speed of light. The reason why a particle with a charge and/or a magnetic moment cannot exceed the speed of light is explained by the special theory of relativity, which says that the duration of time that the electron experiences the accelerating field gets shorter and shorter as the particle gets faster and faster, and consequently, it accelerates less and less. As the particle approaches the speed of light, the duration of time is so short that the particle can no longer accelerate. According to the special theory of relativity, the particle is only moving through a relative and interdependent space-time. The Doppler theory also explains why particles with a charge and/or a magnetic moment, which are the only kind of particles that can interact with binary photons, the carrier of the electromagnetic force, cannot exceed the speed of light. Special relativity makes no predictions about the effect of temperature on the velocity-impulse relation, while the Doppler theory predicts that as the temperature increases, the impulse needed to accelerate a particle to a given velocity will be greater because of the increased velocity-dependent optomechanical counterforce caused by the binary photons on the charged particle.

The Doppler effect experienced by the binary photon can also be used to describe and explain the electrodynamics of moving bodies and why particles with a charge and/or a magnetic moment cannot go faster than the speed of light (Wayne 2010a; Figure 2.23).

When an electron is accelerated through an electric field in a cavity, it moves through a photon gas. According to Planck's blackbody radiation law, when the temperature of a cavity is greater, the number of photons in the cavity is greater, and their wavelength is shorter. This means that at any temperature greater than absolute zero, which according to the third law of thermodynamics developed by Walther Nernst, is unattainable, there will be photons. This means that there will be binary photons in any space through which a particle with charge and/or magnetic moment moves.

If a particle is moving through a photon gas, then the binary photons that scatter from the front of the moving particle will be blue-shifted because of the Doppler effect expanded to the second order, and the binary photons that scatter from the back of the moving particle will be red-shifted (Figure 2.24).

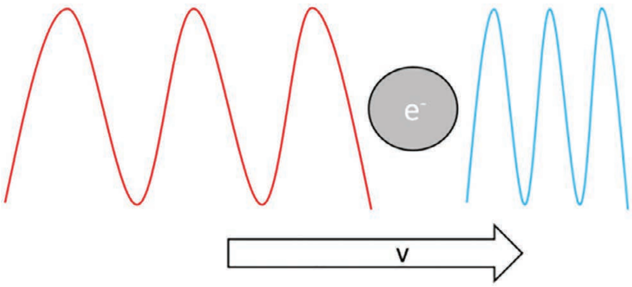

FIGURE 2.24 According to the Doppler theory, at any temperature greater than absolute zero, a particle moves through a photon gas as described by Planck's blackbody radiation law. As the particle moves through the photon gas, it experiences the photons through which it moves as being Doppler-shifted. The binary photons that strike the leading side of the particle are blue-shifted by the Doppler effect, and the binary photons that strike the trailing side of the particle are red-shifted. When the particle velocity is greater, the difference is greater between the blue- and red-shifted binary photons. Since the linear momentum of the binary photons is inversely proportional to their wavelength, the binary photons through which the particles move exert an optomechanical counterforce on the moving particle. In this way, light itself prevents particles with a charge and/or a magnetic moment from exceeding the speed of light. Only particles with a charge and/or a magnetic moment can interact with the binary photons, the carriers of the electromagnetic force.

The binary photons that collide with the back of the moving particle can also be considered to be red-shifted as a result of the Compton effect, and the binary photons that collide with the front of the moving particle can also be considered to be blue-shifted as a result of the inverse Compton or Sunyaev-Zel'dovich effect (Rybicki and Lightman 1979; Shu 1982).

Since the energy and linear momentum of binary photons are inversely proportional to their wavelength, the blue-shifted binary photons that collide with or scatter from the front of a moving particle will push the particle backwards more than the red-shifted binary photons that collide with or scatter from the back of the moving particle will push the particle forwards. When the particle moves faster, the difference is greater between the wavelengths of the binary photons hitting the front and back of the moving particle, and the optomechanical frictional counterforce provided by the binary photons through which the particle moves is also greater. As the electron approaches the speed of light, the frictional counterforce approaches the accelerating force. Since the acceleration of the electron is proportional to the difference between the accelerating force and the frictional counterforce, when the frictional counterforce equals the accelerating force, acceleration is no longer possible. This means that light itself prevents a particle with charge and/or magnetic moment from moving faster than the speed of light.

Friction in physics is dismissed as fundamentally negligible and unimportant (Einstein and Infeld 1938). However, a biophysical plant biologist knows that a frictional counterforce is experienced by anything that moves, including a substrate diffusing towards an enzyme (Wayne 2009b), water moving through a membrane (Wayne and Tazawa 1990), the thylakoids moving through the stroma during chloroplast biogenesis (Paolillo Jr. and Reighard 1967), nuclear-encoded proteins passing through the chloroplast envelope (Jarvis and López-Juez 2013), proteins trafficking through plastid stromules (Hanson and Sattarzadeh 2013), chloroplasts moving through a cell (Kadota et al. 2009; Wada 2013), and leaves tracking the movement of the sun (Koller 2011). By extrapolation, I have found that at any temperature above absolute zero, friction is inevitable and that binary photons have the properties necessary to provide the optomechanical counterforce that prevents particles, with a charge and/or magnetic moment that makes them capable of interacting with photons, from exceeding the speed of light.

According to the optomechanical model of how binary photons limit the speed of a moving particle to that of light, when the temperature of the space through which the particle moves is greater, the number of binary photons is greater, and the optomechanical counterforce or the resistance to acceleration is greater. Consequently, the optomechanical counterforce hypothesis is testable since the counterforce exerted on the moving particle increases with temperature. If the speed in which a particle is accelerated by an impulse *is not* temperature dependent, then the special theory of relativity gives a better explanation of the limiting speed of particles. If the speed in which a particle is accelerated by an impulse *is* temperature dependent, then the theory of the optomechanical counterforce provided by Doppler-shifted binary photons gives a better explanation of the limiting speed of particles. I look forward to someone measuring the impulse-velocity relationship at 3 K and 300 K in a linear accelerator. According to the optomechanical counterforce theory, the impulse needed to accelerate a particle to a given velocity should be 10,000 times greater at 300 K than at 3 K (Wayne 2010a).

The fact that radiation through which a body moves exerts friction on that body has planetary and cosmological effects. Radiation friction becomes significant when the temperature of the radiation and the velocities of the galaxies moving through it are great. This situation occurs in our solar system close to the sun, where Mercury, the planet with the greatest velocity, exhibits an anomalous precession of the perihelion. The first success of Einstein's general theory of relativity was to account for the anomalous precession of the perihelion of Mercury. This solution required time and space to be "robbed of the last trace of objective reality." However, Wayne (2015b) showed that it is possible to interpret Einstein's relativistic correction for describing the precession of the perihelion of Mercury in terms of a gravitational force that obeys Newton's law of gravitation corrected with a radiation friction-induced tangential velocity-dependent term and operating through Euclidean space and Newtonian time.

Wayne (2015c) also suggested that the decrease in the velocity-dependent radiation friction occurring because of the expansion of the universe may be the cause of the observed acceleration of the expansion of the universe that is attributed to mysterious dark energy. Interestingly, a decrease in the density of light energy and the apparent domination of dark energy become one and the same.

Wayne (2015c) has also shown that it is possible to use the concept of radiation friction to derive Einstein's equation that describes the equivalence of mass and energy.

When we look at the development of the photosynthetic system (Majeran et al. 2010) and the "adaptive walk" taken in the evolutionary history of photosynthetic plants (Niklas 1997), there seems to be an undeniable arrow of time. Yet, according to the Standard Model of Physics, time is an illusion because the fundamental equations of physics do not have an arrow of time. According to Brian Greene (2004), "Even though experience reveals over and over again that there is an arrow of how events unfold in time, this arrow seems not to be found in the fundamental laws of physics." However, the reversibility of time *is* the foundational assumption, and *only* equations that are quadratic in time (t^2) are allowed to be called fundamental. This is why the second law of thermodynamics, which according to me, foundationally describes and explains the observed unidirectional arrow of time, is not considered to be a fundamental law of physics.

By taking into consideration the optomechanical counterforce produced by Doppler-shifted binary photons, I have been able to combine Newton's second law of motion with the second law of thermodynamics to produce a fundamental, relativistic, and irreversible law of motion (Wayne 2012a). It states that processes are irreversible because Doppler-shifted binary photons that collide with any moving object radiate away at the speed of light. These binary photons cannot be rounded up to reverse the natural process.

2.11 THE REAL WORLD: MATHEMATICAL OR MORE?

Is it possible to come up with laws of physics that coincide with the visual world? In his Nobel lecture, Heisenberg (1933) stated that "The impossibility of harmonizing the Maxwellian theory with the pronouncedly visual concepts expressed in the hypothesis of light quanta subsequently compelled research workers to the conclusion that radiation phenomena can only be understood by largely renouncing their immediate visualization." One could no longer ask, where is a given photon in space and time? Because, according to Walter Heitler (1944) "there are no indication that, for instance, the idea of the 'position of a light quantum' (or the 'probability for the position') has any simple physical meaning." More recently, David Griffiths (2005) wrote:

> 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). 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.

According to Armstrong (1983), the photon is not a physical unit with any form of localization but more like coefficients in a Fourier series until it is commanded into existence.

Mathematics seems to have trumped other forms of knowledge about the natural world. James Jeans (1945) wrote that "the history of theoretical physics is a record of the clothing of mathematical formulae which were right, or very nearly right, with physical interpretations which were often very badly wrong." In *The Mysterious Universe*, Jeans (1934) wrote,

> Lapsing back again into the crudely anthropomorphic language we have already used, we may say that we have already considered with disfavour the possibility of the universe having been planned by a biologist or an engineer; from the intrinsic evidence of his creation, the Great Architect of the Universe now begins to appear as a pure mathematician.

I think that the current mathematical models in physics that consider all particles fundamentally as mathematical points, matter as being fundamentally massless, friction to be a fiction, and space and time to be fundamentally an illusion are too simplistic in their assumptions, and because of this, they may be misleading when it comes to describing the real world. Consequently, I am endeavoring to create a realistic theory of the photon, which inevitably creates friction as a result of the Doppler effect expanded to the second order, where space and time are real-world quantities defined by common sense and only approximated by mathematical equations (Synge 1951, 1970). My point of view contrasts with the mathematical physicists who think that the mathematical equations are fundamentally real and anything less abstract is accidental and misleading (Tegmark 2007).

After reading Hermann Weyl's book *Space, Time and Matter*, Felix Bloch (1976) told Heisenberg "that space was simply the field of linear operations." Heisenberg replied, "Nonsense, space is blue and birds fly through it." Heisenberg was warning Bloch that "it was dangerous for a physicist to describe Nature in terms of idealized abstractions too far removed from the evidence of actual observation." Einstein also thought that idealized abstractions provided inadequate pictures of the world. When Max Born's wife Hedwig asked Einstein, "Do you believe that everything can be pictured in a scientific manner?" Einstein answered, "Yes, it is conceivable but it would be of no use. It would be an inadequate means of expression—like representing a Beethoven symphony in terms of curves of air pressure" (Born 1965).

Wholistic, intuitive, aural, and visual interpretations of reality contrast with the current orthodox interpretation of reality where reality is completely described mathematically by the foundational principles of uncertainty and relativity, and consequently, events do not really take place in a cause and effect manner over unidirectional and linear time in three-dimensional space. The model of the binary photon also makes it possible to understand how a laser works without invoking Einstein‘s theory of stimulated emission where an incoming photon interacts with an excited atom in a way that the interaction energy is zero, and the interaction does not require any energy (Wayne 2016b). According to Bohr (1934), the commonsense yet illusional view of reality prevails because most people do not have experience with velocities that are comparable to the speed of light and with objects as small as atoms (Miller 1994). The binary photon allows for a physical and mathematical description of the real world, capable of visual imagery, and consistent with common sense and intuition, where time differs from space, friction is not a fiction, and all effects require a cause.

2.12 SUMMARY OF THE PROPERTIES OF A BINARY PHOTON

The importance of plants in transforming the energy of light to the requirements for life was recognized by Julius Robert Mayer (1845), the founder of the first law of thermodynamics (Tyndall 1915). Mayer wrote,

> Nature undertakes the task of storing up the light which streams earthward—of condensing the most volatile of all powers into a rigid form, and thus preserving it for our use. She has overspread the earth with organisms which while living take into them the solar light, and by the appropriation of its energy generate incessantly chemical forces. These organisms are plants. The vegetable world constitutes the reservoir in which the fugitive solar rays are deposited and rendered ready for useful application. With this economical provision the existence of the human race is also inseparably connected. The reducing action exerted by solar light on both inorganic and organic substances is well known. This reduction takes place most copiously in full sunlight, less copiously in the shade, being entirely absent in darkness, and even in candlelight. The reduction is a conversion of one form of energy into another—of mechanical effect into chemical tension.

Given the importance of light to plant life in terms of photosynthesis, photomorphogenesis (Wayne and Hepler 1984, 1985), and photomovement (Wayne et al. 1991), I became interested in the nature of the photon. The nature of the light quantum has been questioned ever since Einstein proposed it in 1905. On December 12, 1951, Einstein wrote to his friend Michele Besso: “All the fifty years of conscious brooding have brought me no closer to the answer to the question, ‘What are light quanta?’ Of course, today, every rascal thinks he knows the answer, but he is deluding himself” (see Klein 1970).

C. S. Lewis (1952) had some advice on how to progress when it comes to solving a problem. He wrote that

> We all want progress. But progress means getting nearer to the place where you want to be. And if you have taken a wrong turning, then to go forward does not get you any nearer. If you are on the wrong road, progress means doing an about turn and walking back to the right road; and in that case the man who turns back soonest is the most progressive man. We have all seen this when doing arithmetic. When I have started a sum the wrong way, the sooner I admit this and go back and start over again, the faster I shall get on. There is nothing progressive about being pigheaded and refusing to admit a mistake. And I think if you look at the present state of the world, it is pretty plain that humanity has been making some big mistake. We are on the wrong road. And if that is so, we must go back. Going back is the quickest way on.

Perhaps you will agree that it has been productive for me to question the assumptions that led to the mathematical point-like, quantum mechanical photon and instead begin with the assumptions that 1) the photon may not be a mathematical point, 2) time may not be bidirectional and nonlinear, and 3) friction may be omnipresent and cannot be ignored. This skepticism is reminiscent of the rules that Rene Descartes (1637) developed to discover true knowledge about light:

> The first was never to accept anything for true which I did not clearly know to be such; that is to say, carefully to avoid precipitancy and prejudice, and to comprise nothing more in my judgement than what was presented to my mind so clearly and distinctly as to exclude all ground of doubt.
>
> *The second, to divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate solution.*
>
> *The third, to conduct my thoughts in such order that, by commencing with objects the simplest and easiest to know, I might ascend by little and little, and, as it were, step by step, to the knowledge of the more complex; assigning in thought a certain order even to those objects which in their own nature do not stand in a relation of antecedence and sequence.*
>
> *And the last, in every case to make enumerations so complete, and reviews so general, that I might be assured that nothing was omitted.*

The ideas on the nature of the photon that I present here are incomplete and still in progress. They are the best I have to offer, but some may be wrong. Arthur Schuster (1898), the person who first came up with the idea of anti-matter, reminds us that as scientists, we should occasionally think about the unknown and perhaps even the unknowable. I hope my ideas developed from my background as a biophysical plant cell biologist have stimulated you to think about the photon. Here is a summary of my conclusions:

- The photon is not an elementary particle but a composite particle composed of two semiphotons, and it is a boson composed of two fermions. The mass-energy of the boson is not unique but depends on the frequency of the photon.
- The semiphotons are conjugate particles. One semiphoton has positive mass and the other has

negative mass. The positive mass semiphoton is equivalent to a particle (matter) and the negative mass semiphoton is equivalent to an antiparticle (antimatter).
- CPM symmetry, as a way of comparing and contrasting matter and antimatter, is useful in defining the binary photon and its properties.
- A binary photon cannot occupy a single mathematical point, and, thus, by necessity, it must have extension.
- The gravitational force between the two conjugate particles provides the motive force that causes the negative mass semiphoton to chase the positive mass semiphoton unidirectionally in space and time. This is why light moves.
- As the carrier of the electromagnetic force, the binary photon must carry charge yet remain electrically neutral. To remain electrically neutral, the semiphotons have opposite charges. The charges of the semiphotons confine the speed of the center of gravity of the binary photon to the speed of light.
- The interactions between the semiphotons and the electric permittivity and magnetic permeability of the vacuum provide the frictional force necessary to constrain the velocity of the photon to the speed of light.
- The two semiphotons rotate with opposite senses around the axis of propagation in a manner that gives the binary photon one unit of angular momentum and a magnetic moment.
- The rotating semiphotons generate a transverse sinusoidal linearly polarized electric field and electric dipole moment.
- The rotation of the semiphotons also results in a three-dimensional circularly polarized magnetic field. The magnetic field is orthogonal to the electric field, and the two fields are a quadrature out of phase.
- The binary photon, with its electric dipole moment and orthogonal magnetic moment, is fit to be the gauge boson that carries the electromagnetic force.
- The wave functions for the rotational motion of the semiphotons in the transverse plane are solutions to the Schrödinger equation for a boson.
- The internal structure of the binary photon may provide the hidden variables or the variables that were hidden to the founders of quantum mechanics that call into question the fundamental nature of the uncertainty principle.
- The model of the binary photon describes the refraction of light while conserving energy and linear momentum. By having enough degrees of freedom to invoke intrinsic and contingent linear momenta, it also solves the long-standing paradox of the Minkowski and Abraham momenta.
- The model of the binary photon, unlike Maxwell's model of the electromagnetic field, satisfies the boundary conditions of Kirchhoff's diffraction equation and quantitatively describes the observed inflation due to diffraction.
- The model of the binary photon is useful in describing and explaining the Faraday effect.
- The model of the binary photon has been tested in that it is able to predict the double deflection of starlight in Euclidean space and Newtonian time as the general theory of relativity does for a mathematical point-like photon in warped space-time.
- By postulating that the Doppler effect expanded to the second order is fundamental, that the wavelength and frequency of light is relative, and that space and time are absolute, the relativity of simultaneity and the reason why a particle with a charge and/or magnetic moment cannot exceed the speed of light can be described and explained in terms of the binary photon moving through Euclidean space and Newtonian time. Thus, the postulate of an interdependent and relative space-time may be superfluous, and the foundational value of the special and general theories of relativity may be called into question by the binary photon.
- Lastly, the binary photon, with its time-varying electrical dipole and magnetic moments, is fit to initiate photochemical charge separation that leads to the photosynthetic fixation of carbon dioxide, the evolution of oxygen, and life as we know it.

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NOTES

1. When the mass is constant and invariant, the linear momentum (Leibniz's dead force or *vis mortua*) is equal to the derivative of the kinetic energy (Leibniz's living force or *vis viva*) with respect to velocity: $\frac{dKE}{dv} = \frac{d\frac{1}{2}mv^2}{dv} = mv$.
2. Historically, there has been contention concerning the relation between rotational motion and spin (Tomonaga 1997). According to Landau and Lifshitz (1958), "in quantum mechanics, some 'intrinsic' angular momentum must be ascribed to an elementary particle, regardless of its motion in space. This property of elementary particles is peculiar to quantum theory . . . , and hence is essentially incapable of a classical interpretation. In particular, it would be wholly meaningless to imagine the 'intrinsic' angular momentum of an elementary particle as being the result of its rotation about 'its own axis', if only because we cannot ascribe any finite dimensions to an elementary particle."
3. Sing to the tune of Mack the Knife (Pais 1986):

Und Herr Jordan	Und Herr Jordan
Nimmt Neutrinos	Takes neutrinos

Und daraus baut	And from those he
Er das Licht.	Builds the light.
Und sie fahren	And in pairs they
Stets in Paaren	Always travel
Ein Neutrino	One neutrino's
Sieht man nicht.	Out of sight.

4 Edwin Salpeter came to Cornell to work on the model of a binary photon with Hans Bethe (personal communication).

5 From the Latin word *conjugare* meaning yoked-together, united, or married and from the mathematical meaning of changing the sign from positive to negative or negative to positive.

6 In terms of the signs of charge, $\aleph q P_{matter} = -\aleph q P_{antimatter}$.

7 The vector division is performed with vectors that have direction in one-dimensional vector space where their magnitudes are described by real numbers and their directions are either parallel or antiparallel.

8 See Wayne (2012c) for the complete equations of symmetry that include a coefficient $\aleph$ that keeps track of the sign of the mass, where $\aleph$ is +1 for positive mass and −1 for negative mass. The electric fields generated by the charges cancel when ($\aleph$q) of the leading photon equals -($\aleph$q) of the trailing photon. In terms of the electric field, a negatively charged electron with negative mass is equivalent to a positively charged electron (positron) with positive mass, and in both cases, the electric field lines point away from the charge.

9 The center of gravity of a wave packet moves with a group velocity equal to the speed of light, whereas the particles formed by a wave packet do not all move at the same velocity (de Broglie 1924; French and Taylor 1978). The particles at the front of the wave packet that represent the short wavelengths move with a phase velocity greater than the speed of light, and the particles at the back of the wave packet that represent the long wavelengths move with a phase velocity less than the speed of light. Consequently, the wave packet spreads over time. In addition, according to quantum electrodynamics (QED), light has an amplitude to go faster and slower than the vacuum speed of light (Feynman 1985). In a binary photon, the velocities of the semiphotons are greater and less than the speed of light but are coupled in a harmonic oscillator so that the binary photon does not smear out while the center of gravity moves with a velocity equal to the speed of light. The longitudinal oscillation could explain the oscillation in radiation pressure (Einstein 1909b). Longitudinal polarization has been observed experimentally (Wang et al. 2008; Ye et al. 2013).

10 Note that I found that the second term in these equations postulated in the last edition of this handbook had to be modified from to $\frac{\lambda}{4}\left(1-\cos\left[2\pi\nu t\right]\right)$ to satisfy $\frac{2\lambda}{(2\pi)^2}\left(\cos^2\left[2\pi\nu t\right]\right)$ observed interference effects. All subsequent equations based on the change in this term have also been changed.

11 The spring constant is a one-dimensional property related to flexural stiffness (in N m^2), which is a two-dimensional property that is important for accessing the mechanical properties of the photosynthetic leaf blade and its supporting petiole (Niklas 1992).

12 As a reference, the spring constant of a binary photon of visible light is similar to the spring constants of the neutrophil microvilli and the elastic cytoplasm, which are 4×10^{-5} N/m (Shao et al. 1998; Hochmuth 2000) and 10^{-5} N/m (Guo et al. 2014), respectively.

13 Humphry Davy (1798) noted that "Light when perfectly freed from the attraction of other bodies & supplied with its necessary quantity of corpuscular motion is in an eminent state of elastic fluidity & then may be properly called Light."

14 This explains why the lateral resolution of optical systems, including those used for superresolution microscopy, is approximately three times greater than the axial resolution (Wayne 2014a; Lovier et al. 2020).

15 Although the final equation given in Wayne (2014b) is correct, there is a factor-of-two error in calculating the cross-sectional area of a photon that was canceled out by unnecessarily considering the polarization of the photon.

16 Anticlockwise and clockwise are defined as the binary photon approaches the observer. With anticlockwise rotation, the thumb of the right hand points in the direction of propagation, and the fingers of the right hand curl with the sense of rotation of the positive mass semiphoton or the combined mass binary photon. With clockwise rotation, the thumb of the left hand points in the direction of propagation, and the fingers of the left hand curl with the sense of rotation of the positive mass semiphoton or the combined mass binary photon.

17 Here, the expectation value is for the monochromatic binary photon that is described by a wave with a single characteristic wave number (k), not by a set of numbers in a matrix and not by an infinite number of waves, where each wave with its characteristic wave number (k) has a different amplitude.

18 According to the model of the binary photon, the angular momentum does not precess around the axis of propagation. The angular momentum has an eigenvalue along the axis of propagation only while the eigenvalues for the angular momentum vanish in the x-y plane. Note that for a given monochromatic binary photon, the angular momentum times the angular frequency of rotation is twice as large as the rotational kinetic energy and is equal to the negative of the transverse rotational potential energy.

19 The symbol q used here is equivalent to Einstein's ε.

20 Coulomb's law only applies to a mathematical point that cannot blow apart. Assuming that the semiphotons are not mathematical points and the circumference has width, we ask in the spirit of Henrí Poincaré, what stops the charge of a semiphoton from repelling itself and splitting into fragments? I assume that the charge is indivisible and that the mass of the charged particle provides the Poincaré force necessary to hold the charge within a small volume. As a result, the electrical potential decreases exponentially with distance in a manner analogous to the Yukawa potential (de Broglie 1962).

21 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 $+e$. I emphasize that the charge is a free parameter, and the choice made here is a limitation of the theory. Although 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.

22 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.

23 Note that when the curl of B points in the direction, the magnetic $\hat{x}$ field lines are in the yz plane. When the curl of

B points in the direction, the magnetic $\hat{y}$ field lines are in the xz plane. When the curl of B points in the direction, the magnetic $\hat{z}$ field lines are in the yx plane.

24 The direction of the linear momentum vector depends on the sign of the mass of the semiphoton and its velocity. Thus, oscillating semiphotons in a binary photon have linear momentum vectors that point in the same direction at any given time during the oscillation. The linear momentum increases as the semiphoton with positive mass moves in the direction of propagation and decreases as the semiphoton with positive mass moves antiparallel to the direction of propagation. In order for linear momentum to be conserved in a harmonic oscillator, the "kinetic" linear momentum must be transformed into "potential" linear momentum (the spring constant) jus~t as the kinetic energy is transformed into potential energy.

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