Classical Aspects of a Photon Wave Function Ψ.

Vivian Robinson
ETP Semra Pty Ltd
PO Box 100,
Canterbury, NSW, 2193
Email viv@universephysics.com

Abstract:

Through various observations light and other forms of electromagnetic radiation have displayed both wave and particle properties. This wave – particle duality of photons made it difficult to reconcile a structure or mathematical expression of a photon in which both properties co-exist in the one entity. Under the Einstein - de Broglie model of photons, this was designated by the wave function Ψ. This article suggests a physical structure and mathematical formalism of Ψ in which photons are both a particle and a wave.

Introduction:

Matter free space has properties that allow the passage of electric and magnetic fields through it. Those properties include the electric permittivity ε_0 and magnetic permeability μ_0. Maxwell (1865) determined that they allowed free space to transmit electromagnetic waves at speed, *c*, given by

$$\varepsilon_0 \mu_0 = 1/c^2 \qquad (1$$

Their accepted values are ε_0 = 8.85418.. x 10^{-12} Farad per metre (F/m) and μ_0 = 4π.10^{-7} Henry per metre (H/m) respectively.

Many experiments established that there were indeed waves of electromagnetic energy. They were experimentally verified by diffraction measurements, the generation of radio waves and others observations. They had a frequency υ and wavelength λ, related through

$$\upsilon\lambda = c = (\varepsilon_0 \mu_0)^{-1/2} \qquad (2$$

Experimentally *c* has been measured at 2.9979.. x 10^8 m/s.

Together the work of Planck (1900 A, B) and Einstein (1905 A) established that the waves were discrete packets of electromagnetic energy. Each packet, now called a photon, has energy *E* given by

$$E = h\upsilon \qquad (3$$

where *h* is Planck's constant, 6.62607.. x 10^{-34} m^2 kg/sec. They were experimentally verified by predictions of the shape of black body radiation and the photoelectric effect. They still retained their properties of wavelength and frequency.

Having established some of their properties, it is necessary to describe a structure of photons that can give them those and other properties. The starting point is ε_0 and μ_0. This presentation rejects the Born model and its associated Copenhagen convention that the photon is a point particle that has its various properties mathematically attached in a Hamiltonian (Chandrasekar, 2012). That enables the correct answer to be obtained mathematically. It does not give any insight into its structure. This representation starts with the Einstein (1905 A, B) – de Broglie (1957) model (Vigier, 1992; Evans and Vigier, 1994) that a photon can be described by a wave function Ψ by giving a mathematical and physical description to Ψ using classical concepts.

The Role of ε_0 and μ_0

It is hypothesised that the photon is a disturbance in ε_0 and μ_0. A disturbance in ε_0 will generate an electric field *E* in the direction of the disturbance. It will automatically generate a disturbance in μ_0, perpendicular to that direction, generating a magnetic field *B* perpendicular to *E*. That disturbance travels through space at speed *c*, perpendicular to both *E* and *B*, as given in equation 1.

As well as allowing electric and magnetic fields to travel through free space, ε_0 and μ_0 also resist and store the passage of electric and magnetic fields respectively. If they did not resist them, photons would travel infinitely fast with $c = \infty$. If they did not store them, the oscillation would not be able continue. Think of it as striking a bronze bell and a putty bell. A bronze bell will resonate at its designated frequencies as it stores and releases the energy of the strike. A putty bell cannot store energy and therefore will not resonate.

Free space does transmit oscillations in ε_0 and μ_0, indicating it can store energy. For a single photon the energy stored is given by Equation (3. When that energy impacts upon an object, something must happen to it. Experimentally it is observed that something is to impart momentum to the object. That momentum, p, has been observed to be

$$p = E / c = h\upsilon\sqrt{\varepsilon_0 \mu_0} \qquad (4$$

Photons have momentum. Momentum is a property of mass multiplied by velocity. From known properties of free space and observation, this gives photons a mass

$$m_p = E/c^2 = h\upsilon\varepsilon_0 \mu_0 \qquad (5$$

That photons have mass was well expressed by van der Mark and 't Hooft (2000). This model agrees with their work.

Equations (1 to (5 establish some fundamental properties of photons.

i They are transmitted through space by its properties of electric permittivity and magnetic permeability. At this stage no attempt is made to determine if the transmission is facilitated by ε_0 and μ_0, or if ε_0 and μ_0 change their values when the photon passes through their region of space.

ii A photon consists of an electric field *E* oscillating on one direction with an inseparable magnetic field *B* oscillating in unison perpendicular to it and the combination moving at *c* through space in the third direction perpendicular to both *E* and *B*. The oscillation is characterised by its frequency υ and wavelength λ, through Equation (2.

iii ε_0 and μ_0 can both allow and resist the passage of electromagnetic energy, as well as store it. This energy comes in discrete electromagnetic packets now called photons. Each photon has energy given by Equation (3.

iv Their energy gives them momentum, indicated in Equation (4.

v In turn their momentum gives them mass, given in Equation (5.

One of the properties of mass is its ability to resist the application of a force and hence energy. Energy is applied to ε_0 and μ_0. Combined they resist the passage of that energy. (If they didn't, the energy would travel with $c = \infty$. Although c is very rapid, it is not infinitely fast.) It is suggested this ability of ε_0 and μ_0 to resist the application of energy gives the property of mass to the disturbance. This gives the disturbance inertial mass with a velocity, giving it momentum. That momentum can be imparted to an object upon which the photon impinges, increasing its mass. This was one of Einstein's conclusions regarding photons (Einstein, 1905 B).

Physical and Mathematical Models of Ψ

Having established those fundamental properties of photons, it is necessary to establish the form of their wave function Ψ. In its simplest form, a photon is generated when energy *E* is imparted to ε_0 and μ_0, generating an oscillation of frequency υ and wavelength λ. The oscillation starts out from zero, building E to a maximum E_0 and *B* to a maximum B_0, each of one polarity, before decaying back to zero. The oscillation then repeats in the opposite polarity before again going back to zero. In its simplest form, that describes a single wavelength plane polarised photon, as illustrated in figure 1 A. An oblique presentation is used to give a 3-D effect. The fields rise to a maximum in one direction, reverse to zero before repeating their fields in the opposite direction and again reverting to zero. The whole oscillation travels on the central axis perpendicular to both fields at the speed of light *c*. The fields are strongest close to the axis. In the absence of other information it is suggested the electric field intensities E_d at distance *d* from the central travel axis are given by

$$E_d = E_o e^{-d/\lambda} \qquad (6$$

with an equivalent expression for the magnetic field. The intensities diminish with the inverse square of the distance from the travel axis.

This gives the wave function $\Psi_{1,p}$ for a single wavelength plane polarised photon as

$$\Psi_{1,p} = \begin{array}{l} E_{X,d}(z,t) = E_0.e^{-d/\lambda}.\sin(kz - \omega' t) \\ B_{Y,d}(z,t) = B_0.e^{-d/\lambda}.\sin(kz - \omega' t) \\ E_Y = B_X = 0 \end{array} \qquad (7$$

where k is the wave number and ω' is the phase velocity. Other expressions can be used. It should be noted that a positive field in one direction means a negative field in the opposite direction, giving the representation in figure 1 B. This also indicates that there is energy stored in ε_0 and μ_0. Energy is imparted to start the oscillation. As it travels, it rises to a maximum, goes back to zero and restarts in the opposite direction. That cannot happen unless that energy was stored in ε_0 and μ_0. As mentioned in Equations (4 and (5 above, this gives photons their properties of momentum and mass. When the oscillation is absorbed, its momentum is imparted to the absorbing particle, also altering its mass. Integrating over one cycle gives $E_x = E_y = B_x = B_y = 0$.

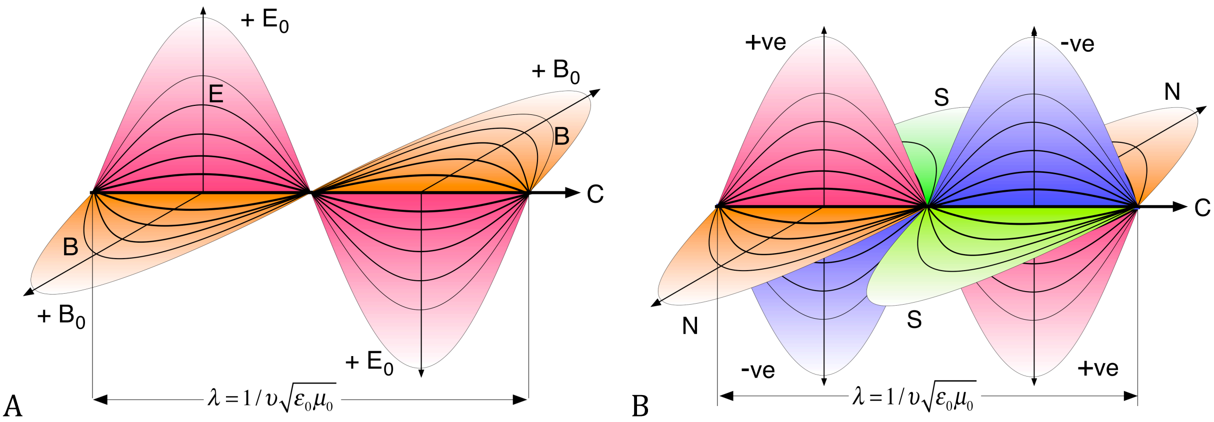

Figure 1 Oblique schematic illustrations of oscillations in the electric, *E*, and magnetic, *B*, fields associated with a single wavelength plane polarised photon.

Another interpretation of a single wavelength plane polarised photon is shown in figure 2. For the field to extend beyond the photon's travel axis, it must impart some of its energy into that surrounding space. The energy permeating that space is illustrated in figure 2. The arrows away from the travel axis represent "photons". They also provide a new direction for photon if the original photon's passage is partially blocked. In that manner, figure 2 illustrates the instantaneous strengths of the electric and magnetic fields. For this reason these "photons: are hereinafter referred to as field photons. They are the electric and magnetic fields associated with the photon. The length of each field arrow represents the energy contained within its segment, not its wavelength. The total of all of these arrows equals the energy $h\upsilon$ of the photon.

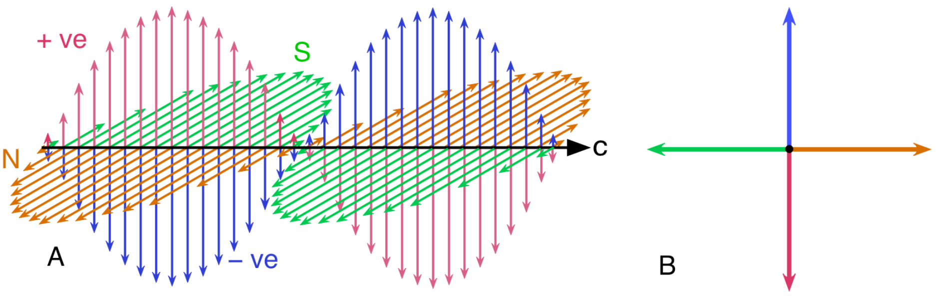

Figure 2 An illustration of a single wavelength plane polarised photon in which the electric and magnetic fields are schematically drawn as field photons. A illustrates an oblique side view. B illustrates the end view as seen from its direction of travel.

An electric charge placed near the photon's axis and in the electric field plane would experience an attraction towards and repulsion from the photon as it passes. Similarly, a magnetised object, monopole or otherwise, would experience the photon's magnetic field if it were similarly positioned near the photon's magnetic field plane. Using the quantum electrodynamics concept of force being due to photon exchange, as the first half of a photon passes a charged (or magnetised) particle, one of the field photons is exchanged with the particle, causing the attraction (or repulsion). As the second half of the photon passes, another field photon is exchanged, returning the photon to its original structure.

This simplistic representation requires two significant modifications. One is that photons are not single wavelengths. This is determined from time taken from when an atom starts to emit a photon until it is finished being $n\upsilon^{-1}$, where *n* is an integer greater than or equal to 1. At this stage the value of *n* appears to vary with different situations. It is often represented as being less than 10, somewhat as illustrated in figure 3.

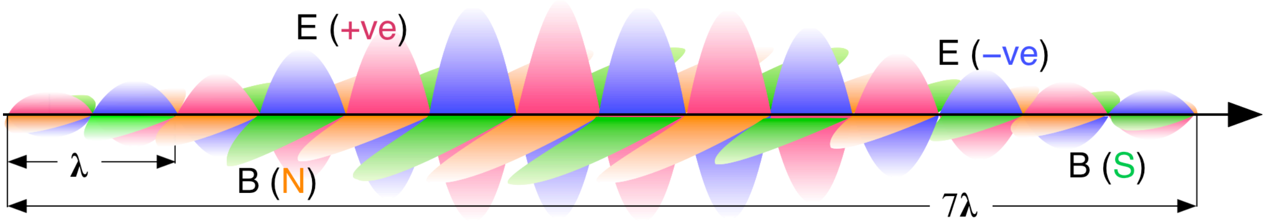

Figure 3 Schematic illustrations of oscillations in the electric, *E*, and magnetic, *B*, fields associated with a plane polarised photon consisting of seven wavelengths.

This gives the wave function $\Psi_{n,p}$ for a plane polarised photon of n oscillations as

$$\Psi_{1,p} = \begin{array}{l} E_{X,d}(z,t) = E_X^*.e^{-d/\lambda}.\sin(kz-\omega' t).\sin[(kz-\omega' t)/2n] \\ B_{Y,d}(z,t) = B_Y^*.e^{-d/\lambda}.\sin(kz-\omega' t).\sin[(kz-\omega' t)/2n] \\ E_Y^* = B_X^* = 0 \end{array} \qquad (8$$

where n is the number of oscillations in the photon and E_X^* and B_Y^* are the maximum field strength of the central oscillation. Figure 3 illustrates the situation where n = 7. Equations (8 and figure 3 illustrate the oscillation starts out small, building up to a maximum E_X^* and B_Y^* before decaying back to zero. While it is doing that, each oscillation builds up to before decaying back to zero again $n/2$ times as the photon passes each space point. Equations (8 are one equation that fulfils those requirements. Other equations are possible.

The second modification required is that many photons are spin polarised, not plane polarised. Spin polarised means their electric and magnetic fields rotate as the photon moves. For a single wavelength, this is illustrated in figures 4 B, which is based upon the representation in figure 2. Figure 4 A illustrates the positive field making three complete 360° revolutions over three wavelengths, with the field starting out from zero, rising to a maximum at $\lambda/4$ before going to zero again at $\lambda/2$ while rotating through 180°. This process is repeated once more to complete one wavelength. Because the polarity reverses after one wavelength, the same situation is repeated for the second half of the wavelength. This is repeated as the photon travels. Figure 4 B illustrates one wavelength for both fields of both polarities, the electric fields being opposite each, and both perpendicular to the magnetic fields, which are also opposite each other. Figure 4 C illustrates an end view of the assembly, showing that each of the field polarities is limited to one side of the photon. To illustrate the rotation of the fields, figures 4 A and 4 B were drawn with an oblique presentation. Drawn in a plain geometric presentation does not give any three dimensional or rotational appearance.

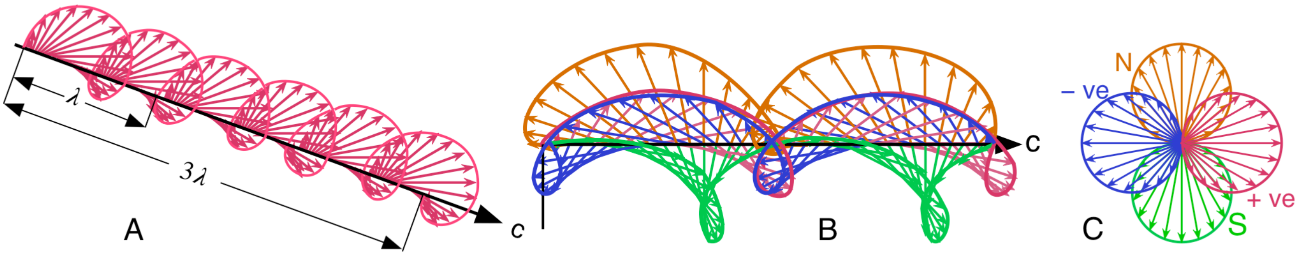

Figure 4 Oblique schematic illustrations of circularly polarised photon oscillations in the electric, E, and magnetic, B, fields, with those fields rotating 360° in one wavelength. A shows an isometric view of the positive electric field making six revolutions in three wavelengths. B shows the four fields in a horizontal isometric view of one wavelength. C shows the distribution of the fields when looking at the approaching photon.

This gives the wave function $\Psi_{1,c}$ for a single wavelength circularly polarised photon as

$$\Psi_{1,c} = \begin{array}{l} E_{X,d}(z,t) = E_0.e^{-d/\lambda}.\sin^2(kz-\omega t) \\ E_{Y,d}(z,t) = E_0.e^{-d/\lambda}.\sin(kz-\omega t)\cos(kz-\omega t) \\ B_{X,d}(z,t) = B_0.e^{-d/\lambda}.\sin(kz-\omega t)\cos(kz-\omega t) \\ B_{Y,d}(z,t) = B_0.e^{-d/\lambda}.\sin^2(kz-\omega t) \end{array} \qquad (9$$

where ω is the rotational velocity. Integrating Equations (9 over one complete cycle gives $E_X = {}^1\!/_2\, E_0$, $E_Y = 0$, $B_X = 0$ and $B_Y = {}^1\!/_2\, B_0$. This is reflected in figure 4 C. The vertical (Y) values of *E* and the horizontal (X) values of *B* cancel each other out.

Figure 4 B illustrates the situation involving a single wavelength circularly polarised photon. Just as plane polarised photons have multiple wavelengths per photon, so too do circularly polarised photons. Figure 5 illustrates the situation of a circularly polarised photon consisting of seven wavelengths. The photon rotates once every wavelength. Note that to show the rotation, the electric field is displayed in an oblique manner. The oblique presentation gives the appearance of the electric field below the axis, as mentioned earlier in relation to figure 4.

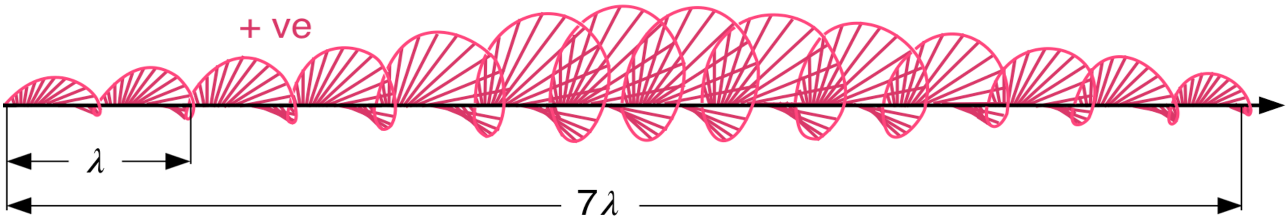

Figure 5 Oblique schematic illustrations of oscillations in the positive electric fields associated with a circularly polarised photon consisting of seven wavelengths.

This gives the wave function $\Psi_{n,c}$ for a circularly polarised photon of *n* cycles as

$$\Psi_{n,c} = \begin{array}{l} E_{X,d}(z,t) = E^*.e^{-d/\lambda}.\sin^2(kz-\omega t)\sin[(kz-\omega t)/2n] \\ E_{Y,d}(z,t) = E^*.e^{-d/\lambda}.\sin(kz-\omega t)\cos(kz-\omega t)\sin[(kz-\omega t)/2n] \\ B_{X,d}(z,t) = B^*.e^{-d/\lambda}.\sin(kz-\omega t)\cos(kz-\omega t)\sin[(kz-\omega t)/2n] \\ B_{Y,d}(z,t) = B^*.e^{-d/\lambda}.\sin^2(kz-\omega t)\sin[(kz-\omega t)/2n] \end{array} \qquad (10$$

where E^* and B^* are the maximum field strength of the central oscillation. Integrating Equations (10 over *n* wavelengths still gives $E_X = {}^1\!/_2\, E_0$, $E_Y = 0$, $B_X = 0$ and $B_Y = {}^1\!/_2\, B_0$. Drawing the remaining three fields, – ve, S and N would create further confusion and is not attempted. A circularly polarised photon of *n* wavelengths would start out with a small amplitude as its fields rotatedwhile going through their respective maxima and minima every half wavelength, build up to a maximum and decay back to zero. Each half wavelength would increase in magnitude, reaching the maximum intensity by the middle oscillations, decaying back to zero as the photon passes through that region of space.

As illustrated in the derivation of Equation (5, a photon has mass $m_p = E/c^2 = h\upsilon\varepsilon_0\mu_0$. That mass is distributed in the electromagnetic fields of the photon. Whether the photon is plane or circularly polarised, the mass is distributed equally around the central axis, see figures 2 B and 4 C. As such the photon's momentum can be regarded as centred on its axis of travel. Because the electromagnetic field is the space surrounding its axis, a circularly polarized photon will have angular momentum.

The measured spin of photons is $h/2\pi = \hbar$. Attributing spin as the angular momentum of the rotating electromagnetic field enables an average mass radius to be calculated. The moment of inertia *I* of a rotating object of mass m is given by $I = mr^2$, where *r* is the average radius of the rotating mass. Angular momentum, *L*, is given by $L = I\omega$, where ω is its angular velocity given by ω = *v/r*. Although the photon is travelling linearly at c, that may not necessarily equate to the equivalent rotational rate of the average centre of mass. Setting the rotational rate of the centre of mass at c and using $I\omega = h/2\pi$ gives

$$\frac{h\upsilon}{c^2}.r^2.\frac{c}{r} = \frac{h}{2\pi}$$

which, because $\lambda = c/\upsilon$ simplifies to

$$r = \frac{\lambda}{2\pi} \qquad (11$$

If the photon's centre of mass is rotating with an instantaneous linear velocity of c at an average distance of $\lambda/2\pi$ from its axis, it will have the observed angular momentum of $\hbar$. Other ratios of the instantaneous linear velocity of the centre of mass and its radius may be possible, which would still give the same angular momentum value of $\hbar$. The important feature here is that it is possible for a circularly polarised photon to have angular momentum of $\hbar$. This requires the centre of mass to spiral around the axis at $\sqrt{2}.c$. It does not violate the special relativity restriction that nothing can travel faster than c because it is still only moving in its travel direction at *c*.

It follows from the structure in figure 5 and Equations (10 that if the photon has *n* oscillations in its extent, each oscillation will be less extensive by an average of *n*, reducing the average angular momentum to $h/2\pi n$. There are *n* oscillations so $\hbar$ remains the total angular momentum. It means that the average centre of mass radius of rotation becomes

$$r = \frac{\lambda}{2\pi n} \qquad (11\ A$$

The spin of particles was originally measured as angular momentum. With the introduction of quantum mechanics treating particles as points, the name angular momentum was changed to spin because a point cannot have angular momentum. Spin became a quantum mechanical property with no classical physics analogy. It is easy to check if the angular momentum is the origin of spin. Circularly polarised photons will have spin and plane polarised photons will not have spin.

For a single oscillation plane polarized photon, the physical representations of the wave function $\Psi_{1,p}$ is given by figures 1 and 2. Equations 6 express its mathematical form. For a plane polarized photon of *n* oscillations rising to a maximum, the physical representations of $\Psi_{n,p}$ is given by figure 3. Equations 8 express its mathematical form. An oblique view of the physical representation of a single wavelength circularly polarised photon is given in figure 4 B. Figure 4 A schematically illustrates the passage of the positive electric field over three wavelengths. Figure 4 C illustrates that the polarities of the electric and magnetic fields of a circularly polarised photon will always be on one side of the photon. Its waveform $\Psi_{1,c}$ is given in Equations 9.

It is suggested the most common form of light photons is indicated in figure 5, which schematically illustrates an oblique view of the positive field of a circularly polarised photon as it rises to a maximum and decays back to zero in *n* (= 7) oscillations. Its waveform $\Psi_{n,c}$ is given in Equations 10. Giving a schematic representation of the negative field and the north and south magnetic poles on the same diagram presents something too difficult to interpret in a two dimensional drawing.

Two reasons suggest that $\Psi_{n,c}$, figure 5 and Equations 10, represent the most common form of light photon. The *n* oscillations are due to the time it takes for an electron to transition from one energy level to the lower energy level and thus emit the photon. The second is that, with the electron being a toroidal electromagnetic field composed of a rotating photon (Williamson and van der Mark, 1997; Robinson 2011), the rotating structure will, if emitted perpendicular to the electron's toroid or plane of rotation, impart a twist to the emitted photon's field, causing it rotate. It is this rotating field that imparts non linear polarisation to the light photon.

There are two other features to note about this model. One is that there does not appear to be any physical reason why the only rotational states are no rotation, that is plane polarised, and rotating through 360° in one wavelength, circularly polarised with spin $\hbar$. If a photon's electromagnetic field were to rotate through 360° in two wavelengths, it would have half the angular momentum and be a spin ½$\hbar$ photon. Similarly, if it rotated once per half wavelength, it would have an angular momentum of 2$\hbar$. It may well be possible to establish structures that enabled the different photon spin states to be achieved.

In the same manner, it is possible that the electric and magnetic fields may "borrow" energy from each other. E could increase to $E^{+\beta}$ for one (half) cycle. This requires B to decrease to $B^{-\beta*}$ for the second (half) cycle. This would require β^* to have such a value that

$$E^{+\beta} x B^{-\beta*} = E x B \qquad (12$$

This would result in an individual photon being elliptically polarised. Its other properties would remain the same.

Properties of Photons with Wave Function Ψ

Photon mass

The above has described a possible structure of photons. They exist because space has the property that it can transmit, store and resist the passage of electric and magnetic fields through it. These are inherent properties of electric permeability ε and magnetic permeability μ. For matter free space these are designated ε_0 and μ_0 respectively. The ability of ε_0 and μ_0 to facilitate the passage of an electromagnetic field enables a photon, to travel through space. Their ability to store energy means they can hold energy for the time period when that energy is passing through them, returning the energy to the photon once it has passed through. The ability of ε_0 and μ_0 to resist the passage of an electromagnetic field means that it requires energy to commence an oscillation. Once started the energy will continue through free space. If it were not resisted, the photon would travel infinitely fast. The energy required to start the oscillation is stored in the local ε_0 and μ_0 as the photon is passing through it. That energy is returned to the oscillation once it has passed through that region of ε_0 and μ_0.

That photons have mass has been well expressed by van der Mark and 't Hooft (2000). This model is not in conflict with their work. Through $p = E/c$, this energy $E = h\upsilon$ gives the photon its property of momentum *p*. A photon travelling between an emitter and absorber takes energy and momentum from the emitter and imparts them to the absorber (Einstein 1905 B). Dividing its momentum by its velocity gives the photon its mass $m_p = p/c = h\upsilon/c^2$.

That mass only exists when the photon is travelling at the speed of light through its travel medium. If that medium is free space it will travel at *c*. If it is a transparent medium such as glass where the electric permittivity and magnetic permeability are larger than ε_0 and μ_0, the photons will travel at a slower speed given by

$$c' = \sqrt{\varepsilon_0 \mu_0 / \varepsilon' \mu'} \qquad (13$$

where ε' and μ' are the electric permittivity and magnetic permeability of the medium respectively. The refractive index n_{ri} of the medium is given by

$$n_{ri} = c / c' \qquad (13\ A$$

As the photon moves from ε_0 to ε' and μ_0 to μ', it slows down from *c* to c / n_{ri}. It still retains its same frequency υ because it has the same energy *E* and Planck's constant *h* has not changed. Its wavelength is shortened. When the photon travels through the medium back to ε_0 and μ_0, conservation of energy *E* means that it resumes its travel at *c*. The higher values of ε' and μ' over ε_0 and μ_0 gives the impetus to the photon to increase its speed.

Photons of this structure have no rest mass unless they are in a medium in which $\varepsilon_0 \mu_0 = 0$. Then they cannot exist and have no mass, rest or otherwise. In all other situations a photon at rest is not producing any disturbance in ε_0 and μ_0. With no disturbance there is nothing to resist. The photon does not exist and has no mass. All experimental attempts to determine a rest mass for photons have produced results experimentally indistinguishable from zero (Olive et al., 2015). Photons have mass when travelling at *c* (or *c′*), They do not have a rest mass because they do not exist at rest.

Photon spin

This model makes firm predictions about photon spin. It defines spin as angular momentum with its centre of rotational mass distributed at distance *r* given in the derivation of Equations 11. As figures 1 to 5 illustrate, their electric and magnetic fields are distributed around their central travel axis. This means their mass is not located on their central travel axis, being distributed around it. From this it follows that plane polarised photons have no angular momentum and hence no spin. Circularly polarised photons will have angular momentum. The extent of the field and hence mass distribution of a photon to give the observed angular momentum of $\hbar$ is given by Equation (11 for a circularly polarised photon of a single wavelength. For a photon of *n* oscillations, the average radial distribution is given by Equation (11 A.

It is suggested photons emitted from electrons will be circularly polarised if the electron is a toroidal electromagnetic field (Williamson and van der Mark, 1997) or rotating photon (Robinson 2011). The rotating electromagnetic field will emit photons spinning circularly on their axis as they travel. It is this spinning that gives circularly polarised photons their $\hbar$ spin if they rotate through 360° every wavelength. Conservation of angular momentum requires that the rotating electron to change its ${}^1/_2\hbar$ spin from say up to down or plus to minus.

On the other hand, photons emitted from a linear source such as a radio transmitter will be plane polarised. In the same manner, photons emitted sideways when particles, such as when electrons have their directions changed in a magnetic field, will, in all probability, be plane polarised. They will be emitted by the electron without it having to change its spin direction.

Wave-Particle Duality

This proposed structure makes it easy to resolve their wave particle duality. Any one of the above figures shows that photons are electric and magnetic field oscillations in ε_0 and μ_0. In its simplest form these oscillations give photons wave properties in the same way oscillations in other media give wave properties in that media. This does not imply that ε_0 and μ_0 are a medium. They are a property of nothing. They have constant values in flat Minkowski space-time. Their properties in curved Minkowski space-time are not discussed here. Because neither ε_0 nor μ_0 are zero, they can transmit electromagnetic oscillations that carry momentum p, and energy $pc = h\upsilon$ through space. A photons' particle property comes from the limited extent of the electromagnetic field oscillations in ε_0 nor μ_0.

Photons having this structure are not single points. They have extended dimensions. Their lateral extent exceeds their wavelength, although with reduced intensity. It is impossible to define the position of a photon within those dimensions. Each position on a photon can interact through its field photons, see figure 2. These field photons generate the electromagnetic field associated with a photon. A photon is not a single point. Nor is it a line. It is a complex electromagnetic structure spread out over a distance of $n\lambda$ in its direction of travel, with a lateral extent greater than λ and a wave pattern imposed upon it with a length periodicity of λ time periodicity of υ^{-1}. This places limitations on a photon's location. It is never a single point and its position can never be accurately determined. This spread of a photon's electromagnetic field enables it to "experience" the world around it and react to different circumstances just like any other wave.

In this manner, the one structure can explain both the wave structure and particle structure of photons. Its limited extent causes it to behave like a particle, particularly for the emission of light and other electromagnetic radiation and its adsorption in the photo-electric effect. The oscillatory nature of its electromagnetic field is a wave and generates diffraction and interference patterns.

Both waves and particles reflect with the angle of incidence equal to the angle of reflection. If a photon encounters a surface with discontinuities over its wavelength, its wave properties override its particle properties. If a similar photon has sufficient energy that, when it is absorbed by an electron, it imparts its energy to that electron, its particle property of energy $E = h\upsilon$ change the energy of the electron. The photoelectric effect is its best known physical example. The change of colour of some materials when exposed to sunlight is one of the most frequently observed chemical effects of this phenomenon. A photon impart sufficient energy to an electron to either break a chemical bond responsible for one colour or form another bond responsible for a different colour.

Each portion of a photon has an electromagnetic component, its field photons, that have similar properties. This can have at least two physical effects. In the event that a photon encounters an obstruction, it can emerge from the obstruction with a change of direction. This is considered to be the origins of the diffraction and interference effects associated with waves. In diffraction, the photon encounters a single obstruction and its direction is altered depending upon how it encounters that obstruction. An individual photon will emerge from that obstruction in a slightly different direction. Multiple photons will emerge from it with a high probability that each will emerge in a slightly different direction. This gives the edge of a sharp object imaged from a single source a slightly diffuse appearance on a distant screen.

There is one significant difference between the wave properties of a photon and those associated with a medium, such as ripples on water. In the latter case, an obstruction blocks that portion of the wave impinging on it. Only the unobstructed portions of the wave will be transmitted to produce the diffraction or interference pattern. A photon partially impinging upon an obstruction will be either entirely absorbed or entirely transmitted. A photon encountering an edge obstruction will diffract around that obstruction if it is not absorbed. The probability of the photon being transmitted or absorbed by the edge depends upon how close the photon's axis is to the edge. The closer is the photon's travel axis to its edge, the greater the probability of it being refracted through a larger angle because its field is stronger.

When a photon impinges upon a single slit it will pass through it and diffract the same as any other wave. Not all photons impinging upon the slit will be transmitted. The smaller the slit's width, the greater will be the scattering because more photons will be closer to the edge, giving a greater average change to the direction of individual. The smaller slit also means a lower probability that a photon will be transmitted, giving a lower intensity.

The situation with photons passing through two slits can be more complicated. If the slits are too far apart for an individual photon to pass through both, a beam of light will only show two diffuse slit images on a screen on the other side. There are two possibilities when photons impinge upon slits that are close enough for each photon to pass through both slits. In the absence of other effects, it retains the same phase and recombines to produce the typical interference pattern.

Through which slit does the photon pass? Attempts have been made to determine this by monitoring one or both slits. Such monitoring requires an electric or magnetic monitor to be placed on one or both slits. This gives rise to the second possibility. If placed on one slit only, the monitoring device interacts with the photon's electromagnetic field, altering it. This alteration means the wave fronts through the two slits are no longer in phase. Like other waves out of phase, they will not form the diffraction pattern.

It is suggested this is the origins of the quantum effect, where the existence or otherwise of the diffraction pattern depends upon whether or not it is observed. The process of observing one and not the other causes that portion of the waveform passing through the monitored slit to be altered. The photon's field travels through both slits but the alteration in the waveform through the monitored slit means the two now no longer have the same phase. This prevents the waveform generating an interference pattern with itself. This gives the appearance that monitoring one slit causes the waveform to collapse. It does not mean that Ψ of Equations 10, or any of the other equations, has collapsed.

In this model, Ψ does not collapse because it is being observed. The photon's Ψ still passes through both slits. However its passage through the monitored slit alters its phase, making it out of phase with the other portion of Ψ passing through the unmonitored slit. Out of phase wave forms do not interfere. It is suggested that this classical model of Ψ can explain other quantum effects attributed to photons.

Conclusion

The above has presented a physical model and associated mathematical equations for four wave possible functions Ψ for photons, single oscillation and multiple oscillation plane and circularly polarised photons. The photons are propagated through the electric permittivity ε_0 and magnetic permeability μ_0 of free space, or their equivalent ε' and μ' in a medium. Under this model the wave and particle properties of the photon co-exist simultaneously in Ψ. Their wave properties are due to the undulations in ε_0 and μ_0. Their particle nature is due to their limited extent. In two slit interference studies, the photon passes through both slits, maintaining their phase and generating the interference fringes. Monitoring through which slit the photon passes, causes the phase through which the monitored slit portion of the photon's wave to change, putting the two portions of the wave out of phase, preventing interference from occurring. There is considerable scope to expand this study.

List of References:

Chandrasekar N (2012); "Quantum Mechanics of Photons", Advanced Studies of Theoretical Physics, **6**, pp 391-397

De Broglie L (1957); "Mechanique Ondulatoire du Photon", et Theorie Quantique des Champs 2nd Edition, (Gauthier – Villars) Paris

Einstein A. (1905A); "Uber der lichtelektrische Werkung; von P Lenard", Annalen der Physik, 17, pp 132 – 139

Einstein A. (1905B); "Ist die Trägheit eines Körpers von seinem Energiegrehalt Abhängig?", Annalen der Physik, **17**, pp 639 - 641

Evans M and Vigier J-P (1994); "The Enigmatic Photon, Volume 1: The Field $\mathbf{B}^{(3)}$", Fundamental Theories of Physics, Kluwer Academic Publishers, Dordrecht, Ch 3

Maxwell, JC (1865); "A Dynamical Theory of the Electromagnetic Field", Philosophical Transactions of the Royal Society London, **155**, pp 459-512

Olive KA, et al. (2015): http://pdg.lbl.gov/2015/listings/rpp2015-list-photon.pdf

Planck M (1900 A); "Auf das Gesetz der Energieverteilung im Normalspektrum" Annalen der Physik, **1**, pp 719-736

Planck M (1900 B); "Über eine Verbesesrung der Weinschen Spektralgleichung", Verhandlungen der Deutschen Physikalischen Gesellschaft, **2**, pp 202-204

Robinson VNE (2011); "A Proposal for the Structure and Properties of the Electron", Particle Physics Insights, **4**, pp 1-18

van der Mark MB and 't Hooft GW, (2000) "Light is Heavy", van Atom tot Quantum, Nederlandese Natuurkundige Vereninging, pp 1-6

Vigier J-P. (1992); "Present Experimental Status of the Einstein - de Broglie Theory of Light", Proc. I.S.Q.M. 1992 Workshop on Quantum Mechanics, Tokyo

Williamson JG and van der Mark MB (1997); "Is the electron a photon with toroidal topology?" Annales de la Foundation Louis de Broglie, **22**, pp 133-178