Modeling the photon

Charles Akins 2015

Abstract

The photon is studied, and a proposed semi-classical causal model is presented, which satisfies the requirements for spin, spin angular momentum, circular or planar polarization, and the ability to display orbital angular momentum. A cause for the superposition of spin states is presented which would result in the appearance of planar polarization and orbital angular momentum. An initial cursory model for the neutrino is also presented.

Basic Model:

We will start with a common helical model for the photon which allows for either right or left spin 1 photons, which complete one rotation in one wavelength and travel through the vacuum at the velocity c. We will call this the "twisted ribbon" model for the photon - ***Figure 1***.

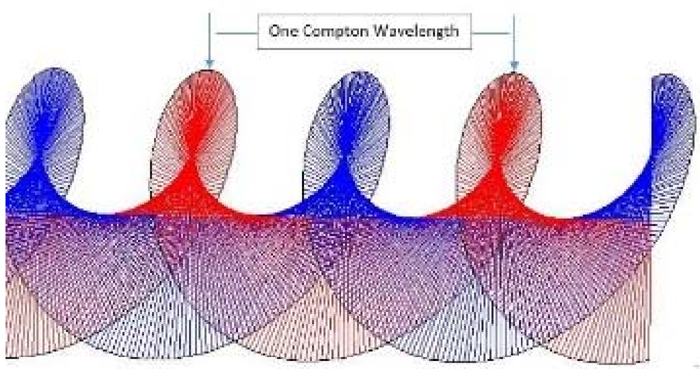

Figure 1

Since $E = hf$ where E is energy h is Planck's constant and f is frequency, and the photon is a spin 1 particle, then we know that the photon completes one revolution in the time it takes to travel one wavelength at the velocity c (represented by the blue arrows in *Figure 1*). We therefore know that the angle of the advancing wavefront is 45°. We arrive at this angle 45° by using a simple derivation which allows us to use units which geometrically represent the field vectors in units which coincide with the dimensions of the model. Since the wave circulates around the helix once in one wavelength, we know it travels one wavelength around the circumference while traveling one wavelength longitudinally. This leads us to geometrically represent the field amplitude vectors in units which correspond to the spatial dimensions of the photon and electron. It also appears that the actual effective RMS radius values of the field vectors fit the mechanism of these models and match the units chosen in this manner.

The photon is moving forward at the velocity c so we know the velocity of the wavefront is therefore $v_{wf} = c\sqrt{2}$.

$$v_{wf} = c\sqrt{2} = 4.239705600007665e + 08 \ m/S \quad (1)$$

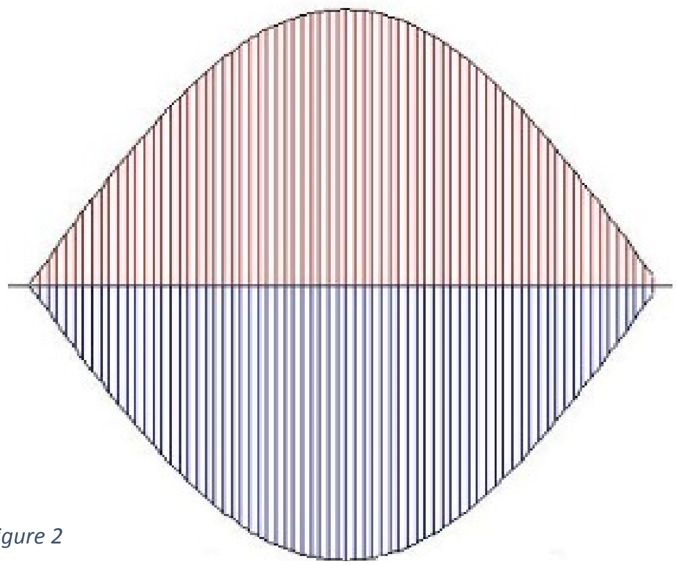

Figure 2

The helical model presented is preferred since energy remains conserved, and the spin characteristics of the photon are apparent.
The length of the photon we suggest and model here is one wavelength λ. The shape of the photon field is 180 degrees of a sine wave of the wavelength 2 λ. So that the untwisted E field ribbon of the photon appears similar to ***Figure 2***.

The photon used in our model is helical.

Figure 2 illustrates the shape of the untwisted photon ribbon model we will use. Our photon model is a helical wave so this flattened illustration would be twisted into a helix so that the envelope line drawing for the E and M fields appears as in ***Figure 3***.

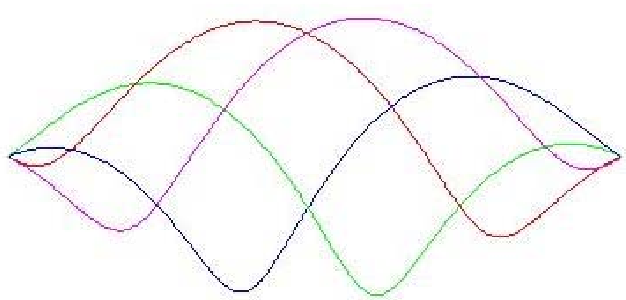

Figure 3

The dimensional RMS amplitude of the photon wave envelope is $r_p = \frac{\lambda}{2\pi}$ and since the envelope is sinusoidal, the peak amplitude is $A = \sqrt{2}\,\frac{\lambda}{2\pi}$.
If this model is correct then we can take a look at the meaning of Planck's constant h in this context. Again we refer to $E = hf$ which relates energy to frequency and find the wavelength: $\lambda = \frac{c}{f}$.
Planck's constant tells us how much energy is confined in a photon of a specific frequency and allows is to understand how the energy density of a photon determines the photon frequency. In other words the energy density is the underlying cause for the size and spin rate of the photon. So for a photon, the effective energy density is the total energy divided by the effective (RMS) area enclosed.
To calculate area we can write $Area = 2\pi^2 {r_p}^3$ so energy density is $D_E = \frac{E}{2\pi^2 {r_p}^3}$ expressed in Joules per meter^3.
By substitution we can write: $2\pi^2 {r_p}^3 D_E = hf$ or $h = \frac{2\pi^2 {r_p}^3 D_E}{f}$.

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Field density is related to energy density.
Our field strength (density) can be expressed as:

$$E_{fld} = \sqrt{\frac{6hf}{\pi\varepsilon_0\lambda^4}} = \sqrt{\frac{6E}{\pi\varepsilon_0\lambda^4}}$$

$$B_{fld} = \sqrt{\frac{6hf}{\pi\mu_0\lambda^4}} = \sqrt{\frac{6E}{\pi\mu_0\lambda^4}}$$

Energy in the E field is: $E_E = \frac{\pi\varepsilon_0\lambda^4 {E_{fld}}^2}{12}$ and energy in the B field is: $E_B = \frac{\pi\mu_0\lambda^4 {B_{fld}}^2}{12}$

The photon's longitudinal momentum is: $L = \frac{h}{\lambda}$

The photon spin force required against that momentum is: $F_{tw} = \frac{L\,c}{r_p} = \frac{hc}{r_p\lambda} = \frac{2\pi E^2}{c\,h}$

E field contribution to spin force: $F_{twe} = \frac{hc}{2r_p\lambda} = \frac{\pi E^2}{c\,h}$

B field contribution to spin force: $F_{twb} = \frac{hc}{2r_p\lambda} = \frac{\pi E^2}{c\,h}$

The spin force is half of the total EM field force of the photon: So the total force is: $F = \frac{4\pi E^2}{c\,h}$

The E field total force is: $F_e = \frac{2\pi E^2}{c\,h}$ and the total B force is: $F_m = \frac{2\pi E^2}{c\,h}$

Half of the force is expended on spin, and the other half is expended confining the EM field and creating the increased energy density and therefore field density, which in turn reduces the size of the photon and causes frequency to increase with energy increase.

The full extent of the photon's fields reach far beyond the effective RMS radius used for these calculations of forces. The E fields reach off to infinity getting weaker by the inverse of the square of the distance from the photon. The radial dimensions used here are the effective RMS values appropriate for these calculations, but in no way limit the ability of the photon to react to fields or charges at greater distances. However, in order for E fields to influence the photon, the influencing fields will have to be of a finite size, small enough to have a principal interaction region which is less than one wavelength of the photon. Otherwise the photon will appear immune to any E field influences, which are symmetrical and significantly larger than this, due to the spin of the photon. The interaction of these small finite external fields is the effect we call diffraction.

Photonic EM fields are quantized due to the mechanism we have described. Energy in the E and M fields causes them to have an attractive force and a twist force producing spin, confining and defining the EM wave packet so that it follows that *E=hf*.

Maxwell's equations give us insight into the longitudinal, and planar sinusoidal interactions of E and M waves but do not specifically address the spin interactions which contribute to photonic quantization. If a photon is spinning in the X, Y plane and we view it from the X, Z plane, we see sinusoidal amplitude variations in the waves. The action of the wave itself is moving in the Z axis and spinning. So when we measure the fields in any plane around Z we are only sensing a part of the total wave action. One effect of the confining forces and the resultant change in energy density is the interesting phenomenon that the spin angular momentum always remains at the value of $\hbar$ or $\frac{h}{2\pi}$. Without the confining forces, reducing the radius while the frequency is increased, this spin angular momentum value would change for photons at different energy levels. But the spin angular momentum remains constant, due to the effects the EM forces have on the photon as a particle.

Spin:

We can review that for a spin 1 particle we know that the EM wave completes one revolution in the time it takes to travel one wavelength at the velocity c. We therefore know the spin angle θ is 45°. We also know the spin can be either right or left. So there are two spin states or modes which are allowable. We can better understand why left or right spin states are allowed by looking at illustrations of the fields themselves.

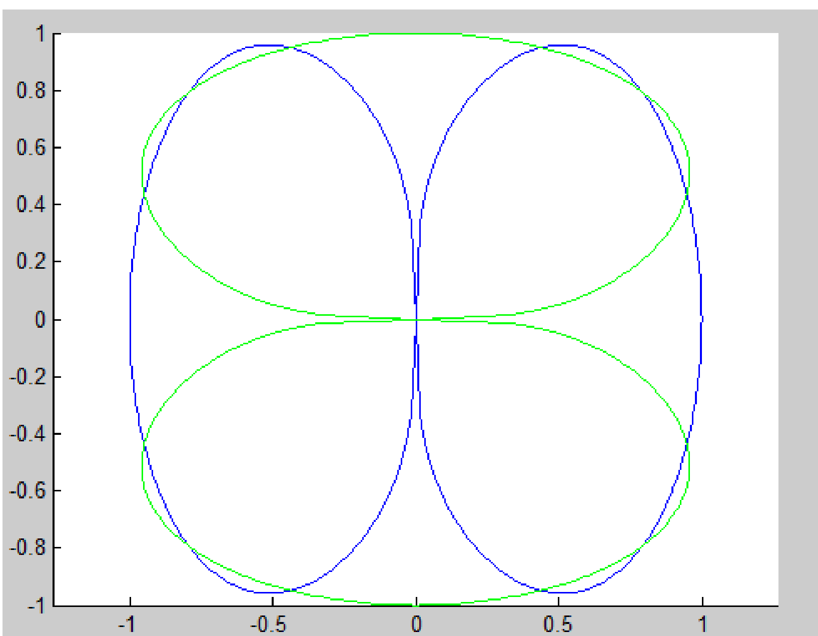

Figure 4

Let us look at an illustration of the photon field lines. We will view the photon from the front, so that its direction of travel is toward the reader, perpendicular to the plane of the page.

In ***Figure 4***, the blue lines model the electric field and the red lines the magnetic field. Now let's find the points of strongest interaction between these electric and magnetic fields.

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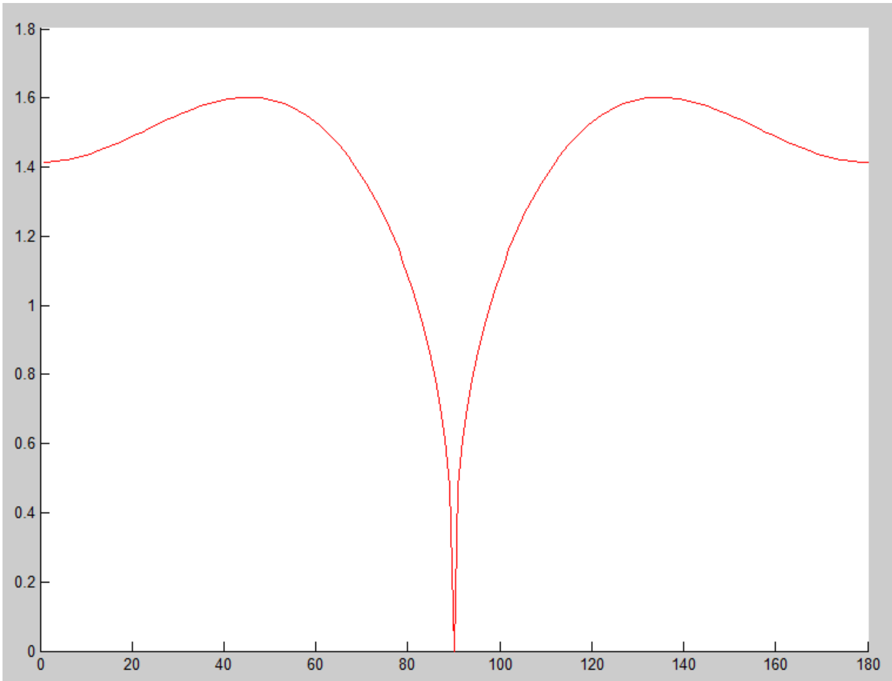

In ***Figure 5****,* which plots the sum of the fields per angle in degrees, we can see that the strongest interaction points are at 45 degrees (spin left), 135 degrees (spin right).

So when we superimpose these points of strongest interaction bewteen the E and M fields, on the field illustration, as shown in ***Figure 6*** in red lines, it becomes easier to understand that the photon may spin left or right, at a spin angle of 45 degrees, which gives us a spin 1 particle.

Figure 5

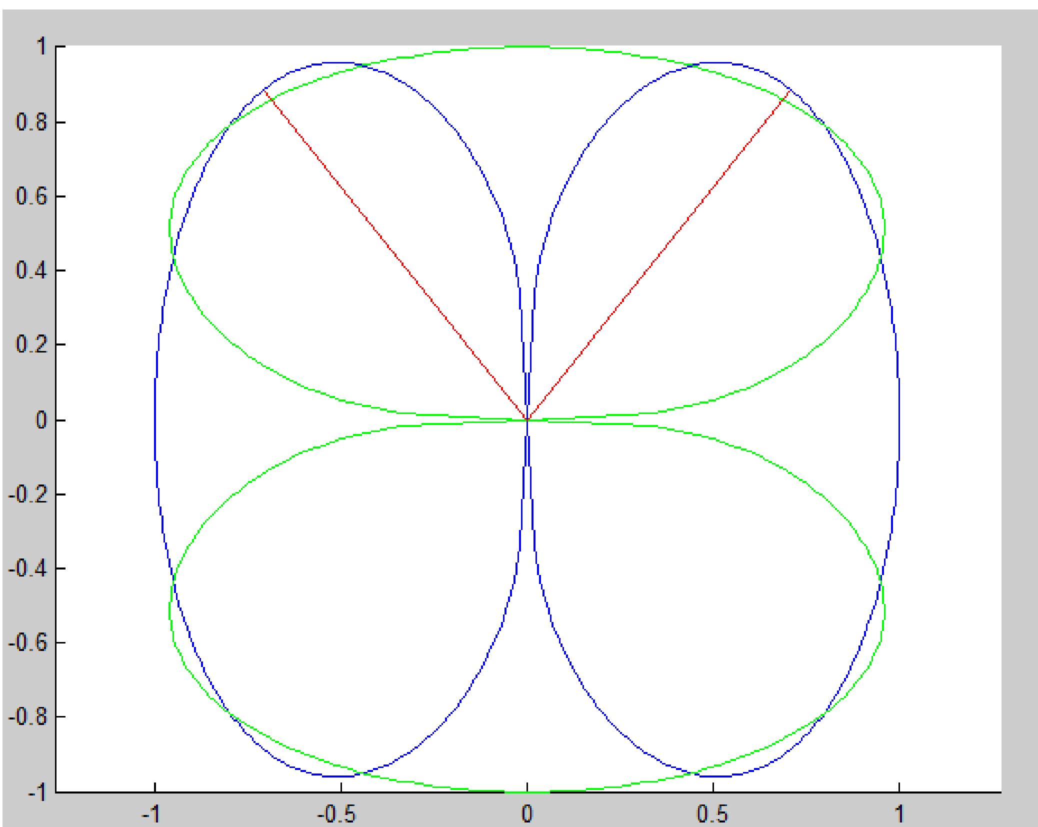

Figure 6

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Polarization and Orbital Angular Momentum:

The Standard Model depicts plane polarization as a superposition of spin states for the photon. We would like to suggest three possible, more causal, and perhaps more practical approaches, and then chose the one that best describes the known behavior of the photon.

1) First Suggestion: It is known that more than one EM wave can be at the same location in space and that the sum of the E fields is the E field we can measure. We might then propose that a plane polarized photon is comprised of a composite of two EM waves and is simply a right and a left circularly EM wave each with ½ the energy of the photon. The phase relationship of the two EM waves therefore determines the plane of polarization. After this step, it becomes easy to envision Orbital Angular Momentum OAM as well. A photon possessing OAM is simply two EM waves with a continually shifting phase difference which causes OAM in the sum of the fields. In order for this polarization and OAM hypothesis to work, the confinement forces and energy density of the photon will be due to the sum of the fields of the two EM waves comprising the photon. This sum will give us the correct photon energy density, and therefore the correct set of quantization parameters, like internal spin and frequency, related to energy. Possible Problems: It may be that the measured spin of the plane wave photon configuration suggested here would be zero.

2) Second Suggestion: Photon spin can be either right or left. If a single EM wave is able to regularly switch spin directions two times in one wavelength, it will appear to have a planar polarization, but the spin will still me measured as an instantaneous value of $\hbar$. If the switch in spin states occurs more or less often than exactly a factor of two in one wavelength, the photon would exhibit an effect similar to OAM as well. Possible Problems: If the spin state can toggle between right and left on a periodic basis we would need to find a cause and mechanism for this spin state switch which can comply with the strict requirements for plane polarization and/or orbital angular momentum.

3) Third suggestion: The wavefront of the photon does not have to spin. The planar EM wave may have an angular "spin-like" perpendicular flow momentum component. So that a momentum component exists perpendicular to the planar E field and perpendicular to the direction of travel. The direction of the spin momentum vector for the negative portion of the wave is opposite to the direction for the positive portion of the wave producing a spin momentum term. Due to the conservation of energy, the wavepacket envelope must remain intact and propagate as a unit. This approach allows us to dismiss the difficult notion of superposition of spin states. No "superposition" of spin states is required for such a

model to display planar polarization and to be measured as having a spin component. Orbital angular momentum might then be explained by adding a helical twist to the planar wave, which would in effect, more gradually shift the directions of the spin angular momentum component vectors, as these spin angular momentum vectors react with the fields of the particles they become incident upon. Possible Problems: This solution has all components, including the wavefront, propagating at the velocity c, which makes it more difficult to create an accurate model of an electron from a confined photon, unless we take some liberties with assigning a cause to an increased wavefront velocity of $v_{wf} = c\sqrt{2}$.

When the photon is analyzed in the manner expressed so far in this study, we see that forces are very likely present which are not accounted for in the Lorentz-Maxwell line of electromagnetic analysis. We can also see that important understandings of some of the force mechanisms are missing from the Maxwell field equations. We conclude that this requires an extension of the field equations to fully accommodate spin and to define the missing force components.

Once that is done, we would no longer need non-electromagnetic explanations, such as Poincare forces, for the definition of electromagnetic confinement of the photon, or other elementary particles. We suggest that the reason the required spin terms are missing, is that Maxwell's equations were formulated based on experimental data which was macroscopic, and principally a longitudinal analysis of the fields, and therefore does not contain the generally more microscopic and localized spin terms. We propose that spin does not exist without a cause, and that we cannot simply state that spin is a property of a particle, without inquiring about every detail which might cause this property.

Starting with the "naive" approach that spin of the photon is caused by a force which must be acting against the momentum of the EM wave, we have identified a force which precisely answers many questions about spin and particle confinement. We have identified casual means for the creation of particles from EM waves, for quantization, and superposition of spin states in photons.

Neutrinos:

As we attempt to define the spin cause for the photon we should leave open the possibility for a light-speed particle (or slightly faster) which has a spin frequency that is twice the spin frequency of the photon, when compared to the longitudinal wavelength, this particle is the neutrino. If a neutrino is a similar to a photon but with a spin angle θ of 45° and a radius of $r_n = \frac{\lambda}{4\pi}$ it would display an angular momentum of $\frac{1}{2}\hbar$ which is a half-integer spin. This would give us a ***very weakly interacting***, approximately light-speed particle, with half integer spin, and no charge. In fact it would interact, on average, significantly less than half as much as a photon of the same energy.

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Experimental evidence so far seems to indicate there are three flavors of neutrinos, and three antineutrinos. All the standard neutrino particles have a right-handed spin and all the antineutrinos have a left-handed spin. While it is possible that a neutrino-like particle could exist with any energy level, similar to the energy level range of photons, it may be that nature only has particle mechanisms to create the six different varieties we have discussed.

Photons and Mass:

We have argued that a photon is a confined EM wave. We have defined forces for confinement, and quantization, of the EM wave. The photon is however, **unlike mass carrying particles**, in that the photon can be viewed as being "**at rest"** when traveling through the vacuum at the velocity *c*. The implications are interesting when relating the photon to mass terms. For the photon, "at rest" is moving at the velocity c, and its rest mass is zero under these circumstances. But when a photon enters a diffractive media, the EM fields of the photon interact with the fields of the media. This effectively changes the permittivity and permeability that the EM wave in the photon experiences. This slows the photon to less than the velocity *c*. From a quantum mechanical perspective, we could then assign a relativistic mass term to the photon, but only when it is moving ***slower*** than the velocity *c*.

Future Work:

A more in-depth discussion of the neutrino models is in order, with forces, momentum, and interaction considerations, fully explored.

Creating the full set of field equations, by extending Maxwell's equations, is a next step in this line of research.

We can start the process of building a new, full set, of microscopic field equations, including spin terms, by starting with first principals and working from the ground up.

Starting with the analysis of the photon forces, we can create a means to convert energy to spin force, and photon confinement force. Both of these forces serve together as quantization forces.

Required Computations:

Given: Energy…

Frequency: $f = \frac{E}{h}$

Wavelength: $\lambda = \frac{c\,h}{E}$

Radius: $r_p = \frac{\lambda}{2\pi}$ or $r_e = \frac{\lambda}{4\pi}$

Longitudinal Momentum: $L = \frac{h}{\lambda} = \frac{hf}{c} = \frac{E}{c}$

Spin Angular Momentum: $S_{am} = E\ J\ c\ r_p$ or $S_{am} = h\ 2f\ J\ c\ r_e$ where J is a conversion factor from energy in Joules to mass in Kg.

Spin Force: $f_{spin} = \frac{r_p\ c}{L} = \frac{E}{r_p}$

Longitudinal Confinement Force: $f_{conf} = \frac{r_p\ c}{L} = \frac{E}{r_p}$

Given: Frequency…

Energy: $E = hf$

Wavelength: $\lambda = \frac{c}{f}$

Radius: $r_p = \frac{c}{2\pi f}$

Longitudinal Momentum: $L = \frac{hf}{c}$

Spin Angular Momentum: $S_{am} = h\ f\ J\ c\ r_p$ or $S_{am} = h\ 2f\ J\ c\ r_e$ where J is a conversion factor from energy in Joules to mass in Kg.

Spin Force: $f_{spin} = \frac{h\ f}{r_p}$

Longitudinal Confinement Force: $f_{conf} = \frac{h\ f}{r_p}$

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