The Photon

Visible light is just a small part of a much of a much broader spectrum of electromagnetic radiation, ranging from radio waves at one end through microwaves, visible light and X Rays to gamma rays at the other end of the spectrum. All of these different and seemingly diverse types of radiation are the various manifestations of just one type of particle, the photon.

Evidence for the existence of the photon first began to emerge at the end of the 19th Century when Max Planck showed that radiation from black bodies could only occur in discrete packets or quanta[i]. Initially Planck believed that this quantization effect was merely a quirk of the mathematics necessary in order to solve the equations; however, in his landmark 1905 paper on the photoelectric effect, Einstein showed conclusively that the quantization effect was real and this led Einstein to propose the existence of the photon as the particle of light.[ii] Further experimental evidence emerged when Compton demonstrated that X Rays are red shifted as they passed through a carbon target, a phenomenon now known as Compton Scattering and which could only happen as a result of collisions between discrete X Ray photons and electrons in the carbon. The term Photon derives from the Greek word φως (phos) meaning light and was first coined in 1926 by the American physical chemist Gilbert Lewis (1875-1946).

Light is known to travel through a vacuum at close to 300,000 km per second. It is this high speed which gives the photon its special significance. Photons are amongst the fastest moving objects in the universe and as a consequence they act as a sort of universal messenger, transporting information and energy throughout the universe. The known universe is only known because of the existence of light and more recently other forms of electromagnetic radiation. It is through our senses and sensors, acting on incident photons, that mankind knows about the very existence of the solar system, the stars, the planets and the galaxies. It is the fact that light travels (more or less) in straight lines which allows us to determine the position of objects in space and from this their motion. Based on an understanding of the photon and the atom, our knowledge extends beyond the mere presence and position of these objects, scientists are able to extrapolate to discover the chemistry and composition of these distant objects.

A complete understanding of the nature of the photon is therefore vital to an understanding of the universe itself. Conversely if the model of the photon is even slightly wrong, the effects, magnified by the vast distances and times involved in the universe, are likely to seriously distort our view of the way the universe works.

Current models of the photon are far from satisfactory with many gaps in our understanding and explanations of phenomena which are found wanting. One of the most widely known phenomena, that of refraction, is well described but lacks any proper explanation, polarisation too is well understood, but poorly explained and no serious consideration whatsoever appears to have been given to the question of the overall bandwidth of the photon.

Norman Graves, March 2012, Wokingham UK

The Bandwidth of the Photon

James Clerk Maxwell was the first person to connect light with other forms of electromagnetic radiation and in so doing he showed that the bandwidth of electromagnetic radiation extends beyond that of just light. Since then the spectrum has been broadened to include radio waves, microwaves, infra-red, visible light, ultra violet radiation, X-rays and gamma rays. Current thinking places no upper boundary on the frequency or energy of an individual photon.

Planck showed that the energy of a photon is proportional to its frequency; the higher the frequency, the higher the energy[iii]. If the upper frequency limit were truly boundless then we could expect to see evidence of photons with truly massive energies and yet such photons are not seen. This strongly suggests that there is a physical constraint on the maximum amount of energy that a single photon can carry and hence also that there must be a limit to the maximum frequency of the photon. This raises the obvious question as to where such a limit lies - and the less obvious one; as to what is the mechanism imposes such a limit.

In the classical model of the wave, the frequency of the wave, its wavelength and its velocity are related to one another by the simple equation:

$$F = \frac{v}{\lambda} \qquad \textbf{Equation 1}$$

Where F is the frequency in Hz, v the velocity and λ the wavelength

If the photon energy is limited in some way then there must come a point where this equation breaks down. The concept that the wavelength of the photon can extend all the way down to zero while the velocity of light remains constant for all wavelengths cannot hold true since to do so would imply that any such photons would have infinite energy.

This means that either there is a minimum wavelength for the photon; a lower limit of wavelength below which the photon cannot exist, or that the velocity of light is not constant, but varies with the frequency and that it would have to do so in such a way that the velocity has a value of zero at zero wavelength.

Wave Particle Duality

One of the problems that has beset physicists for at least the last three hundred years is the seemingly contradictory nature of the photon. On the one hand it can be seen as behaving like a wave while on the other hand it can be seen to have particle like properties. Despite the work of Planck, Einstein and Compton at the beginning of the 20th Century, debate has continued over the nature of the photon. The origins of this debate go back to at least the middle of the 17th century; to the time of Hooke and Newton. Hooke supported the view of Huygens and believed that light was a wave, while Newton was of the opinion that it was "corpuscular" in nature.

Since the middle of the 20^{th} century an uneasy truce has arisen in the form of the Wave Particle Duality. This seeks to suggest that light is simultaneously both a wave and a particle, but that it only manifests itself as one or the other when an observer is looking for that particular property.

In practical terms the wave particle duality does yield some positive results. It suggests that if one is looking for wave like properties such those associated with interference or diffraction; then it is appropriate to use the wave equations and the mathematics associated with wavelike phenomena. If on the other hand one is looking to examine the particle-like properties such as black body radiation then it is the mathematics of discrete phenomena and the associated equations that are more appropriate. Wave particle duality is in this sense a truism. If the photon did not obey wave equations then it could not have wavelike properties and if it did not obey the equations of discrete particles then it could not have particle like properties. The fact that it does both does not constitute an explanation of the nature of the photon but merely represents a statement of what is observable. Wave Particle Duality is a description and not an explanation. At best it is an uneasy compromise and at worst it has led to complacency among the physics community, who have more or less given up on looking into the nature of the photon in the mistaken belief that it is fully explained by the Wave Particle Duality.

The Nature of Mass

Current conventional wisdom is that all forms of mass are always positive[iv], however there is no real reason to suppose that this is always the case. It is perfectly feasible for mass to take on both positive and negative values in much the same way that electrical charge can be either positive or negative, although the situation is a little more complex when it comes to mass than it is with the case of electric charge.

Mass manifests itself in two quite distinct forms, on the one hand there is gravitational mass which is described by Newton's gravitation equation and deals with the static forces between objects which have mass. The equation relates the masses of the two objects to the distance between them.

$$F = \frac{G\, m_1\, m_2}{R^2}$$ **Equation 2**

The shape of the equation is similar to that governing the force due to electrical charge, which also obeys an inverse square law.

On the other hand there is inertial mass, which is described by Newton's second law: force equals mass times acceleration.

$$F = ma$$ **Equation 3**

Inertial mass is therefore a measure of the resistance of an object to acceleration, so the larger the inertial mass, the greater the force that is required to accelerate it at any given rate.

Inertial mass is a dynamic force and so depends on their being some sort of motion involved. The fact that the object is accelerating must mean that even if the object was not moving at one instant, then it certainly will be some small interval later. Because the object is moving, it must be subject to the effects of relativity. Normally these do not have any significant effect unless the velocity is close to that of light, but there is one important characteristic of relativity that applies no matter what the velocity.

The factor Gamma serves to modify the mass of a moving object and is defined as

$$\gamma = \frac{c}{\sqrt{c^2 - v^2}}$$ **Equation 4**

The presence of the square root in the equation means that Gamma can be taken to be either positive or negative.   So while gravitational mass may take on values which are either positive or negative, inertial mass, which is the product of gravitational mass and Gamma, can be thought of as always positive.

In practical terms this means that all objects tend to display inertia which acts as *resistance* to acceleration, irrespective of whether their mass is positive or negative. It means that Newton's second law should correctly be rewritten as:

$$F = |m|\, a$$ **Equation 5**

That is force equals the **absolute value of mass** times acceleration.

Gravitational mass can thus take on values which are either positive or negative, in much the same way as electric charge. It is possible to draw several other parallels between electric charge and gravitational mass. Both obey the inverse square law. Both are bipolar, that is can have positive or negative values. Both can be attractive or repulsive. Here though there is an important difference. In the case of electrostatic force, like poles repel one another and unlike poles attract. In the case of gravitational force like poles attract one another, while unlike poles repel one another. And the force of gravity is much weaker than the electrostatic force.

Antimatter is the mirror of matter. For each particle of matter there is an equivalent particle of antimatter. So for example the electron has an antimatter equivalent which is called the positron, the proton has an antiparticle equivalent called the antiproton and so on for each of the fundamental particles of nature. Interestingly however the photon has no antiparticle; its antiparticle equivalent is the photon, so in effect the photon is its own antiparticle.

The characteristics of antiparticles are diametrically opposed to their particle equivalents, so for example if a particle has positive charge, then its antiparticle will have negative charge of the same magnitude. Hitherto it has always been assumed that, since all matter is assumed to have positive mass, an antiparticle must also have positive mass, but there is no direct evidence to support this idea. No practical earthbound experiment can directly measure the gravitational mass of an antiparticle. All that can ever be measured is its inertial mass, and this is always positive - which in turn has led scientists to suppose that gravitational mass is also always positive. It is argued here that particles have positive gravitational mass and that antiparticles have negative gravitational mass, equal in magnitude but opposite in sign to their particle equivalent, while both types of particle display positive inertial mass. In this context therefore gravitational mass can be described as an additive quantum value. That is the overall mass of an object is the arithmetic sum of its constituents, be they matter or antimatter, and taking due account of the polarity of their respective masses.

It is the symmetry of the photon as both a particle and its own antiparticle, combined with the idea that mass is an additive quantum value that suggests that maybe the photon is not just a simple particle, but a composite or compound particle. So the photon can be thought of as being composed of a pair of objects, a particle and its antiparticle equivalent, and if gravitational mass is additive this then would account for it having zero overall mass.

The Photon as a Binary Particle

A wave possesses a number of defining characteristics including its amplitude, its frequency and its phase. When thinking of particles one thinks in terms of entities which have physical size, mass, inertia and momentum. In the absence of the ether it is difficult to conceive of a wave as having particle-like properties. Waves in general only exist by virtue of the medium through which they are transmitted. A particle on the other hand can exist in a vacuum and can be seen to display wave-like properties if its motion is circular.

A rotating particle has both frequency and phase and if it is moving through space it also has a wavelength. While frequency and phase can both be seen in a rotating object, the rotation of a homogeneous object in the absence of an ether-like substance or medium does not produce an observable effect. If we take the moon for example; the moon only displays phases because it is illuminated by the sun. In this case the sunlight acts as a sort of ether, illuminating the moon. For a particulate object to produce wavelike properties in the absence of an ether it must be self-contained and for this to happen both extremities of amplitude must be present within the object itself.

Light presents itself as an electromagnetic wave having positive and negative excursions but overall is electrically neutral. A particulate photon must therefore contain both positive and negatively charged elements, however when positive and negative electrical charges are co-located the charges cancel one another out. The two areas representing positive and negative electric charge within the photon must therefore be physically separated, leading to the idea that the photon is a composite binary system comprising particles which have symmetrically opposite characteristics.

Exactly the same considerations as apply to electric charge can be applied to mass. If gravitational mass is bipolar and can take on both positive and negative values then two such particles of opposite polarity would have gravitational mass which cancelled out. The compound particle formed by these two elements would have zero aggregate mass, it could be considered to be neutral with respect to mass.

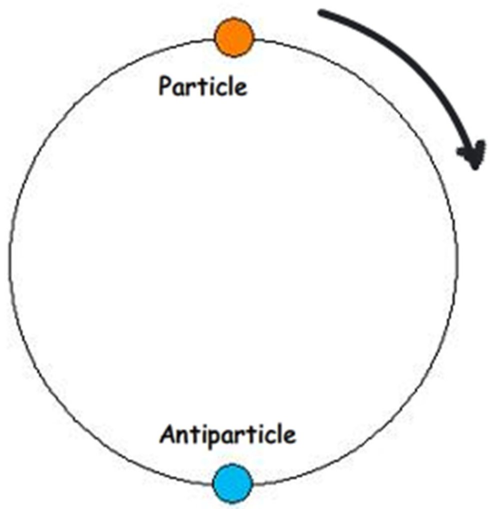

Figure 1 The Binary Photon

The model proposed for the photon is that of a binary system consisting of a pair of particles. They are physically separate, but locked in mutual orbit. The particles are of opposite polarities, one being a particle and the other its antiparticle equivalent. Where one has positive charge the other has negative charge and where one has positive mass the other has negative mass. The particles form a symmetrical pair with respect to one another and so overall the photon has zero charge and zero mass.

Polarization

Such a binary system provides a simple physical model for polarisation. The particles have equal but opposite mass and orbit around an axis which is perpendicular to, and which bisects the line joining them. It is the orientation of this axis with respect to the direction of travel that expresses the photon's polarization. If the axis of rotation is at right angles to the direction of travel, then the photon is plane polarized. If it is in line with the direction of travel, then it has circular polarization. Any other angle between the axis of rotation and the direction of travel results in elliptical polarization of varying degrees. Both plane polarized and elliptically polarized light can be further described by a second angle with respect to some arbitrary datum, leading to the idea of vertically polarized or horizontally polarized light.

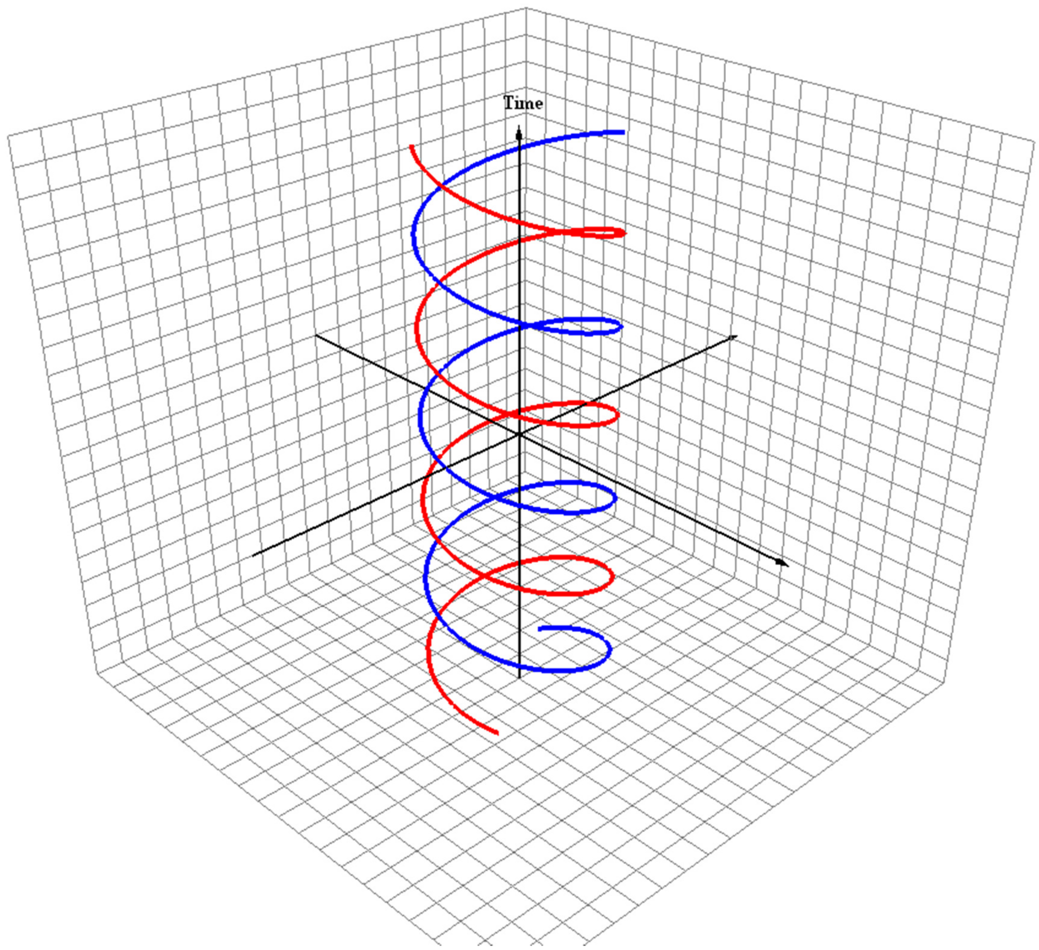

Figure 2 Trajectories of the Particles

The paths described by each of the two constituent particles as the photon travels through space are interlocking spirals; the exact form depending on the polarization. For circular polarized light the two paths will form a double helix. For plane polarized light the two particles follow paths which are overlapping cycloids, while for elliptically polarized light they follow overlapping compound helio-cycloids[1].

In all of these cases however the length of the path taken over a complete cycle or over a whole number of cycles is the same. Mathematically the simplest of these cases is that of the double helix. Considering just one of these particles and cutting the cylinder along which such a helix is inscribed and unrolling it, it is evident that the path length followed by each particle forms the hypotenuse of a right angled triangle, the other sides being the distance traveled over one cycle and the circumference as shown in Figure 7.3.

[1] Author's note - I can find no existing term to describe a compound curve which is part way between a helix and a cycloid and so I have adopted the term helio-cycloid to describe such a curve.

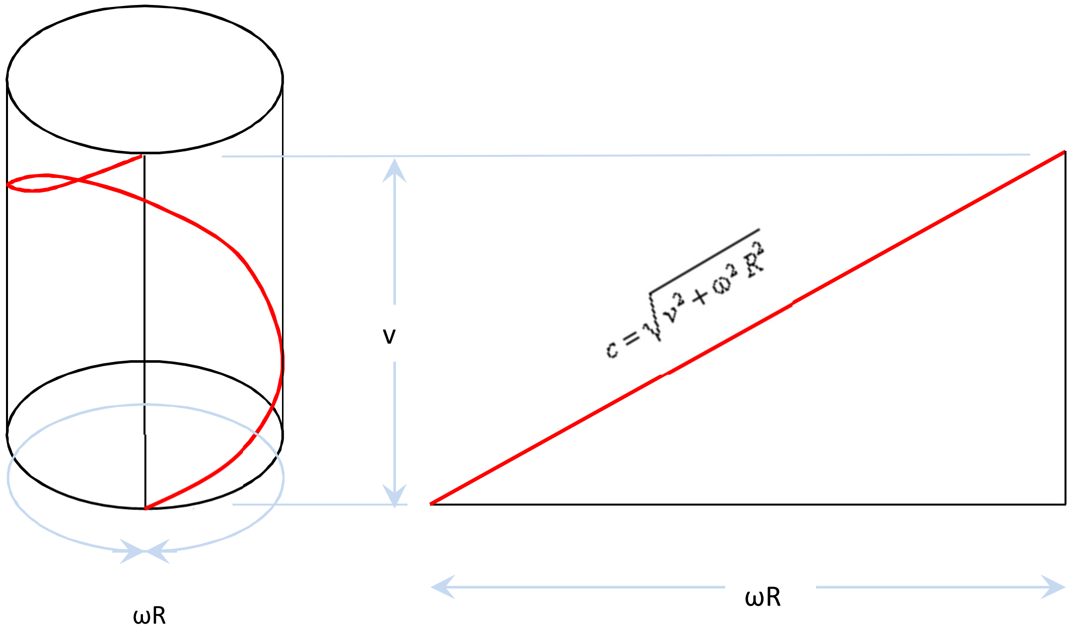

Figure 3 Velocity of Propagation

Nothing can travel faster than light, however for the purposes of this stage of the analysis the two particles can be considered as traveling along their respective paths at the speed of light.

The progress made in the direction of travel, the propagation velocity, must then always be slightly less than this and can be calculated using Pythagoras theorem as:

$$v = \sqrt{c^2 - \omega^2 r^2}$$ **Equation 6**

- Where v is the velocity of propagation, ω is the angular frequency and r is the radius of the photon.

From this it can be seen that v is always less than c and so it seems that not even light can travel at the 'speed of light[2]'!

Einstein showed in his Special Theory of Relativity that an object's mass varies with its speed in relation to an observer. When the observer and the object are both at rest in the same

[2] The term 'speed of light' is used to refer to c which is taken to be the limiting velocity beyond which nothing can travel. The term 'velocity of propagation' is used to describe the speed with which the photon propagates in its direction of travel and the term 'trajectory speed' is used to describe the speed of the constituent particles along their respective trajectories.

reference frame the object displays its so called Rest Mass. At any other speed with respect to the observer the object possesses a higher mass known as its Relativistic Mass[v]. In this case the speed of the particles is close to that of light where relativistic effects are significant. Relativistic Mass is always higher than the Rest Mass and is calculated by multiplying the Rest Mass by a factor γ (Gamma).

Gamma is related to the velocity of propagation, *v* and to the "speed of light", *c* and is given by the formula:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$ **Equation 7**

Which can be rearranged and rewritten as:

$$\gamma = \frac{c}{\sqrt{c^2 - v^2}}$$ **Equation 8**

This equation for Gamma and that for the velocity of propagation of the photon can be combined to eliminate the, as yet unknown, term for velocity, *v*. In the resulting combined equation the two c^2 terms under the square root cancel one another out, leaving a simple value for Gamma:

$$\gamma = \frac{c}{\sqrt{c^2 - \left(c^2 - \omega^2 r^2\right)}}$$ **Equation 9**

$$\gamma = \frac{c}{\sqrt{\omega^2 r^2}}$$ **Equation 10**

$$\gamma = \pm \frac{c}{\omega r}$$ **Equation 11**

And so the masses of the particles which form the photon each have a value:

$$m' = m_0 \gamma = \pm \frac{m_0 c}{\omega R}$$ **Equation 12**

Where m' is the Relativistic Mass of the particle and m_0 is the Rest Mass of the particle.

Having calculated the effective or relativistic masses of the two particles, it is now possible to calculate the energy of the photon. The energy possessed by a point object rotating in a circular orbit at a fixed radius from an axis is given by the standard textbook formula[vi]:

$$e = \frac{1}{2} I\omega^2$$ **Equation 13**

Where I is the Moment of Inertia and ω is the angular velocity. The moment of inertia of such a mass m rotating about an axis at a radius r is given by the standard textbook formula:

$$I = m\, r^2$$ **Equation 14**

Here however the photon is in a reference frame which is moving at velocity v, close to the speed of light, with respect to a stationary observer. The masses of the individual particles are increased due to the effects of relativity by factor Gamma and so:

$$I = \frac{m_0\, c}{r\omega} r^2$$ **Equation 15**

The r term and r^2 term cancel so this can be simplified to give:

$$I = \frac{m_0\, cr}{\omega}$$ **Equation 16**

This is the case for a single particle, here there are two particles in mutual orbit and diametrically opposed. One of the particles has positive gravitational mass and the other negative gravitational mass, however both have positive inertial mass so both contribute equally to the moment of inertia and so to the rotational energy of the system. On the other hand the aggregate mass is zero and so the photon has no direct kinetic energy.

The total energy therefore is:-

$$e = 2\,\frac{1}{2}\,\frac{m_0\, cr}{\omega}\,\omega^2$$ **Equation 17**

After cancellations this gives an equation for the energy of the photon as:

$$e = m_0\, rc\omega$$ **Equation 18**

Planck developed another equation for the energy of the photon expressed in terms of its angular frequency and a constant of proportionality.

$$e = \hbar\omega$$ **Equation 19**

Comparing these two equations, both of which represent the energy of the photon, it can be seen that:

$$\hbar = m_0 rc$$ **Equation 20**

Rearranging this equation can be transposed to give the value for the radius at which the particles orbit.

$$r = \frac{\hbar}{m_0 c}$$ **Equation 21**

Since $\hbar$, m_0 and c are all constant, it follows that r, the radius of the photon, is also constant. It also is evident that this must be true for all frequencies. The equation can be rewritten using a capital R to denote that this is the constant radius.

$$R = \frac{\hbar}{m_0 c}$$ **Equation 22**

Maximum Energy and Frequency

Having determined that the radius of the photon is constant for all frequencies it is possible to substitute this value back into the equation relating frequency to velocity and so determine the overall frequency characteristic of the photon.

$$v = \sqrt{c^2 - \omega^2 R^2}$$ **Equation 23**

With R as a constant it is evident that there is an upper limit to the frequency of the photon which is reached when the frequency is such that the term under the square root reaches zero. This condition occurs when $c = \omega R$ and so it is possible to define the upper limit for the frequency of the photon as

$$\omega_{\max} = \frac{c}{R}$$ **Equation 24**

Using Planck's equation it is also possible to calculate the maximum energy of a photon.

$$e_{\max} = \hbar\omega_{\max} = \hbar\frac{c}{R} = \hbar c\frac{m_0 c}{\hbar} = m_0 c^2$$ **Equation 25**

Where m_0 is the rest mass of one of the two particles which make up the photon

The Electron and the Positron

There are a number of possible candidate particle pairs which together might make up the photon and it is possible to draw up some general characteristics. The particle and its antiparticle must each carry electric charge; otherwise the photon itself would not have any of the electromagnetic properties with which it is commonly associated. Being a particle and its antiparticle equivalent means that they carry opposite charge and, since unlike charges attract, the particles are attracted towards one another. It is this attractive force, balanced against the centrifugal force that is responsible for binding them together.

Possible candidate particles include the electron and positron and the proton and antiproton. Both meet with these general characteristics, however there is some evidence to suggest that the electron and positron are the most likely particles involved, but before going into this it is first necessary to consider another phenomenon associated with light, namely refraction.

Refraction

Refraction was first quantified by Snell in the 17th Century[vii]. Newton and Huygens disagreed over the nature of refraction; Newton believed that light speeded up on entering a refractive medium, while Huygens believed that it slowed down. Both agreed that there was a change in speed. The dispute was finally resolved, long after both Newton and Huygens were dead when Foucault was able to measure the speed of light in water and show that light travels slower in materials with a higher refractive index.[viii]

Refraction presents physicists with an interesting problem: When light enters an optically dense refractive medium it slows down. However it does so without losing any energy. Similarly when light exits an optically dense refractive medium it speeds up and again it does so without gaining energy. This is contrary to most other situations where objects change velocity in response to changes in energy. A bullet, for example, fired from the air into water will slow down on entering the water. This is because the increase in friction causes the bullet to lose energy. However the obverse is not true, a bullet fired from under the water does not speed up on leaving the water and entering the air.

To date there has been no really satisfactory way to explain refraction. The currently held view is that the photons are absorbed and then re-emitted by the atoms of the refractive medium, but this is far from satisfactory. It fails to explain how and why the photons are absorbed or why they are absorbed for just such a particular time as to cause the photon to slow by the correct amount, nor indeed just how and why the photon should continue to travel in the same direction.

The binary photon on the other hand presents a very simple explanation. On entering a refractive medium the bond between the two particles which make up the photon is affected by the electrical properties of the medium in such a way as to stretch the bond. This increases the radius of the photon and has an effect on the velocity. No energy is lost during this process. On leaving the refractive medium, the situation is reversed, the radius reverts back to its original value, the photon speeds up and no energy is either lost or gained.

The energy of the photon is given earlier as:-

$$e = m_0 R c \omega \qquad \textbf{Equation 26}$$

An examination of the terms in this equation shows that m_0 is constant, energy and frequency both remain constant. It follows therefore that the product *Rc* must also be constant if energy is to be conserved. Any change in radius must be accompanied by a corresponding inverse change in speed.

On entering a refractive medium the photon slows and its radius increases slowing down the photon's velocity of propagation by increasing the radius at which its constituent particles orbit, thus preserving energy. On exiting the refractive medium its radius reduces; the velocity of propagation increases and the photon is seen to speed up again without a change in energy.

Particles and Pair Production

At very high frequencies, close to ω_{max}, this effect of refraction would cause the photon to decompose into its constituent particles. If a photon at a frequency close to ω_{max} enters a refractive medium then its radius will increase, but the radius multiplied by the frequency must remain less than the velocity of light *c*, otherwise the photon will disintegrate.

For the photon the velocity of propagation is given by the equation:

$$v = \sqrt{c^2 - \omega^2 R^2}$$ **Equation 27**

If ω is close to ω_{max} and *R* is increases to the point where ωR is greater than *c* then the term under the square root becomes negative; the situation is not viable and photon disintegrates. Its constituent particles then fly off in opposite directions. The precise speed at which they do so will depend on the energy of the incident photon.

Experimental evidence for just such a phenomenon exists and is well documented. It is referred to as Pair Production and occurs when a high energy photon in the presence of an atomic nucleus is seen to disappear to be replaced by an **electron** and a **positron** which fly off in opposite directions.

This is frequently cited as an example of energy transforming into matter in accordance with Einstein's equation, however a far more straightforward explanation is proposed here. Here it is argued that the photon is made up of an electron and a positron locked in mutual orbit and that Pair Production occurs when the photon decomposes into its constituent parts due to stresses caused by refraction in the vicinity of the atomic nucleus.

Having established that the particles which comprise the photon are a positron and an electron and using the known value for the rest mass of the electron substituting in the equation for the radius of the photon it is possible to calculate the value for *R* as:

$r = R = 3.86159 \times 10^{-13}$ **m** **Equation 28**

Substituting the value for the rest mass of the electron into the equation for the maximum energy of the photon shows e_{max} to be 511 KeV and the maximum frequency ω_{max} to be $7.7634*10^{20}$ **Radians/sec** or $1.2356*10^{20}$ **Hz**.

Plotting the velocity of propagation against frequency using a logarithmic frequency scale gives the characteristic shown in Figure 4

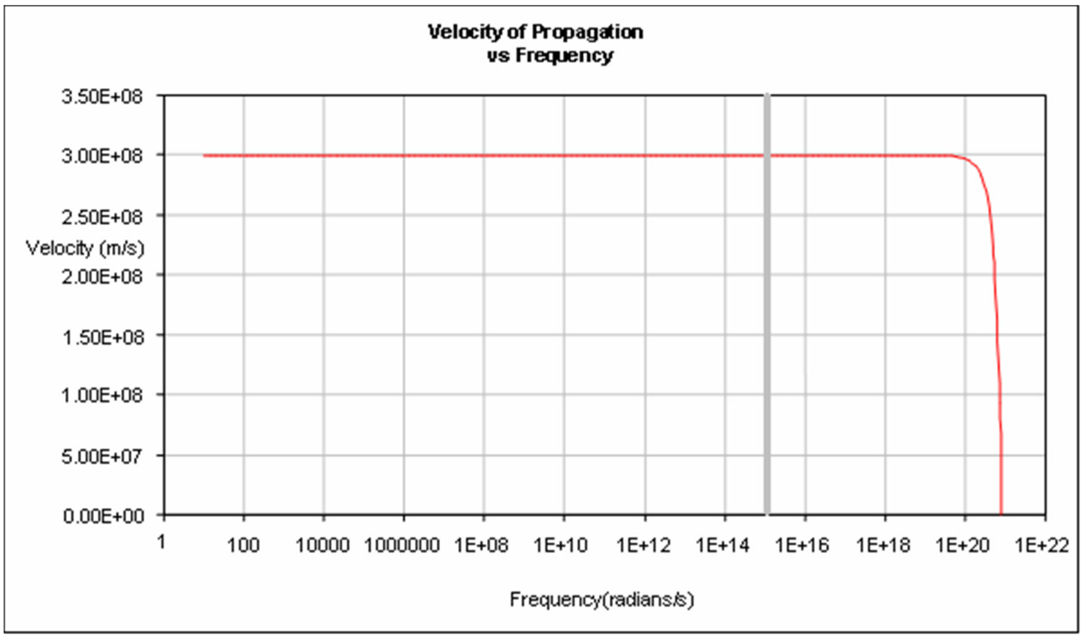

Figure 4 Velocity of Propagation vs Frequency

Overall, the characteristic is that of a low pass filter with velocity close to *c* over a range of frequencies extending from zero to approximately 10^{19} radians/sec, after which the velocity falls off very rapidly to zero.

Visible light occupies the frequency range from approximately $2.7*10^{15}$ to $4.7*10^{15}$ and is indicated by the dark band in Figure 7.4. Over the visible spectrum the velocity of propagation lies within 10^{-9} % of that of the speed of the particles along their trajectories. The velocity of propagation remains within 1% of this speed until the frequency is beyond 10^{20} and then falls off rapidly to a maximum frequency at $7.7634*10^{20}$ **rads/sec**.

Time Dilation and Frequency Multiplication

According to Einstein's Special Theory of Relativity time is a function of speed. Objects that move fast experience time at a slower rate than other objects moving more slowly. Two clocks, one running on earth and the other running on a spaceship orbiting the earth at high speed, will show different times. The moving clock will run slower than the stationary clock

- and it is not just the clock that runs slower, it is time itself, so an astronaut on the spaceship will be younger than his twin brother who stays behind on earth[ix]. The effect only becomes significant at speeds comparable to the speed of light. Time dilation is a function of velocity and is normally expressed in terms of Gamma[x], which has been shown in this case to be:

$$\gamma = \pm \frac{c}{\omega R}$$ **Equation 29**

But since

$$\omega_{max} = \frac{c}{R}$$ **Equation 30**

Gamma can also be rewritten as

$$\gamma = \frac{\omega_{max}}{\omega}$$ **Equation 31**

Time in the domain of the photon is slowed down. The extent by which it is slowed is the factor Gamma. An external observer sees the photon traveling with velocity v and frequency ω. An observer travelling in the domain of the photon will see the same number of cycles but in a domain where time is slowed. Such an observer will therefore see the frequency of the photon as being higher by a factor Gamma. An observer in the domain of any photon will see it as having a frequency of ω_{max}.

This answers an interesting question which was first posed by Einstein. Einstein once famously asked what it would be like to ride on a beam of light, here finally is the answer. To an observer riding on a beam of light, or at any rate travelling alongside and observing a photon, then no matter what the frequency or energy of the photon in some other domain, the observer will always see it as having the maximum possible frequency and energy.

All photons thus look the same when viewed from within their own reference frame. At maximum energy a photon has zero velocity of propagation. By arranging to move at the same velocity as a photon, an observer is entering the domain of the photon and in so doing he is adjusting his own clock in such a way that the photon frequency appears to be ω_{max} and its energy appears to be e_{max}.

This also provides another insight into why the photon must have constant radius for all frequencies. To any observer travelling alongside the photon and experiencing time at the same rate as the photon, all photons look alike. They all have the same frequency ω_{max}. The same photon seen by an observer in a different reference frame would have a different frequency and would of necessity be moving with respect to that reference frame. It would have to have the same orbital radius however, since this is unaffected by relativity. In a sense all photons are identical, the difference between photons of different frequency and of different energy comes down to a question of the reference frame from which they are observed and how this reference frame relates to that of the photon itself. This is also consistent with the characteristic of figure 4, which shows that a photon with zero velocity of propagation must have frequency $\omega_{max.}$

The idea that photons have a constant radius and are seen to have the same frequency within their own reference frame greatly simplifies the calculations involved in determining their internal dynamics. It simplifies the calculations concerning the forces that bind the constituent particles together, since it is now only necessary to consider the one domain of the photon itself.

Relativistic Velocity

Speed is calculated by dividing the distance traveled by the time taken and is normally regarded as being invariant with relativity. A moving observer and a stationary observer both agree on their relative speed but go about calculating it in different ways. For the stationary observer the speed is simply the distance between two points divided by the time taken to traverse that distance, with both time and distance measured at non relativistic speeds.

$$v = \frac{d}{t}$$ **Equation 32**

For the moving observer the distance traversed is compressed due to relativity however the time taken to traverse the distance is also reduced by the same factor Gamma.

$$v = \frac{D}{T} = \frac{d/\gamma}{t/\gamma} = \frac{d}{t}$$ **Equation 33**

There is however one circumstance where this may not be the case. For a stationary observer we normally require the use of two clocks in order to measure velocity; one at the point of departure and one at the point of arrival (at least conceptually). An object which is in orbit however returns once per cycle to its point of departure and so we can measure the orbital period of such an object with a single clock.

Thus for an object in orbit it is possible to define two velocity terms[3]. For the first of these the term Actual Velocity has been adopted and is simply the distance around the orbit divided by the orbital period as measured by the stationary observer. The second velocity term is the distance around the orbit as measured by the moving observer divided by the time as measured by the stationary observer. Such a velocity term straddles or couples the two domains and so could sensibly be called the “Coupling Velocity” or possibly the Relativistic Velocity. A simple calculation shows that the Coupling Velocity is related to the Actual Velocity by the same factor Gamma an hence

[3] In fact it is possible to define a further two velocity terms, the relativistic distance divided by the relativistic time and the actual distance divided by the relativistic time. The first of these is the invariant velocity discussed earlier. As a stationary observer we do not have any direct access to the moving clock and so these velocities can only be described mathematically and appear to have no physical significance.

$$v_c = \frac{d}{T} = \frac{d}{t\gamma} = \frac{v}{\gamma}$$ **Equation 34**

Thus far Coupling Velocity is only a definition and if it has ever been considered before it has been assumed to have no physical significance. However there is one set of circumstances where such a velocity term may indeed be justifiable and that is when dealing the orbital velocity. It is considered meaningful to use this Coupling Velocity term when dealing with orbital velocities such as occur when calculating angular momentum centripetal and centrifugal force.

Binding Forces

Viewed from within this inertial frame, the photon appears as a positron/electron pair in mutual circular orbit at a frequency ω_{max} and at radius R.

There are four candidate forces which could act on the electron and positron and so must be considered and either accommodated or eliminated:-

- Gravity
- Electromagnetic force
- Electrostatic force
- Centrifugal force

Gravitational force

Given that the particles are of opposite mass polarity then the gravitational force, consistent with the idea that gravitational mass is bipolar, will be repulsive. To an observer in the domain of the photon, the particles will appear to be moving around their orbital paths at near light speed. This means that their mass will be affected by relativity, increasing the magnitude of the mass by a factor Gamma. However, despite this, it will be shown that the magnitude of the gravitational force is insignificant compared to other forces and so can be ignored. The magnitude of the gravitational force is given by the expression:

$$F_g = \frac{G\, m_0^2\, \gamma^2}{4R^2}$$ **Equation 35**

- Where G is the gravitational constant.

Electromagnetic force

Consider first the case of the electron; it generates a magnetic field due to its motion. However the strength of this magnetic field at the opposite side of the orbit, where the positron is located, remains constant. The positron thus finds itself in a magnetic field where the magnetic field strength is constant. Since there is no movement of a charged particle with respect to the magnetic field there is no resulting force. The same consideration applies to the positron field and the electron. Overall therefore there is no magnetic force acting on the particles.

Electrostatic force

The positron and electron have opposite electrical charge, so the electrostatic force is attractive. The magnitude of the electrostatic force acting on each particle is given by:-

$$F_e = \frac{Kq^2}{4R^2}$$ **Equation 36**

Where *K* is the electrostatic force constant, *q* is the charge on the electron (or positron) and *R* is the radius of the orbit. Electrostatic charge is not affected by relativity.

Centrifugal force

For a simple non-relativistic case, the centrifugal force is given by:-

$$F = \frac{mv^2}{r}$$ **Equation 37**

- Where *m* is the mass, *v* the tangential velocity and *r* the radius. Here, however, the velocity is sufficiently close to the speed of light, *c*, that it is necessary to take into account the effects of relativity.

Relativity will affect both the mass term and the velocity term. This latter because it is argued here that velocity terms involved in equations relating to orbital motion are affected by relativity.

Firstly this means that the mass will increase by a factor γ where:

$$\gamma = \frac{c}{\sqrt{c^2 - v_t^2}}$$ **Equation 38**

The term v_t is the tangential velocity or trajectory speed of the particle.

The tangential velocity v_t of the electron/positron is very close to *c*, which means that the distance traveled by each particle is compressed by a factor Gamma and it is this velocity $\frac{v_t}{\gamma}$ that contributes to the centrifugal force. However since v_t is extremely close to *c* the centrifugal force is given by:

$$F_c = \frac{(m_0\gamma)}{R}\left(\frac{c}{\gamma}\right)^2$$ **Equation 39**

Which after cancelations simplifies to give:

$$F_c = \frac{m_0 c^2}{R\gamma}$$ **Equation 40**

For the photon to be stable these all of these forces must be in balance. Ignoring gravity as being insignificant, ignoring magnetic forces as being nonexistent and equating the centrifugal and electrostatic forces gives the equation:

$$\frac{K q^2}{4 R^2} = \frac{m_0 c^2}{R\gamma}$$ **Equation 41**

Which can be simplified to give;

$$\frac{K q^2}{m_0 R c^2} = \frac{4}{\gamma}$$ **Equation 42**

The orbital radius of the particles has already been shown to be given by:

$$R = \frac{\hbar}{m_0 c}$$ **Equation 43**

Substituting this value into the denominator of the equation for force balance, the equation can be rewritten as:

$$\frac{K q^2}{\hbar c} = \frac{4}{\gamma}$$ **Equation 44**

The left hand side of this equation is the Fine Structure Constant, α which has a value of

$$\alpha = 7.2973525376 \times 10^{-3}$$ **Equation 45**

The value of Gamma can therefore be calculated as γ = 548.143998716.

From this it is possible to calculate the tangential or orbital velocity of the electron in the domain of the photon using the equation;

$$\gamma = \frac{c}{\sqrt{c^2 - v_t^2}}$$ **Equation 46**

Rearranging this gives a value for v_t;

$$v_t = c^2 \sqrt{\frac{\gamma^1 - 1}{\gamma^2}}$$ **Equation 47**

Substituting the numerical value of γ gives the tangential velocity as:

$$v_t = 0.999998336\, c$$ **Equation 48**

That is 99.9998336% of the speed of light.

Just to confirm that gravity does not seriously contribute to the forces binding the photon together, it is possible to take this value for Gamma and calculate the gravitational force. The result of this calculation shows the gravitational force to be $7.26*10^{-38}$ times smaller than either the centrifugal or the electrical force and so justifies the decision to ignore gravity as being insignificant.

Angular momentum

It was John Nicholson who first observed that Planck's constant has the units of angular momentum. He proposed therefore that Planck's constant was the angular momentum of the electron orbiting the hydrogen nucleus. Bohr then used this to calculate the radius and velocity of the electron in the hydrogen atom. Bohr however took no account of the effects of relativity. Here it is assumed that both the electron and the positron are affected by relativity and that they are both orbiting at near light speed.

If Nicholson was right about Planck's constant being a measure of the angular momentum of the orbiting electron and by implication that of the orbiting positron then, using Relativistic Velocity, Planck's constant is seen as a limiting value for angular momentum. The effect would not be significant at low velocities, but if the electron and positron were orbiting at close to light speed then –

$$\hbar = \left(m_0 \gamma\right) r \left(\frac{v}{\gamma}\right)$$ **Equation 49**

Both the mass term and the velocity term are affected by relativity. The mass term because mass increases by factor Gamma as the object's velocity approaches the speed of light and in this case the velocity term is affected because we are dealing with an object in orbit and it is therefore appropriate to use Coupling Velocity which is the Actual Velocity divided by Gamma.

The two Gamma terms will cancel. The terms for rest mass, Planck's constant and the speed of light are all constants, which must therefore mean that the orbital radius is also a constant.

Hence

$$\hbar = m_0 R c$$ **Equation 50**

This is in agreement with Equation 22 and so two different methods of calculating the orbital radius each return the same result.

The structure of the photon

The introduction of two very simple and plausible postulates, that certain orbital velocity terms are themselves affected by relativity and that gravitational mass is bipolar and adds arithmetically; provide the basis for a model of the photon in which the photon has material form. The photon is seen as a composite binary system, comprising two particles locked together in mutual orbit. They are held together by the balance of electrostatic and centrifugal forces. The effect of special relativity on the velocity of the particles serves to constrain the orbital radius to have a fixed value for all frequencies.

The effect of these two simple postulates is wide ranging, beyond simply providing an explanation for the photon.

Particles are seen to be fundamental constituents of matter. These are objectively real point particles having mass and deterministic position and velocity in the sense that Einstein understood rather than Bohr's subjectively real wave particles. The photon is made up of a pair of such real particles and so takes on a material form.

Transformations of matter into energy can be described as a process involving the combination of matter with antimatter to form photons which have no mass but contain energy. The reverse process, the transformation of energy into matter involves the decomposition of a photon into its constituent particles.

The model shows the wave nature of the photon, hitherto enshrined in the mysterious wave particle duality, to be simply associated with the orbital motions of the constituent particles of the photon.

The model sheds light on the nature of the hitherto mysterious fine structure constant which is seen as simply the ratio of two velocities or two lengths.

The model extends the scope of a single set of physical laws from the scale of the atom and beyond at approximately 10^{-20} m all the way to the scale of the universe at approximately 10^{20} m.

The implications of this physical model of the photon are far reaching. It affects our view not only of the photon itself but of the entire universe. If antimatter is possessed of negative gravitational mass and if the photon is symmetrical with respect to mass and provides our only view of distant stars and galaxies then it opens up the possibility that entire star systems are made out of antimatter. Such star systems would be gravitationally repulsive to similar systems composed of matter. In such a universe it is not necessary to invent concepts such as dark energy or dark matter.

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