Resolving the Wave/Particle Duality Conundrum of the Photon

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Abstract
Selectively considering light as being either a wave or a particle (the photon) in order to explain different behaviours lacks scientific robustness. For those behaviours currently explained by a wave-like nature, this paper considers what the characteristics of the photon must be in order for it to exhibit each of these behaviours. Effectively, deducing the physical parameters of a photon from an analysis of observations. The basic thesis is that the photon is a 'particle' of energy in the form of a quantum of space-time distortion, akin to a quantized piece of a gravitational wave. How this gives the photon apparent 'momentum', why the photon cannot be an EM wave and related issues are suggested below. Alternative explanations are given for behaviours such as diffraction, refraction, partial reflection, interference (double slit and interferometry) and polarisation. It is hoped that these alternative explanations can be developed to the point where wave/particle duality is no longer considered to be a valid concept.

Keywords: photon, duality, diffraction, partial reflection, refraction, interference, polarisation, double slit, electron, least action, gravity.

Contents:

1. Introduction

The ‘wave particle duality’ of the photon has been used as a concept to explain different observed behaviours of the photon. Einstein stated in his paper of 1935, [AE_Dlty]: “*One is thus led to conclude that the description of reality as given by a wave function is not complete*.” Perhaps by treating the photon completely and only as a discrete entity, specifically as a ‘packet’ of energy, the “*description of reality*” could become a bit nearer to being “*complete*”.

1.1 Maxwell’s Inference: The original concept of light as being specifically an electromagnetic wave seems to have come from James Maxwell. According to Richard Feynman, [RF_Lctr2_18] section 18.5, Maxwell calculated the speed of propagation of electric and magnetic fields from his equations using measurements of the force between charges and the force between two wires carrying currents. Maxwell remarked on the mysterious coincidence that his calculated speed was nearly the same as the measured speed of light. “*We can scarcely avoid the inference, that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena*”. There is little (if any?) evidence that the photon has any measurable direct affect on, or is directly affected by, electric or magnetic fields. There are ‘electro-optic effects’ such as the Faraday effect whereby light has a change in polarisation if it passes through a medium that is in a magnetic field. This is described in [WikiMF_Effect], section 2, by “*The direction of polarization rotation depends on the properties of the material through which the light is shone.*” It would seem to be more plausible that the medium itself is affected by the magnetic field and this effect in turn is then causing the light to change its polarised state. Also from [WikiMF_Effect], section 4, “*The effect is imposed on light over the course of its propagation from its origin to the Earth, through the interstellar medium. Here, the effect is caused by free electrons*” which suggests the effect would not be seen in a truly pure vacuum.

1.2 Light as Waves: Doubts have been raised as to the validity of aspects of the wave based thesis, for example Huygens' construction assumes a wavefront through a slit can be considered as being multiple point sources, which can then interfere with one another. This is a dubious assumption, see David Miller’s letter [DM_Huygens] written in 1991; in particular Note 8, “ *such scalar solutions, while valid e.g. for acoustic waves, are not complete solutions for electromagnetic waves because Maxwell’s equations impose additional constraints* ”. Another example is from [WikiPlrsn] where the section concerning circular polarisation states “*In trying to appreciate how the quarter-wave plate transforms the linearly polarized light, it is important to realize that the two components discussed are not entities in and of themselves but are merely mental constructs one uses to help appreciate what is happening*”. Yet another example, from the University of New South Wales, School of Physics, [UNSW_Pht] end of chapter 4.6:- *“If we imagine light as being like a water wave, it's impossible to picture how a photon is both dispersed enough to create an interference pattern and simultaneously localised enough to interact violently with a single electron.*

For classical waves, e.g. water or acoustic waves, energy is proportional to amplitude squared; for waves in an electric field energy density is proportional to voltage (amplitude) squared. However for light as photons, energy is directly proportional (not a square) to a parameter referred to as ‘frequency’. These two concepts are not compatible. The energy in a wave is dissipated as it travels, but photons remain quantized, photons are not a form of waves, there is no ‘duality’.

1.3 Interference: Thomas Young's famous experiment in 1801 [WikiTY_Slit] seems to support the view that light is a waveform based on the observation of interference pattens which are similar to, for example, the patterns that water waves would produce; however, the similarity is not apparent with a single slit. Also the paper by R Bach et al [RB_2SlitElctn] discusses experiments that seemed to show electron interference leading to the view that electrons also possess wave/particle duality. However, Richard Feynman states in [RF_QED] page 83, that other experiments show that rather than 'interfering', the singular particles (photons and electrons) instead have 'no-go' regions. Photons do not 'cancel' one another out, neither do electrons, conservation of energy being one of many reasons. The elegant mathematics behind Schrödinger's equation derives a probability distribution for a photon's position, it does not prove photons are 'wave packets', see section 2.2 below for further details. The equation does not explain <u>why</u> lots of photons are more likely to go to a particular regions in space-time, but hardly any are likely to go to some other, adjacent regions.

This paper attempts to explain the 'why' behind the 'no-go' observation by considering three physical aspects:-

a) Principle of Least Action, for which Feynman states in, [RF_Lctr2_19]:- " *'Forget about all these probability amplitudes. The particle does go on a special path, namely, that one for which S does not vary in the first approximation.' That's the relation between the principle of least action and quantum mechanics.*", where 'S' is the function for 'Action', see section 2.5 below for further details.

b) how particles would interact with the side walls of the slits at angles of incidence approaching 90 deg due to effects such as the Thomson scattering effect [WikiThmsnSctrg];

c) partial reflection from a glass block within an interferometer.

Slit 'interference' is explained in more detail in section 3.1; the 'interference' effect as observed with a Michelson interferometer is covered in section 3.5.

1.4 Photons: The evidence that light consists of quantum particles of space-time distortion rather than a EM wave seems far more compelling, for example:-

a) the photoelectric effect, as analysed and explained by Albert Einstein in his paper which won him the Nobel Prize in Physics 1921, [AE_1905Ppr] page 2, "*… the energy of a light ray spreading out from a point source is not continuously distributed over an increasing space but consists of a finite number of energy quanta which are localized at points in space, which move without dividing, and which can only be produced and absorbed as complete units.*";

b) Arthur Compton paper of 1923 [AC_XRays] regarding the quantum effects of the scattering of X-Rays on collision with an electron, "*The experimental support of the theory indicates very convincingly that a radiation quantum carries with it directed momentum as well as energy.*";

c) Richard Feynman lecture [RF_Lctr3_1], 1.6 Watching the Electrons, regarding interaction between photons and electrons, "*What we are observing is that light also acts like electrons, we knew that it was 'wavy,' but now we find that it is also 'lumpy.' It always arrives—or is scattered—in lumps that we call 'photons.'*";

d) Richard Feynman's book [RF_QED], pages 14 and 15, in particular in the concluding paragraph: "*You might say that it's just the photomultiplier that detects light as particles, but no, every instrument that has been designed to be sensitive enough to detect weak light has always ended up discovering the same thing: light is made of particles.*";

e) the massless photon has been observed to be affected by a gravitational field, as in 'gravitational lensing', [CW_GR], section 3.4.1. Also, according to [WikiGLens], "*Gravitational lenses act equally on …. not just visible light, but also …. gravitational waves*." This identical gravitational reaction is significant.

Being a quantum of space-time distortion the photon would just follow the lines of curvature of space-time that exists around a large body; the photon's path would be complying with the Principle of Least Action by travelling along a line of equal intensity of the gravitational field, i.e. the photon's potential energy is changed by the minimum amount possible, see section 2.5 below.

f) photons do not interact with one another. Unlike waves, they do not cancel one another out. An example of this complete lack of any interaction is where a very dim trickle of photons from a distant star still reaches us on Earth, fully intact, even if those photons have gone, almost headlong, through the raging blizzard of photons coming out from our Sun. The space-time distortions of two 'colliding' photons would just flow through one another and then continue, unperturbed, on their own separate paths, much in the same way that a gravitational wave mostly just flows unperturbed through a gravitational field;

g) photons have momentum, even though they are massless. This is because a quantum of space time distortion that 'collides' with an electron would cause the electron to move by the photon's gravitational force acting on its mass. The overall effect would be that the photon had momentum. Gravitational waves have been detected by looking for the extremely small movements of test masses that the gravitational waves had created as they passed through;

h) an electric field can push (or pull) an electron that is in its field, based solely on the intensity and polarity of the field; a magnet brought near to a compass can cause the needle to move by an amount based solely on the strength of the magnetic field of the magnet. Neither field can directly interact with a mass. A photon can also move an electron, but by an amount based solely on the mass of the electron. A compass needle is not moved at all by sunlight, no matter how strong; a photon is charge-less so it obviously does not affect an electrical field.

Also, a 'solar sail' functions as the Sun's light 'pushes' on the sail and the photons' potential energy is converted into kinetic energy. Unless the sail was electrically charged or magnetised, an electric or magnetic field would have no effect on it.

1.5 Complex Behaviour: The ‘wave’ concept of light does not seem to have enough degrees of freedom in order to fully explain different complex behaviours, such as refraction, absorption and reflection. A photon’s energy (E) is given by Planck–Einstein relation:- $E = h * f$ where h is the Plank constant and f is the frequency of the wave, i.e. E is proportional to one independent variable, f. Whereas for most (all?) other types of a wave (water, acoustic, electric field) energy is also proportional to one independent variable, but this is amplitude. This fundamental difference between particle and wave questions the whole concept of ‘duality’. These aspects are covered in more detail in sections 3.2) and 3.3) below.

An example of complex behaviour being considered is the absorption of different ‘wavelengths’ of light by water. From [WikiWtrAbs], the way photons are absorbed depends on the state of water (vapour, liquid or ice) and the type of absorption, identified as being a transfer of photon energy via rotational energy, vibration energy or electronic transitions. The absorption by liquid water should possibly be expected to be fairly straight forward, but instead it is presented as a complex graph (copied here as figure 1-1) of the absorption spectrum.

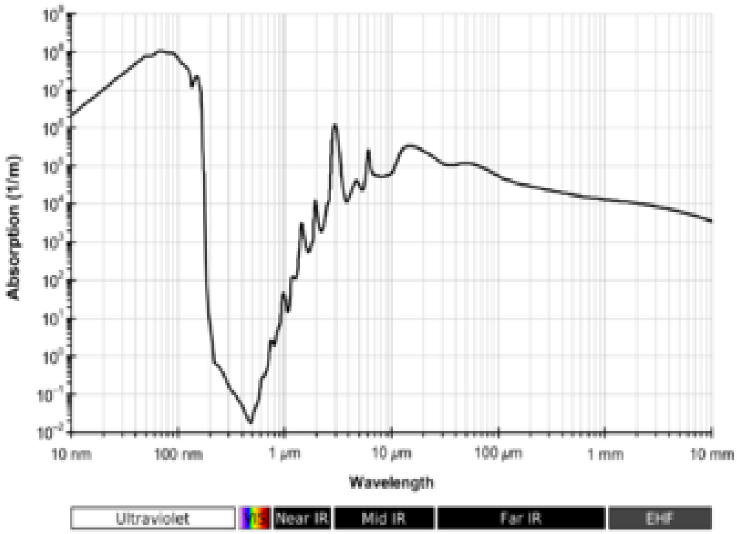

Figure 1-1

This graph shows high levels of absorption within the ultraviolet region, sharply dropping for the visible spectrum, rising (in a very erratic manner) into the infrared before slowly declining into the far infrared. If the wavelength/ amplitude/ energy of a photon is its only independent variable, it would seem likely that absorption would track energy, either up or down, in a fairly smooth, monotonic fashion, possibly with a transition point as some specific limit was exceeded. Instead the graph shows many irregular and very dramatic changes in level of absorption. This strongly suggests the photon must have a number of independent parameters which affect the amount of absorption. Possibly different parameters, affecting different types of absorption come into play at different energy levels. The middle ‘spiky’ section shows a number of sharp peaks which could possibly be where a ‘resonance’ between one of a photon’s particular attribute(s) and one of a water molecule's attribute(s) have become dominant.

Providing a possible explanation for this behaviour is outside the intended scope of this paper, however any explanation based on a particle that has several degrees of freedom would seem to have a better chance of success than any explanation based on just one degree of freedom.

2. Method

The approach taken is to assume that all behaviours currently explained by wave-like considerations must have an explanation based solely on the photon. These various behaviours are considered in turn and the associated observations are then used to determine what the properties of the photon must be in order for it to behave in this manner. Effectively, the method is to suggest a model for the photon from analysis of the experimental evidence already available in various publications, together with propositions made by other researchers.

2.1 Nature of a Photon:

The photon is mass-less, charge-less, carries energy and travels at a velocity of ‘c’ in a vacuum. The specific nature of this particle is uncertain, but considering its ubiquity, the photon should be expected to be of a very fundamental nature. This paper’s premise is that the photon is a 'particle' of space-time distortion, effectively like a quantum micro-portion of a gravitational wave.

The energy of a photon would then be gravitational potential energy. When an object above the Earth’s surface is raised its potential energy is increased; in a similar way, when a photon comes close to an electron, the electron’s potential energy is increased. If the electron is ‘free’ this energy could be converted to kinetic energy and the electron moved, or if the electron is part of an atom the energy could be absorbed. If the energy provided is not sufficient for the electron to jump to a higher energy state, the energy would be rejected by ‘re-emitting’ the photon.

The fact that a gravitational wave and a photon both move at the same velocity of ‘c’ in a vacuum is self-evident. It is to be expected that massless particles would travel at their maximum velocity (which is ‘c’) as they are unconstrained by mass and Fermat's Principle of Least Time applies. Massless entities cannot go faster than ‘c’ because of the end-stop limiting effect of Lorentz contraction and time dilation by the Lorentz factor. At a velocity of ‘c’, time has slowed to a stop for the travelling item, and distance along the line of flight is zero; time cannot slow any further and distance cannot reduce any further so the limit of ‘c’ will be reached.

This limit of ‘c’ would seem to be a fundamental property of space-time. Electrical, magnetic and gravitational fields also move at ‘c’. Presumably as these fields expand out in all directions then, in their space-time reference frame, any change to the field will go everywhere, instantly!

2.2 Considerations of Quantum Mechanics (QM):

The simplistic Bohr model of the atom [WikiBohrModel] is made use of in this paper to explain basic concepts regarding the photon as a particle and its interaction with other entities. The ‘atomic orbital model’ within quantum mechanics [WikiQM] is considered to be a complexity that does not need to be addressed at this stage as this paper considers only the physical behaviour of the photon as a particulate entity. The detail as to whether the electron exists as a spherical particle or a cloud or a vibrating string or whatever, is not relevant to considerations concerning observed physical interactions between photons and other entities, such as a photon moving an electron or choosing a path.

The QM concept of ‘probability amplitude’ is difficult to relate to real world physical effects because the square root of probability is not a meaningful real world concept; neither is the concept of probabilities cancelling one another out, as this would require negative probabilities, which is also (like ‘i’) not a real world concept. The mathematics involved is elegant, but this paper only considers why the observed behaviours are produced by photons and not the ‘pure maths’ equations that can predict those behaviours. However, the model of the photon as an amorphous 3-D shape of space-time distortion could be considered as somewhat similar to the atomic orbital ‘cloud’ of QM.

This paper is very much aligned with Feynman’s statement in [RF_Lctr2_19]:- “ *‘Forget about all these probability amplitudes. The particle does go on a special path, namely, that one for which S does not vary in the first approximation.’ That’s the relation between the principle of least action and quantum mechanics.*”.

2.3 Photon’s Size and Shape:

As a packet of space-time distortion, a photon would hypothetically have shape and dimensions. The dimensions of a photon in three axes, and its energy are all hypothetically independent; this concept is important as it provides the basis to derive possible explanations for different unrelated behaviours. For example, refraction is a behaviour that varies dependant on the photon’s energy, whereas polarisation varies depending on the photon’s spatial orientation. Refraction and polarisation are very different behaviours; it should follow that different physical properties of the photon are responsible.

Using Bohr’s model of the atom [WikiBohrModel] with the electrons in ‘shells’, and considering what happens when a photon is emitted by an electron ‘dropping’ to a lower energy level, something conceptually like the following should apply:-

a) The emission would take a finite amount of time, infinite power is not plausible. The front of the photon would begin moving at ‘c’ as the emission starts, the rear would start to follow a short time afterwards. This could define the non-relativistic length of the photon along its line of flight;

b) The electron is conceptually still moving along an ‘orbital’ path during the emission; this could define the width of the photon perpendicular to the line of flight;

c) The thickness of the photon, i.e. the dimension orthogonal to its length and width, could be related to the photon’s energy. Alternatively, if space-time distortion can have different energy density distributions, then some (or all) of the spatial dimensions could have values that are completely independent from the photon’s energy. Future investigations into the structure of gravitational waves may help to clarify this aspect, but what is important is the concept that the photon would have a number of degrees of freedom, not just the one of energy;

d) Also if the emission is conceptually coming from an electron moving on a ‘circular orbit’, the photon could be spinning around its direction of travel, possibly as a spiral shape, possibly like a misshapen screw thread, which could be considered as almost 3 dimension wave-like!

Whatever the hypothetical shape of the photon, it would be subject to relativistic effects. The Wikipedia article on Special Relativity [WikiSR] discusses the Time Dilation and Length Contraction effects and the implications of travelling at (or close to) a velocity of 'c'. Of particular relevance, from [WikiLnthCntrc]:-

"*Given the thickness of the atmosphere as measured in Earth's reference frame, muons' extremely short lifespan shouldn't allow them to make the trip to the surface, even at the speed of light, but they do nonetheless. From the Earth reference frame, however, this is only made possible by the muon's time being slowed down by time dilation. However, in the muon's frame, the effect is explained by the atmosphere being contracted, shortening the trip.[13].*" Also:-

"*Heavy ions that are spherical when at rest should assume the form of 'pancakes' or flat disks when traveling nearly at the speed of light. And in fact, the results obtained from particle collisions can only be explained when the increased nucleon density due to length contraction is considered*."

2.4 Photon's Motion:

Taking the concept of a packet of space-time distortion further leads to considerations as to how the photon might travel. The photon moving through the vacuum of space is fairly simple in concept, which is as a minuscule 'blob' of distortion flowing through space-time, similar to a gravitational wave, but in a quantized form. The photon would retain its initial shape as there is nothing acting on it to change its shape, until it interacts with a particle with mass. The interaction with any medium is basically the same for gases, liquids, transparent solids and opaque solids. The action of the photon on the molecules, atoms and free electrons in the medium is gravitational in nature. The distortion of space-time by the photon would act on the mass of each particle as a gravitational force attempting to move the particle. If the particle is a free electron and the photon is of sufficiently high energy then Compton scattering could occur [AC_XRays]; if the electron is part of an atom that is in a loosely bound medium, such as a gas, the electron and/or atom would be relatively easily 'pushed' against the resistance of its particular environment. The movement is described as a 'push', but the paper on the first detection of gravitational waves [BA_GWObs], figure 3 on page 4 states "*...will have the effect of lengthening one 4-km arm and shortening the other during one half-cycle of the wave; these length changes are reversed during the other half-cycle*."; this seems to imply that gravity can 'pull' as well as 'push'! Or it could be that for a very short time interval, the wave increases and then decreases the local gravitational field by a very small amount. However, Compton's paper [AC_XRays], figure 1A shows a "*recoiling electron*", i.e. a 'push'.

Some of the photon's energy could pass to the particle as potential energy, stored as electrostatic or other form of potential energy. As the photon continued on its path, the particle would return to its original stable state and the energy would be released back to the photon somewhat similar to how a compressed spring might react. For liquids and solids the principle is similar in that the photon 'pushes' against the molecules held in place by their molecular structure. If the 'springs' in the structure are too strong then any low energy photons would just bounce off, e.g. visible light photons reflected off of an opaque solid, or some photons could possibly be absorbed or re-emitted as a different colour. However, higher energy photons such as X-ray photons could overcome the 'springs' and force their way through, possible causing changes to the structure. A transparent liquid or glass with a more flexible structure presents more resistance than a gas (but less than an opaque solid) so even lower energy photons are able to find a path through.

The particles within a transparent medium that are being moved by a photon have mass, so reacting to the photon's space-time distortion must take a short time interval to complete their move. This will cause an apparent delay to the photon's flight, reducing its average speed but without any part of the photon moving slower than 'c'. This is because the leading edge will be where some energy is lost from, and the trailing edge is where the energy will be regained. An analogy is a team of racing cyclists where the pack leader peels off to go to the back. The speed of the rest of the pack does not change. However, there is a time delay for the pack overall which is equal to the distance the pack leader is ahead of the rider immediately behind him, divided by the pack speed.

The notion of a photon moving via a series of 'hops' and 'delays' explains why light has been observed to 'move slower' in a transparent medium. As a perfect vacuum exists between electrons, atoms and molecules, then each and every photon <u>must</u> move at 'c', and only at 'c', between them. This concept of a repetitive process of, a short hop at 'c' followed by a short delay, is important to the thesis of why a photon is refracted, see section 3.2.

2.5 Photon's Path:
Distance and time have been used to describe how a ray of light takes a particular path. Fermat's principle of 'Shortest Optical Path' uses shortest distance as a determination of path. From [RF_Lctr1_26] section 26-3, this principle is also known as the principal of least time, "*the principle of least time, or Fermat's principle … light takes the path which requires the shortest time*". However, the path is more complex at the quantum level of an individual photon's path, see Richard Feynman's statement in [RF_QED] page17, of "*The photon and electrons do some kind of dance, the net result of which is the same as if the photon hit only the surface*". His 'some kind of a dance' seems a good description of a motion consisting of a series of 'hops' and 'delays', as described in section 2.4 above.

What seems to apply in the case of the photon is the 'Principle of Least Action', as described in [RF_Lctr2_19]. From P5 of 14:-

"*We have a certain quantity which is called the action, S. It is the kinetic energy, minus the potential energy, integrated over time.*

$$Action = S = \int_{t1}^{t2} (KE - PE)\, dt$$

Remember that the PE and KE are both functions of time. For each different possible path you get a different number for this action. Our mathematical problem is to find out for what curve that number is the least."

It may be overly simplistic, but if this equation is applied to a photon, we get:-

a) the photon has no mass, so KE = 0

b) PE is the (gravitational) energy of the photon, which is a time independent constant

c) therefore the 'curve' is a straight line, parallel to the 't' axis

d) S is then least when the time interval t1 to t2 is least. Which is then precisely the Principle of Least Time.

The Principle of Least Action can also be considered as the 'line of least resistance'. For example, molecules of water in a stream flowing down a mountain follow the gravitational line of least resistance by going around boulders and not over the top, even if that would have been the shorter/faster path. Also, electrons in a bolt of lightning (and the spark in a Van de Graaf generator) is a zig-zag path that follows the electrical path of least resistance. That path is taken only when the electrical potential difference reaches a value that is sufficient to break down the insulation barrier, and is then a path completed in a series of 'hops'. The same should apply to a photon as it attempts to go from a higher ordered energy state as a quanta of gravitational distortion to a lower ordered energy state by absorption into a molecular structure. This is related to entropy increasing, or from the second law of thermodynamics [WikiThmdyn], " … *it spontaneously reaches its own, new state of internal thermodynamic equilibrium".* Or as Richard Feynman put it [RF_Lctr1_44] *"The two laws of thermodynamics are often stated this way: ….Second law: the entropy of the universe is always increasing".*

Photons take very specific, very subtlety different paths just based on very small energy differences. In particular, this is shown by the variety and purity of a spectrum where a beam of white light going through a prism is consistently split into a band of a very finely grained range of colours from red through to violet.

3. Results.

The following behaviours are considered in sections 3.1 to 3.6 below:-

a) Diffraction Patterns: as shown by ‘slit experiments’
b) Refraction
c) Partial Reflection
d) Interferometry
e) Polarisation
f) Other behaviour of photons.

3.1 Diffraction Patterns : as Shown by Slit Experiments

The terms ‘Diffraction’ and ‘Interference’ seem to be not clearly defined. From [RF_Lctr1_30], section 30-1, “*No one has ever been able to define the difference between interference and diffraction satisfactorily. It is just a question of usage, and there is no specific, important physical difference between them*.” As this paper refutes the concept of interference of light, only the term ‘diffraction’ is used, which according to [SOED], is “*The breaking up of a beam of light into a transverse series of dark and light bands or coloured spectra by the edge of an opaque body or a narrow aperture*”.

Single and double slit experiments have been used to demonstrate the banding effect that can be achieved with photons or electrons. A photon (or electron) source is set up in front of a mask consisting of a thin sheet of opaque material with one (or two) narrow slits cut into it. A screen or other detecting device is set up on the other side of the mask. The relative dimensions of the slits and general layout are chosen to emphasis the different types of banding effect. A typical size of the layout for using with light is 1 to 2m between source and screen and slit widths of 10’s of um.

Figures 3.1.1-1 and 3.1.2-1 below are illustrative only; the bounce angles shown are exaggerated in order to present the concept more clearly. In reality a reaction would be expected between a photon or an electron as it comes into contact with the surface, causing scattering effects. It seems reasonable to expect that this reaction will depend on the energy and possibly shape of the photon, with the result that light of different energy forms bands at different positions.

3.1.1 Firstly, considering the diffraction banding effect as seen with a single slit, as described in [UNSW_Slit]. It is hypothesized that the observed banding behaviour, with ‘no-go’ regions in which few photons arrive, is caused by some photons ‘hitting’ the side walls of the slit at an angle of incidence very close to 90 deg.

Figure 3.1.1-1 illustrates the effect with a hypothetical setup.

Black arrow: straight through
Red and blue arrow: 1 bounce
Green arrow: 2 bounces

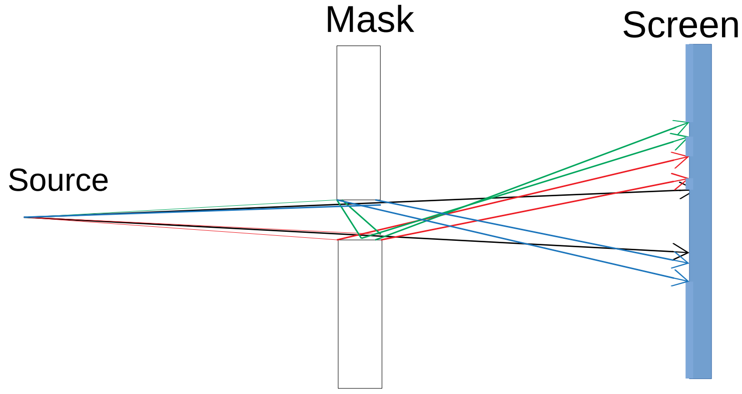

Figure 3.1.2-1

If the thickness of the mask were to be increased slightly, the straight-through beam would be narrower, but the one-bounce beam would be wider. However if the slit was made slightly narrower, only the straight-through beam would be narrowed. If more extreme changes were made to either dimension then two-bounce paths would come into effect, giving bands outside the straight-through path. Further variations of dimensions would lead to 3, or more, bounce bands, which become progressively weaker. Basically the experiment could be set up in order to produce a variety of banding effects.

Some photons will just manage to clear the end of the slit furthest from the source and go straight through. Others on a slightly different path will hit and be reflected in a different direction to form a ‘side lobe’. Additional side lobes will be created by multiple hit photon paths. There will be transition points between no-hit, 1-hit, 2-hit and further odd/even numbered hits. So, for those photons on a no-hit path, they will pass straight through the single slit to the central section of the screen; 1-hit photons hitting the left hand wall of the slit will be deflected out to the right of the central section, a 2-hit photon will be even further deflected, but now out to the left of the central section.

The path taken by the photon will be on the basis of ‘least time’, i.e. the minimal number of bounces path would take preference.

3.1.2 Secondly, in a double slit diffraction banding experiment (as described in [UNSW_Pht]), the least time path for a significant proportion of the photons is a single hit path through one or the other slit to take the photons towards the centre line between the two slits. Therefore, the single large band on the centre line of the screen is contributed to by photons on a path to the left of the centre line going through the left slit and and those to the right going through the right slit. As few as bounces as possible is the least time path

Figure 3.1.2-1 illustrates the effect with a hypothetical setup.

Black arrow: straight through
Red and blue arrow: 1 bounce
Green arrow: 2 bounces

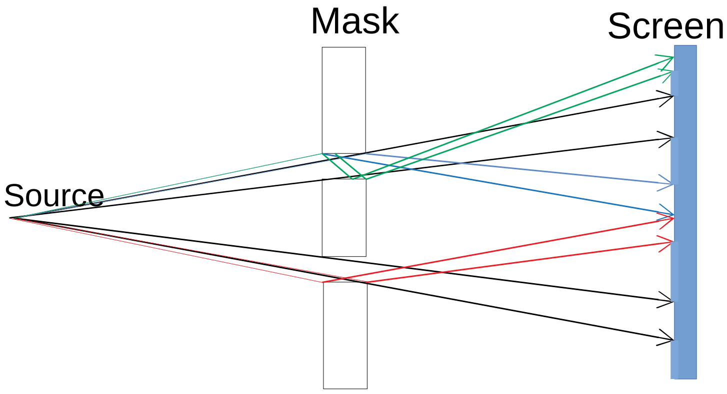

Figure 3.1.2-1

As with the single slit case, as described in section 3.1.1 above, additional side lobes will be created by multiple hit photon paths, with transition points alternating to the left and to the right of the central section for increasing numbers of hits. Also, as described in 3.1.1, changes to the dimensions of the mask will change the configuration of the bands.

Even numbers of bounces will give bands further outside the straight-through band, but odd numbers will give bands within the two straight-through bands.

As illustrated, there are three approximately equal intensity bands (shown by black, red and blue lines) and a fourth, less intense, band (green lines). Also shown are ‘no-go’ regions between the bands.

3.1.3 Photons at incidence angles close to 90deg could be scattered rather than just reflected for two reasons:-

a) the imperfections in the polished surface will be exaggerated as the minute scratches of the side walls will be met ‘face-on’, but the flat surfaces will appear foreshortened, so the scattering effect increases;

b) the surface will appear as a layer of electrons, either as free electrons or electrons at the outer levels of their ‘orbits’ around their parent nucleus. The photons interacting with these electrons will have slightly different paths and there will be a randomness to electron position. This will cause a scattering leading to bands with a bright centre, fading out to the edges. For photons this would be Thomson Scattering, as described in [WikiThmsnSctrg]:-
It is just the low-energy limit of Compton scattering: the particle kinetic energy and photon frequency do not change as a result of the scattering.

3.1.4 Similarly, in experiments where electrons are being fired through a double slit screen there will be a scattering effect. For electrons the scattering would come from an electric charge repulsion effect between the moving electron and the ‘layer’ of electrons in the wall of the slot.

3.1.5 Observing path taken by photons/electrons: It is not possible to observe the path of an individual electron (and by implication a photon), for the reason as stated here:- Richard Feynman lectures [RF_Lctr3_1], section 1.6, Watching the Electrons, regarding Heisenberg’s uncertainty principle, “*If an apparatus is capable of determining which hole the electron goes through, it* ***cannot*** *be so delicate that it does not disturb the pattern in an essential way. No one has ever found (or even thought of) a way around the uncertainty principle*”.

Also within section 1.6 of [RF_Lctr3_1], there is a description of an experiment where the layout shown in figure 3.1.2-1 is modified; a light source is placed behind the middle section of the mask and the screen is replaced by a backstop with a moveable electron detector. The following statements of particular interest are made:-

a) “*Here is what we see: every time that we hear a “click” from our electron detector (at the backstop), we also see a flash of light either near hole 1 or near hole 2 , but never both at once! And we observe the same result no matter where we put the detector*.” This is confirming the particulate nature of the electron, and when the path of the electron is detected, there is no ‘interference’ banding;

b) “*As we turn down the intensity of the light source we do not change the size of the photons, only the rate at which they are emitted. That explains why, when our source is dim, some electrons get by without being seen … If the electrons are not seen, we have interference!”* What could be happening here is that if an electron is hit (and given a jolt by a photon, resulting in a flash), the interaction with the photon causes the electron’s current path to be disrupted and a new path of least resistance is taken. So, instead of a path of bounces leading to ‘interference’ bands, the electron now takes the path direct to the screen resulting in no ‘interference’ bands;

c) “*If we use ‘gentler’ light perhaps we can avoid disturbing the electrons so* *much. Let us try the experiment with longer waves ... for wavelengths much longer than the separation of the two holes (when we have no chance at all of telling where the electron went) that the disturbance due to the light gets sufficiently small that we again get the curve P 12 shown in Fig. 1–3".* The curve P12 is the banded pattern ('interference') type distribution. What could be happening here is that the effect of the photon on the electron is minimal, possibly non-existent, such that the electron is not affected at all, therefore its path is not changed.

3.1.6 Diffraction Grating: Each line of the grating acts like a slit, with each line producing a banding pattern. Due to the closeness of the lines some of the bands from adjacent lines will overlap. Different wavelengths of light produce bands at different angular positions, so to an observer viewing the grating it has the appearance of a repeating spectrum of colours going across the grating.

3.2 Refraction

By considering the behaviour of two examples of refraction, light going through a block of glass and light going through the atmosphere, the following observations can be made:

a) light entering a block of glass changes direction at the interface, it continues in a straight line through the glass and, as it exits the glass, changes back to its original direction;

b) the light apparently moves at a lower speed whilst it is in the glass;

c) light coming in from the vacuum of space starts to reduce in speed as soon as it enters the atmosphere. According to [WikiAtmsrR] this is a gradual process, with the amount of refraction increasing as the density of the air increases;

d) the regions between molecules are a perfect vacuum; the photon travels at 'c' in a vacuum, so it <u>must</u> travel at 'c' as it moves between individual molecules.

From section 26-4 of [RF_Lctr1_26], the behaviour of a photon entering and then making its way down through the atmosphere implies that the loss in speed does not occur just at an 'interface', instead the photon changes speed according to the medium that it is going through. From observation c) above, regarding travel through the atmosphere, the reduction in speed increases as the density (and hence refractive index, RI) of the gas increases, with the result that the light follows a curved path. With a block of glass the reduction of speed happens in the glass as soon as the photon goes through the surface layer. However the photon does not continue to lose speed as it continues through the glass; it does not grind to a halt! Therefore the glass is not creating some sort of continuous drag effect.

The deduction is drawn that the photon must go through a sequence of time delays that occur on an irregular basis, resulting in the <u>average</u> speed through the glass being less than 'c'. The photon travels at 'c' between interactions and undergoes a delay during the numerous interaction processes, i.e. every time a photon interacts with a glass (or gas) molecule, as described in section 2.4 above. As Richard Feynman described the motion through glass, [RF_QED] page17, "*When a photon comes down, it interacts with electrons throughout the glass, not just on the surface. The photon and electrons do some kind of dance, the net result of which* *is the same as if the photon hit only the surface.*"

Higher energy photons have a larger amount of space-time distortion than lower energy photons, resulting in more of an effect on the mass of the electron. This means it takes longer for the electron to be 'moved', so the time delay is greater, i.e. average velocity for blue would be reduced by more than for red. For the least time path (which is also the path of least resistance, with fewer delaying interactions), the blue photon needs to take a shorter path in the glass than that for a red photon, so a blue photon takes a path at a smaller angle of refraction i.e. nearer to the normal to the glass surface.

For every step between interactions that the photon travels it has a delay (Dly) that is dependant on the photon's energy, e.g. DlyRed, DlyBlue or as an average, DlyAvg. For a photon to travel a step of length StepLen would take the time of travel in a vacuum, plus the delay time, i.e. StepLen/c + DlyAvg. The average velocity v is then given by:-

v = StepLen / (StepLen/c + DlyAvg) or v = c / (1 + DlyAvg*c/StepLen).

Reflective Index (n) for a material is defined as n = c/v where v is the velocity in the material. This gives:-

1 + DlyAvg*c/StepLen, or n – 1 = DlyAvg*c/StepLen.

From [WikiRInx] "*For gases, n − 1 is proportional to the density of the gas*". For a gas, density is proportional to the cube of the number of molecules in each of the x, y & z axes. For example, if the number of molecules went up by a factor of 2 in each axis, density would increase by a factor of 8. If density is increased by a factor of 8 then n-1 and hence DlyAvg * c/StepLen would increase by 8. This factor of 8 is attributable to DlyAvg increasing by a factor of 4 and StepLen halving. This is because the photon's cross sectional area determines the number of gas molecules the photon will interact with. The number within the cross sectional area will go up by by a factor of 4, so DlyAvg will go up by 4. Also, as the number of molecules has gone up in each axis by a factor of 2, then StepLen will reduce by a factor of 2.

Interestingly for water, at least, this relationship between n-1 and density seems to approximately apply to the states of liquid and solid as well as vapour. From [Kaye&Laby], for water vapour n is 1.00026, liquid water n is 1.33 and for ice n is 1.31; density for vapour, liquid and ice is about 0.0001, 1 and 0.92 respectively. So the approximate 'density calculated n' based on proportionality against vapour would be for water 1.26, and for ice 1.24, which are both within 10% of the measured values. Also, liquid water is more 'resistive' to a photon's passage than ice; both are made of the same molecules and being a solid ice molecules are more rigidly bound together. This would seem to imply that the higher density (molecules closer together) of water is the reason for this higher 'resistivity'; the rigidity of ice is less of a factor, possibly no factor at all.

3.3 Partial Reflection

The description of partial reflection from a single glass surface in [RF_QED] on pages 17 & 18 describes an experiment with a light source and a detector placed at 'A' above a glass block and another within the glass block at 'B' and states:-

> "*For every 100 photons that go straight down toward the glass at 90°, an average of 4 arrive at A and 96 arrive at B. So 'partial reflection' in this case means that 4% of the photons are reflected by the front surface of the glass,*

while the other 96% are transmitted." The description continues with a comment relating to one of many possible theories, which states:-
"One of them is that 96% of the surface of the glass is 'holes' that let light through, while the other 4% of the surface is covered by small 'spots' of reflective material. Newton realised that this is not a possible explanation."

The description of partial reflection from the top and bottom surface of a sheet of glass in [RF_QED] page 20 describes an experiment where the detector at B is placed below the sheet of glass by:-
"We might expect the front surface to reflect 4% of the light and the back surface to reflect 4% of the remaining 96%, making a total of about 8%." … "With some sheets of glass, we consistently get a reading of 15 or 16 photons – twice our expected result! With other sheets of glass, we consistently get only 1 or 2 photons."
Page 21 continues with the description of experiments on increasingly thicker glass sheets:-
"the amount of light reflected by the two surfaces reaches a maximum of 16%, and then goes down, through 8%, back to zero – if the layer of glass is just the right thickness, there is no light at all."

Page 34 of [RF_QED] refers to this cyclic behaviour as seemingly being unending and happening quicker for blue light than for red light; figure 18 shows the same amplitude for blue and red, going between 0% and 16%, and for blue a cycle time about 1.7 times faster than red, which is about the ratio of their 'wavelengths'.

From consideration of the above descriptions, a number of observations may be made:-

a) an important observation is that reflection is not a specific property; instead it is just the default action in the case when a photon cannot be refracted. Those photons that cannot complete their journey through the glass and then be absorbed, either by the glass itself or by matter on the far side of the glass, or to continue their journey onwards out the other side of the glass, are 'rejected'. They have nowhere else to go other than to be 'bounced' off. As the thickness of the glass is zero in the photon's inertia reference frame, the apparent result of this rejection is that the photon is reflected from the front surface. When the photon reaches the front surface, it will 'detect' there is no way through what is perceived as a zero thickness block and so it reflects off of the front surface;

b) from the descriptions above for the two partial reflection cases (case 1 only a front surface, case 2 a front and back surface) the observation can be made that both of these cases have different behaviours, dependant on what happens at the <u>back</u> surface. In both cases, all of the photons attempt to enter the glass and travel through it. In case 1 most (about 96%) are absorbed by the absorbing material on the other side of the block of glass. In case 2 most (about 84 to 100%) of the photons exit the glass block and travel onwards, out into the air (or vacuum) on the other side of the block;

c) for case 1, the rejection (reflection) of about 4% of the photons comes from not being absorbed by the material on the other side of the block;

d) also for case 1, increasing the thickness of glass does not cause more light to be reflected; it is not an effect that occurs within the glass block. However, for case 2, sometimes, for a particular thickness of glass, 0% is reflected. So in some situations, all of the photons can get through the front surface, are refracted and exit the glass block. Therefore in the single surface case the rejection cannot be at the front surface, it must be at the back surface, i.e. due to the material that the glass block is lying on, such as a lab bench, or a detector;

e) for case 2, the amount reflected is observed to be a cycle of 0% to 16% and back to 0%, which is related to the thickness of the glass as a multiple of the 'wavelength' of the light. This observation leads to the consideration that the length of a photon is most likely related somehow to the concept of 'wavelength';

f) it is suggested that for case 2, the rejection, or not, is determined by the length of the photon. The 0% rejection case being when the photon length is close to fitting an integer number of times within the glass block. The 16% rejection case is when the depth of glass is less optimal as it is a multiple of the photon length, plus a fractional part. For details, see section 3.3.2 below. For the 16% of photons that are rejected, as described in a) above, the reflection will be perceived as being from the front surface;

g) the 'hops' between interactions, in the photon's frame of reference, all happen in zero time over zero distance, making the front surface and the back surface of the glass block appear coincident to the photon. Richard Feynman described this process [RF_QED], page 76 as "*the photons don't really bounce off the surface of the glass; they interact with the electrons inside the glass...reflection and transmission are really the result of an electron picking up a photon, 'scratching its head', so to speak, and emitting a new photon.*" Whether it is a new photon or the same one just moving on after a delay is a moot point.

3.3.1 Partial reflection from single glass surface of 4%:

From the above observations (in particular observation 'd'), the partial reflection of 4% of the photons is because the back surface is not letting 4% of photons out. From the photon's frame of reference, the block of glass would have a thickness of zero along the photon's direct line of travel, so the reflection is perceived to be from the front face. At the back surface those photons that can exit (96%) are those that can be absorbed by the material on the other side of the back surface. However, some glass molecules in the back surface will be in direct contact with molecules of the opaque solid of the material. These few glass molecules would therefore not be in the usual amorphous, liquid-like state of glass; they would be locked in position as an impenetrable barrier to those 4% of photons that are on a path that requires an interaction.

To consider the plausibility of this concept, an order of magnitude estimate of the probability is presented. The radius of a glass molecule is about 500pm, giving an area of about 1e6pm**2. The 4 atoms within the molecule are each about 150pm radius. Assuming that the area of rejection presented by all four atoms is of the order of the area of one of them, this then gives an area of about 7e4pm**2. This gives a ratio of about 7:100, or about 1:15. Allowing for the approximations, the probability of a photon being blocked by the molecular structure of the glass, should be between about 20% to 2%. To an order of magnitude, this covers the observed value of 4%.

3.3.2 Partial reflection from top and bottom of a glass sheet, of from 0% to 16%:

The optimum least action path through the block of glass is a sequence of steps of similar size between interactions. The size of those steps is determined by the refractive index of the glass. A glass block with a depth that is an integer number multiple of steps sizes is the optimum depth in order for the majority of photons to pass through uniformly. A depth having a fractional part of a step as the last step is possibly problematic and will have a higher proportion of photons with a path that is not feasible. The reason for the lack of feasibility is that a short step could be a problem as the trailing edge of the photon would still be on the last delay stage when the leading edge was already clear and travelling at ‘c’ again. This could lead to the photon being split in two, which would violate its quantized state. The photons that would be impeded in this manner are therefore rejected, i.e. reflected.

There is a certain amount of variation as to how big the fractional part may be before a rejection happens, which is why the rejection only reaches a maximum of 16%. The causes of the variation are the photon’s path through the glass (Richard Feyman’s “dance”) as described in section 2.5 and surface irregularities at the microscopic level. If there is an optional, feasible path avoiding rejection, the photon is ‘obliged’ by the second law of thermodynamics to take it, see section 2.5 above.

This effect of variable reflectance is also why a so-called ‘interferometer’ can detect ‘interference’, except in this case the variation is caused by changing the optical path length rather than by changing the thickness of a glass block, for details see section 3.5 below.

3.4 Polarisation

From the thesis discussed in section 2.3 above, a photon would have a notional 3D shape with dimensions referred to in this paper as length (from a non-relativistic observer’s viewpoint) along the line of flight, width and thickness, which are mutually orthogonal to the line of flight. Conceptually, the width is considered as being larger than the thickness, and the orientation of the width dimension in the plane orthogonal to the line of flight defines the polarisation angle, as shown in figure 3.4-1, where:-

The x and y axes are on the page, which is the incident path plane, and the z axis is coming perpendicularly out of the page.

The width of P-polarised photons lies on the x-y plane; the width of S-polarised photons is parallel to the z axis.

When the angle of refraction (ThtRfr) plus the angle of reflection (ThtRfl = ThrInc) is 90deg, then the normal to the refracted path is coincident with the reflected path.

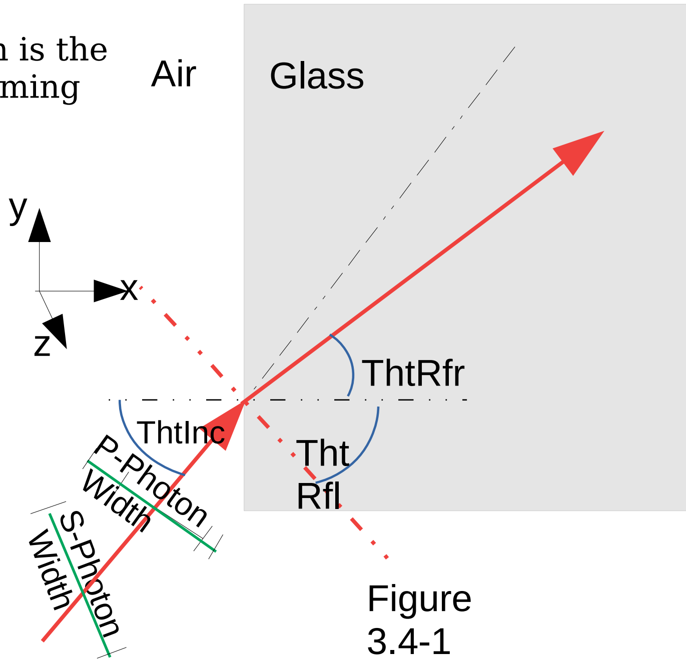

Figure 3.4-1

Assuming the orbit planes of electrons around the nucleus of atoms, and also the orientation of the atoms within the molecules are at random angles, then the orientation of the photon's 'width' (polarisation) of individual emitted photons will be random. Therefore each photon in a beam of light is 'polarised' at a random angle and the overall state of the beam would be 'circular' polarisation. When each photon in a beam strikes the surface of a transparent medium, some/all of those photons that are within a particular angular band would be refracted into the medium. The other photons would be reflected, all of them being at a different angular orientation to the refracted photons, i.e. partially polarised. The optimal path for a photon through a transparent medium is refraction, and then to continue on the least time path to its end destination. Those photons that cannot enter the medium, because their orientation does not allow them to find a suitable path through the medium, have to be reflected. This is the same consideration as in section 3.3 a) above. Glass allows nearly all photons to pass straight through so the likelihood of a rejection is low, only about 4% on average of photons are reflected.

Figure 3.5-1, from [WikiRflct] section 4, relating to the reflectance of water shows that at an angle of incidence from 0 to 10 degrees a few percent of light is reflected for both S and P polarisation, then up to 90 degrees incidence, reflectance of both S and P diverge until they reach 100%. It also shows the dip in reflectance, only for P polarised photons, to zero at Brewster's angle, i.e. the light reflected is all S polarised. Also in [WikiRflct] the figures in section 2 show that for some materials the P polarised can reduce significantly across the range of incidence, whereas S polarised always just increases.

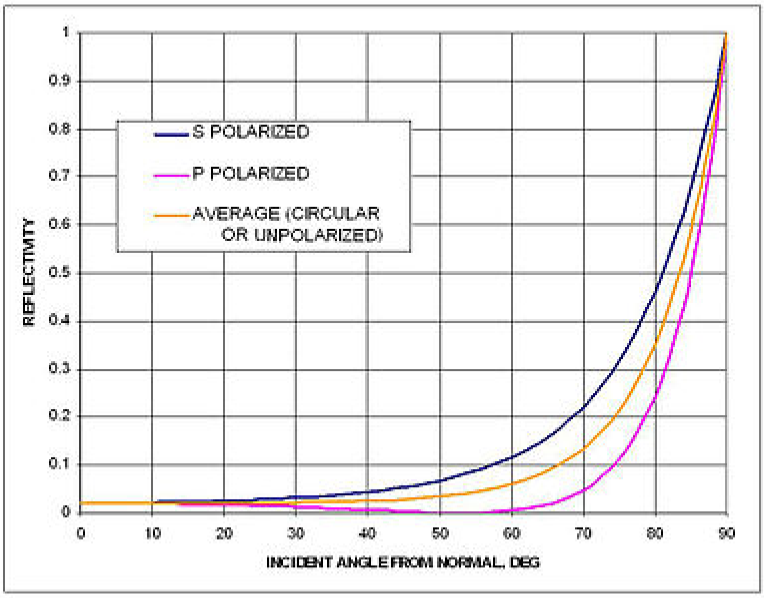

Figure 3.5-1

By considering the behaviour of aspects of polarisation, the following observations can be made:-

a) a reflection from a window is polarised, but one from a mirror is not. This must mean that it is not the action of reflecting that is creating the polarisation effect, it is the failure to refract;

b) Brewster's Angle [WikiBrewster] is the angle of incidence defined by ThtIncBrw = arctan(n2/n1), where n1 is the reflective index of the source material, n2 is for the target material. The important consequence is that for the resulting angle of refraction (ThtRfrBrw) the following relationship applies:-

ThtRfrBrw + ThtIncBrw = 90deg.

So if a photon were to be reflected, it would have to be on a path orthogonal to the refracted path. This implies that for a photon to be rejected it would have to change direction by 90deg, which is not possible due to conservation of momentum constraints. If a photon enters a material and the first choice 'least resistance' path through the material is more resistive than a reflected path, then usually reflection takes place. However, at Brewster's angle, as the reflected path would be orthogonal to the refracted path and the photon would have to 'bounce' off its current path by 90 deg, this would infringe the Conservation of Momentum law. So the photon <u>must</u> refract by choosing another path that is in theory 'less optimal', but is allowable.

This is a similar limitation to that of a Compton scattering by 90 deg; from Compton's equation [AC_XRays]:- *$\lambda' - \lambda = h(1 - \cos \theta) / (me * c)$, where λ is the initial wavelength, λ' is the wavelength after scattering, h is the Planck constant, me is the electron rest mass, c is the speed of light, and θ is the scattering angle.* If θ is 90deg, obviously no scattering occurs;

c) at Brewster's angle of incidence, all of the photons that are P polarised are refracted. This is shown for water in figure 3.5-1 as happening at an angle of incidence of about 53 degrees. A very pertinent aspect shown by figure 3.5-1 is the wide band of angle of incidence (about 20 to 58 deg) where reflection of P polarised photons is reducing, and in particular the range 50 to 55 deg where it is at or close to zero. This shows the effect is gradual, not just at a specific angle of incidence;

d) for any angel of incidence, the reflectance for P polarised light is always less than that for S polarised light;

e) the S polarised light reflectance varies with the angle of incidence although it is orthogonal to the angle of incidence plane;

f) at an angle of incidence of zero degrees a small and equal percentage of both S and P polarised photons are reflected;

g) approaching the limit of an angle of incidence of 90 degrees, all of both S and P polarised photons are reflected.

From these observations, the following conclusions are reached:-

a) the refraction angle corresponds to the least time path, i.e. the path of least resistance to the photons. This is described in more detail in section 3.2 above. Those photons that are exactly P polarised have their largest dimension ('width') in the incidence plane and so are most sensitive to changes in the incident angle. Photons that are close to being P polarised will also be similarly affected, but by a proportionally less amount. The photons that are purely (or nearly) S polarised will be much less affected, as it is only the smaller dimension of a photon ('thickness') that will be affected by a change in the incident angle. Hence the effects shown by figure 3.5-1 of different levels of sensitivity to incident angle;

b) this sensitivity to the angle of incidence for P polarised photons means that as the incident angle goes from zero to 90 degrees the resistance to the path will change. The observed behaviour is that the resistance reduces to a minimum, at which point the P polarised photons will have the greatest likelihood of achieving refraction, i.e. the least chance of being reflected. The incident angle corresponding to this resistance minimum is Brewster's angle.

3.5 Michelson Interferometer

A much modified version of a 'Michelson Interferometer' has been used to detect gravitational waves [BA_GWObs] by measuring the incredibly small amount of movement of a mass 4km from the rest of the equipment.

Figure 3.5.1 is a simplified diagram just to show why photons may, or may not, get to the detector.
The optical paths of interest, from the laser source, are:-
 Blue path, reflected up to mirror M1 and back down to the beam splitter, where it is refracted through the glass and on to the detector.
 Red path, refracted through the beam splitter glass and then on to mirror M2; it is reflected back to the beam splitter, where it is reflected and refracted through the glass and on to the detector.

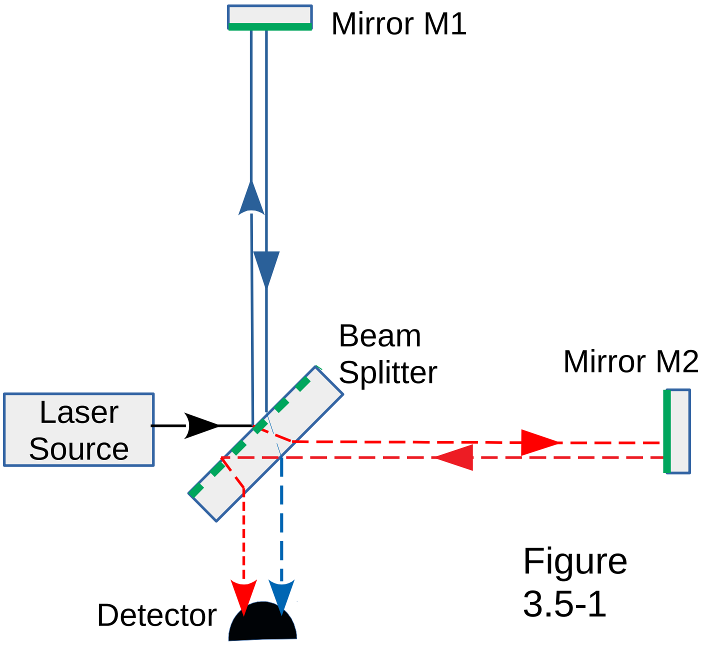

Figure 3.5-1

The figure shows:-
 a) Laser Source: A coherent laser light source producing photons which are all 'in step'. This means all of the photons will arrive at the beam-splitter at the same place with the same (or nearly the same) fraction of a step length for the last step. Half of the photons will be reflected off of the mirrored surface up towards mirror M1; the other half would be candidates for refraction, some (or all) of them may be rejected for refraction in which case they would also be reflected.

 b) Blue path, where photons are reflected up to mirror M1 and back again to the beam splitter where they may be refracted through the glass and on to the detector. If the setup is suitably 'tuned' by modifying the optical path length between M1 and the beam splitter, then the result of zero photons arriving at the detector can be achieved.

 c) Red path, where photons are refracted through the beam splitter, on to mirror M2 and then back to the beam splitter. Some of the photons will be reflected and can then be refracted back through the beam splitter and on to the detector. As with the blue path, suitable 'tuning' of the optical path length between M2 and the beam splitter may result in zero photons reaching the detector.

Why photons are refracted or not is the same effect as for partial reflection off of the two surfaces of a glass block, as described in detail in section 3.3.2 above. Briefly, a photon can only exit a glass block (from a higher to a lower refractive index medium) if the last step of the photon would not cause the photon to be split in two. If that would be the case, then instead of being refracted, the photon must be reflected. In the case of partial reflection for a glass block, 0 to 16% of photons are not refracted, depending on the thickness of the glass. However for a

Michelson interferometer with a coherent laser source all of the photons are ‘in step’. The percentage of photons that are not refracted is dependant on the optical path lengths from the beam splitter to each of the mirrors. So the path length can be ‘tuned’ so that none are refracted, or all are refracted. There will be a gradual change from the optimum path lengths for 0% or 100% where a few, or most, of the photons are refracted due to microscopic effects to the path length, in particular molecular interactions depending on which path a particular photon takes through the glass.

It is assumed that a perfect mirror does not affect a photon other than to reflect it; momentum, spin, energy, polarisation are all unchanged and no delay is introduced. Also the step length is preserved by a mirror in that the fractional part just after reflection is 1 minus the fractional part just prior to reflection.

3.6 Other behaviour of photons

3.6.1 Speed of Light and Motion of Source or Destination:
The photon travels through, and is part of, the fabric of space-time; whether the source or destination are moving or not is independent and irrelevant to the motion of that particular photon. However, a stream of photons would be affected as the time gap between successive photons arriving at the observer would change if the source (or destination) had moved. This is because the distance between the source and observer would change in the time period between successive emissions. The observer would then perceive the successive photons arriving at a rate different to the emission rate of the source. The speed and energy of individual photons would not change, but overall power received would change.

3.6.2 Cauchy’s Equation:
From [WikiCauchy], a simplified version of Cauchy’s empirical equation for glass is refractive index, n = B + C/lambda**2, where lambda is wavelength in um, B and C are constants. For example, for BK7 glass, B is 1.50 and C is .0042; for SF10 glass, B is 1.73 and C is .013.
From [RI_Info] BK7 glass has a value for n of 1.52 and a density of 2.51g/cm**3; for SF10 glass the values are 1.73 and 3.05g/c**3 respectively. So for BK7 glass, a red photon with a lambda of = 0.7um and a violet photon with a lambda = 0.4um, gives us nred = 1.51 and nviolet = 1.53.

The ‘B’ term is far more dominant than the ‘C’ term; for example, comparing BK7 glass and SF10 glass, with an increase in density by a factor of 20%, n increases by about 0.2. But for a proportionally lot larger increase in lambda of 75% (violet to red), n decreases by only 0.02 for BK7 and 0.06 for SF10. So n is more sensitive to a change in density than a change in lambda by about a factor of 40.

This is consistent with the ideas presented in this paper. Most (96%) of photon particles find a way through glass, with the length of the photon not having much relevance. However, a denser glass uses less silicon dioxide (smaller molecule) and more of other compounds with larger molecules such as germanium dioxide or lead oxide. These complex molecules are larger by about an order of magnitude and so, in theory. would present far more resistance to the passage of a photon. This would increase interaction delay time and hence significantly increases n.

3.6.3 Spooky Action at a Distance:
From [WikiQEntgl] Quantum Entanglement presents a paradox referred to as

"*spooky action at a distance*". This is when two photons are generated at the same time and share a complimentary property, for example one has 'spin-up' and the other has 'spin-down'. They are 'entangled' meaning if one photon changes its state, to say 'spin-down', then the other would change to 'spin-up'. The "*spooky*" part is that no matter how far apart the photons are, the change is instantaneous! An explanation for this is that because both entangled photons move at c, then in their inertial frame of reference time has stopped for them; also the distance between their mutual source and their individual destinations is zero. So the change happens to both of them instantaneously and at the 'same' place. However, an external observer in a different inertial reference frame will observe separate destinations for each photon.

3.6.4 Red Shift:
The apparent Doppler shift in the frequency of light towards the red end of the spectrum has been used to determine the distance and velocity away from us of various objects in the Universe, for example exoplanet orbital velocities. It has also been the basis of estimates of Quasar velocity of around 1/6 of 'c' and distance of billions of light years. According to [Wiki3C_273], there is no explanation for this huge velocity.

Rather than Red Shift being due to a Doppler effect it could be that the photons have just lost some of their energy in the course of their incredibly long journey of millions of light years, something similar to the ideas in this article [UToday_Dust]. The fact that X-Ray photons lose some of their energy as a result of collision with electrons [AC_XRays] suggests that other photons could loose a small amount of their energy as a result of collisions with other particles. Collisions with subatomic particles within the near vacuum of space could cause a loss of energy by very small amounts, very infrequently. Over the huge distances between galaxies, possibly all (or nearly all) photons are scattered by a small amount around the general direction of the direct line between the emitter and the observer. It follows that the further the source is away the more energy will be lost and so the red shift will be greater.

A paper (Photon mass drag and the momentum of light in a medium) published 2017 by Mikko Partanen et al [MP_PhtMmntm] also questioned the Doppler theory behind Red Shift:- "*Presently the Hubble's law is explained by Doppler shift being larger from distant stars. This effectively supports the hypothesis of expanding universe. In the mass polariton theory of light this hypothesis is not needed since redshift becomes automatically proportional to the distance from the star to the observer*".

The basis of their thesis is that a photon is accompanied by a mass density wave, which could give the attribute of momentum to the photon. Here in this paper, an alternative thesis is given for the apparent attribute of momentum of a photon, but for a different reason; the basic concept in this paper is that the photon is a packet of space-time distortion acting as a gravitational force that can move a particle with mass as if it had 'momentum'.

Another possibility is a time dilation effect. If the Milky Way galaxy had at some time in the past (or currently) accelerated away from another galaxy, then we would be the 'traveller' and our time would be running slower than time in the other galaxy. Presumably, the speed of light observed in the other galaxy would still be 'c', but light from the other galaxy which was then observed in our galaxy could change in some way, possibly becoming apparently ‘red shifted’? This is similar in concept to the so-called “twin paradox”, as described in [WikiTwinPdx]. The travelling twin (i.e. the one that feels the force of an acceleration) is in a ‘non-inertial reference frame’ and in accordance with Einstein’s equivalence principle and gravitational time dilation, this twin’s clock will advance slower than that of the stay at home twin.

4. Discussion

For this paper different wave-like behaviours of light have been chosen as being those of most interest, and also the most challenging. An explanation has been suggested for each particular behaviour on the basis that the photon is specifically and only, a quantum particle. The plausibility of these explanations is considered by the author to be at least as good as the general level of plausibility of wave based explanations.

5. Conclusions

These conclusions directly follow on from the considerations in section 3 above:-

a) diffraction patterns are caused by photons ‘bouncing’ off of the walls of the thin slit(s) in a mask. The ‘no-go’ bands result from the transition between a different number of bounces. So, if a two bounce path takes the photon to the left of centre of the screen, then a three bounce path will take the photon to the right of centre of the screen. Depending on the setup, this could then form ‘no-go’ regions between the two and the four bounce path to the left of centre, and between the one and the three bounce path to the right;

b) refraction is a result of the <u>average</u> speed of photons being reduced to less than ‘c’. A proton travelling through a transparent medium has a number of interactions with the particles forming the medium. These interactions create time delays to the photon’s travel through the medium, but the photon still travels at ‘c’ between the interactions. The photon travels through the medium in a series of ‘hops’ and ‘delays’;

c) partial reflection occurs when a photon fails to be refracted through a block of glass; the photon is perceived to be reflected from the front surface. For the single surface reflection case, this is caused by photons not being able to exit the block and absorbed by the material on the other side of the block. For the two surfaces reflection case, the cause of a failure to refract is that the path through is not allowable. The optimal path for a photon is when an integer number of times its length is close to the thickness of the glass. A fractional part that would be ‘left over’ at the exit from the block could result in a photon separating into two parts, which is not allowable as a photon is a quantum entity;

d) polarisation is an effect due to the photon’s cross-sectional dimensions. Some photons have an orientation such that the probability of finding a path through the gaps between molecules is low. These photons are more likely to be blocked than photons with an orthogonal orientation, so the overall effect is polarised light;

e) a Michelson ‘interferometer’ does not make use of wave interference, instead it uses the effect of variable reflectance as discussed in conclusion c) above. Except in the ‘interferometer’ case the variation is caused by changing the optical path length rather than by changing the thickness of a glass block.

f) photons move at the same velocity of c independent to any motion of the source. This is because the photon is created as a packet of distortion in space-time itself, and moves off as a ‘blip’ in space-time in a direction determined by its creation and at its preordained velocity of c. However, the source is travelling ‘through’ space-time, it is not a part of space-time, so its motion is irrelevant to the photon; the photon and the source are moving in different ‘domains’. In addition, in the photon’s inertial reference frame, time has stopped so travelling from source to destination has taken zero time and from the photon’s reference frame perspective, the source is stationary.

6. Changes Applied to Previous Issue:- PhotonPaper01

a) Minor changes to some parts of text throughout the paper in order to improve clarity, but without changing technical detail;

b) Address queries and suggestions raised by Dr R G Adams regarding Quantum Mechanics;

c) Address issues related to interferometry;

d) Insertion of section, 3.5 Michelson Interferometer, considering ‘interference’.

Acknowledgements

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