On the Nature of Light Quanta – A Radically Different View

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Abstract

It has been over 150 years since light was first considered a form of electromagnetic radiation. There is substantial evidence that the current well-established theory, that light quanta (photons) are a form of electromagnetic radiation, is incorrect. This is largely because the theory was first introduced based on assumptions not evidence. The experimental evidence, and the requirements of quantum mechanics, are largely incompatible with the existing theory and the conceptual models regarding the nature of light quanta. Several inconsistencies associated with the current belief and the associated conceptual model are identified. An entirely new and radically different conceptual model is proposed. A conceptual model that embraces what is currently known about light quanta, from both a classical and quantum-mechanical perspective. The proposed conceptual model strongly supports the "Information Interpretation" of quantum mechanics; a growing belief that information is a fundamental aspect of nature. Several examples of common phenomena, such as the "double-slit" experiment, are discussed to show how the proposed model of light quanta provides a simpler and more consistent explanation of experimental results and removes many of the apparent mysteries.

1. Introduction

This paper challenges the well-established theory that light is a form of electromagnetic radiation, and presents a radically different conceptual model of light quanta.

All topics are presented with a bare minimum of (or no) supporting mathematics. There is of course a need for the mathematics, and it often provides insights that words alone cannot, but fundamental concepts should be explainable in simple terms. There is a quote, sometimes attributed to Albert Einstein and sometimes to Richard Feynman, "*If you can't explain it simply you don't understand it well enough.*" The issue is not with the existing mathematics but with the conceptual model behind it. The challenges to existing theory are conceptual not mathematical, and the proposed conceptual model does not require any new mathematics.

The conceptual model and examples deal only with light quanta. Other quantum entities[1], such as electrons, will have aspects related to the proposed conceptual model, but light quanta have zero rest mass so they are the extreme case. Quantum field theory views all particles as excited states of their respective fields. That principle is fully accepted for all massive[2] particles, but in the interest of clarity and simplicity, all discussions involving particle interactions just use the particle name rather than specifying an interaction with the particle field.

As one learns about the different ideas, the conceptual models, that have existed over the many years that we have struggled to understand and make sense of the universe, it becomes quite apparent that ideas and conceptual models are transitory. Some exist very briefly while others last for ages. Some of the long-lived conceptual models only need minor adjustments as we learn more, but others endure even though they are completely wrong.

The "geocentric" model is such an example. This conceptual model has the earth ("geo") at the center of the universe and all other celestial objects (moon, planets, sun, stars) orbiting the earth. The geocentric model can be traced back at least to Plato about 400 BCE[3]. Claudius Ptolemy introduced a modification, about 100 CE[4], that also provided the mathematics to perform very precise calculations of planetary motions. The Ptolemaic model had some complicated details but the basic idea was that each planet and the sun moved on a small sphere or circle, called an "epicycle", and that each epicycle moved on a larger sphere or circle, called a "deferent". Stars moved on a transparent celestial sphere that was outside of the planetary spheres. The geocentric model lasted until Nicolaus Copernicus introduced the "heliocentric" or sun-centered model in 1543, so it endured for at least 2,000 years. This clearly shows that a conceptual model, can have complicated mathematics that provides very precise calculations, be accepted by most experts, last for a very long time, and be completely wrong.

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[1] "entity" is used because words such as "object" and "particle" imply questionable physical aspects.

[2] "massive" just means a particle that has some mass, it does not mean it has a lot of mass.

[3] BCE = "Before Common Era", which used to be designated "BC".

[4] CE = "Common Era", which used to be designated "AD".

The existing conceptual model of light and photons presents many inconsistencies with experimental results and developments in quantum mechanics. Typical comments about the inconsistencies go something like "Its quantum mechanics so that is just the way it is.", and if someone, two thousand years ago, asked about "epicycles" and "deferents" they probably got a similar reply. Did we make a fundamental error at some point? Did we create a conceptual model that made sense at the time, and has endured for many years, and is quite wrong?

What gets us into trouble is not what we don't know.
It's what we know for sure that just ain't so. [5]

2. Background Information

A brief review of our current understanding of light, the significant events that led to our current understanding, and some details that provide a conceptual framework for the nature of light quanta being proposed.

2.1. The evolution of theories about light prior to quantum mechanics

This section presents a brief chronological review of the major events that shaped our current theories regarding the nature of light prior to the development of quantum mechanics.

Debate about the nature of light has continued from antiquity to present day, and there are still aspects of light that are not explainable given our current understanding.

A question about a very fundamental aspect of light, dominated the debate in the 1600's; is light a wave or is it comprised of tiny particles? The two sides of this debate were lead by two leading scientists of the day; Issac Newton (English) and Christiaan Huyghens (Dutch). Newton argued that light was made of particles (he called them "corpuscles"), and Huyghens argued that light was a wave. The wave model slowly became more popular as the particle model made some incorrect predictions. The debate seemed to be settled in 1801 by the now famous "double-slit" experiment devised by Thomas Young. This experiment showed that light that passed through two slits created an interference pattern that could only be explained by the wave model. Light was clearly a wave.

The speed of light has been measured by many individuals over the years. Light speed was measured in 1728, by James Bradley, to be about 301,000 Km/sec, and then measured more precisely in 1862 by Leon Foucault to be 299,796 Km/sec.[1] The currently accepted value is 299,792.45 Km/sec, so the speed of light was quite accurately known by 1862.

In 1865 James Clerk Maxwell published his equations for electromagnetism and the speed he calculated for electromagnetic (EM) wave propagation. Because the speed of light and

[5] Source unknown but often attributed to Mark Twain (Samuel Clemens).

his calculated speed for EM wave propagation, were essentially identical, he assumed light was simply high frequency EM radiation.

In 1900 Max Planck discovered that the minimum possible energy, that could be emitted, at any frequency of light, was a product of the frequency and what is now called Planck's Constant (h). He also discovered he could explain the spectral distribution of the light emitted from a "blackbody"[6], if he restricted the total energy emitted (E_T) at any frequency (f [7]), to integer amounts (n) of the minimum possible energy.

The minimum energy at any frequency: $E = hf$

The total energy at any frequency: $E_T = nhf$

Max Planck's discovery in 1900 that emitted light has a minimum energy (a quantum of energy), and that it is emitted only in integer amounts of that minimum energy, is considered the birth of quantum physics.

In 1905 Albert Einstein published a paper on the photo-electric effect, which is generally credited with introducing the idea that light itself is composed of energy quanta.

> *According to the concept that the incident light consists of energy quanta of magnitude Rβν/N, however, one can conceive of the ejection of electrons by light in the following way. Energy quanta penetrate into the surface layer of the body, and their energy is transformed, at least in part, into kinetic energy of electrons. The simplest way to imagine this is that a light quantum delivers its entire energy to a single electron: we shall assume that this is what happens.* [2]

The energy quanta he needed to explain the photo-electric effect had to behave as little particle-like packets of energy, so they did not actually behave the way Maxwell's equations said EM waves should. But they had to be EM waves because Maxwell had already established that light was a form of EM radiation – and what else could they be?

Light composed of "*energy quanta*" was difficult to reconcile with the wave theory of light. Many thought that question had been resolved by Thomas Young's double-slit experiment back in 1801 (more than 100 years earlier). It now seemed that light was somehow both a wave and a particle. It had to be a wave because of the double-slit experiment, and now it had to be a particle to explain the photo-electric effect according to Einstein. This apparently contradictory situation was given the label "wave-particle duality".

After 1905 quantum physics developed fairly rapidly and by about 1930 the physics world had essentially split into two major areas: "**classical physics**" that dealt with the everyday normal-scale issues, and "**quantum physics**" that dealt with the world of the very small entities (atomic and sub-atomic) including light-quanta.

[6] A "blackbody" is an idealized object that absorbs all incident radiation, so it appears black, but is also in thermal equilibrium, so it emits light in accordance with its temperature.

[7] The greek letter "ν" (nu) is also commonly used in physics to represent frequency.

2.2. Why do we currently think that light is electromagnetic radiation?

James Clerk Maxwell is generally given credit for the idea that light is a form of electromagnetic (EM) radiation, but the credit should go to Michael Faraday. In his 1865 paper Maxwell clearly states that Faraday proposed the idea years earlier.

> *The conception of the propagation of transverse magnetic disturbances to the exclusion of normal ones is distinctly set forth by Professor FARADAY in his "Thoughts on Ray Vibrations." The electromagnetic theory of light, as proposed by him, is the same in substance as that which I have begun to develope in this paper, except that in 1846 there were no data to calculate the velocity of propagation.* [3]

Credit is probably given to Maxwell because, in his 1865 paper, he presented the equations that define the behavior and interaction of electric and magnetic fields, and he calculated the speed at which EM fields must propagate. From his comment about Faraday's theory, he clearly already thought that light might be EM radiation, so when he discovered that EM radiation propagated at the same speed as light, he made the rather natural assumption that light was EM radiation.

> *This velocity is so nearly that of light, that it seems we have strong reason to conclude that light itself (including radiant heat, and other radiations if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws.* [3]

In his 1905 paper on the photo-electric effect, Einstein introduced the idea of light-quanta and described them as little packets of energy "*localized in space*", but these "*energy quanta*" were very different from Maxwell's EM waves.

> *According to the assumption considered here, when a light ray starting from a point is propagated, the energy is not continuously distributed over an ever increasing volume, but it consists of a finite number of energy quanta, localized in space, which move without being divided and which can be absorbed or emitted only as a whole.* [2]

Back in 1865 Maxwell had assumed that light must be some form of EM radiation, so in 1905 (40 years later) Einstein seems to have just accepted that it was, even though he was clearly aware that his energy-quanta were completely unlike EM radiation. EM waves <u>are</u> "*continuously distributed over an ever increasing volume*" (they spread out), so they are <u>not</u> "*localized in space*", and they <u>cannot</u> be "*absorbed or emitted as a whole*". But they had to be EM waves – Maxwell had already established that they were – and what else could they be?

Planck clearly stated that he was only certain that energy is emitted at the source and absorbed at the destination. What happens in between is just an assumption.

> *For I do not seek the meaning of the quantum of action (light quantum) in the vacuum but at the sites of absorption and emission, and assume that the processes in the vacuum are described exactly by Maxwell's equations.* [2]

The speed that Maxwell calculated is commonly called "the speed of light" and is denoted "c"[8]. Einstein's General Relativity predicted the existence of gravity waves and that they would also travel at "c". Thanks to the success of LIGO[9], we now know that gravity waves are real, and "c" is now more correctly considered as the "cosmic speed limit".

We now know that waves of completely different phenomena travel at "c". EM waves and light waves could also be waves of entirely different phenomena that travel at this speed. There may well be other waves, of as yet undiscovered phenomena (dark matter waves?), that also travel at this speed. The fact that waves of different phenomena travel at the same speed does not mean the phenomena are the same.

Maxwell made his assumption that light was a form of EM radiation in 1865. Max Planck would not develop his equations for black-body radiation, in which he introduced the idea that light emission and absorption are quantized, for another 35 years. Einstein's idea that light was little localized bundles of EM energy that he called light-quanta, was even further into the future. So back in 1865 the world of physics settled comfortably on the belief that light was EM radiation – with no actual evidence. Some ideas, once they are firmly entrenched, can be very difficult to change.

> *The fact that an opinion has been widely held is no evidence whatever that it is not utterly absurd; indeed in view of the silliness of the majority of mankind, a widespread belief is more likely to be foolish than sensible.*
>
> Bertrand Russell

We now know a great deal more than we did back in 1865 but seem stuck on the belief, with little or no actual evidence, that light is a form of EM radiation. In fact, there is a good deal of evidence that light is not EM radiation. As previously stated, light-quanta have qualities that are very different from EM radiation. If Maxwell knew, what we know today, he probably would not have jumped to the conclusion that he did.

The belief that light is a form of electromagnetic radiation and that it is comprised of little bundles of electromagnetic energy called photons, has impeded the development of a conceptual model of light that is consistent with experimental evidence. Einstein himself lamented about his own inability to make any progress in his 1951 letter to his friend Michele Besso: "*All these fifty years of pondering have not brought me any closer to answering the question, what are light quanta.*"

The theory that various apparently different phenomena, starting with low frequency radio waves and moving to successively higher frequency micro-waves, infra-red light, visible light, ultra-violet light, x-rays and gamma-rays are all just forms of EM radiation that differ only in frequency, is a simple and elegant theory that most experts today accept unconditionally. However there have been other simple and elegant theories that most experts of the time accepted, that were quite wrong. There was once a well accepted theory that all matter was composed of four basic elements: earth, air, fire, and water. There was once a well accepted theory that all celestial bodies orbited the earth. The fact

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[8] "c" was probably chosen, as it is the initial letter of "celeritas", the Latin word meaning speed.

[9] LIGO = Laser Interferometer Gravitational-Wave Observatory.

that a theory is simple and elegant. and that most experts of the time accept it, does not mean it is correct.

In their 1989 paper "Evolution of the modern photon", Kidd, Ardini, and Anton, discussing the fact that Bohr initially rejected Einstein's idea of light quanta, make the following observation:

> *Contrary to the general belief that physics theories rise or fall solely on the basis of physical evidence, it would appear that the evidence is often conflicting and that a good deal of the short-run direction of physics, at least, has been determined by the judgements and philosophic preferences of strong personalities (i.e. authorities) in the field ...* [4]

2.3. How are photons different than electromagnetic radiation?

There are significant differences with how EM radiation and photons are created, how they propagate, and how they are detected. The creation, propagation and detection of EM radiation are described by Maxwell's equations. The creation and detection of photons is described by quantum mechanics, but quantum mechanics does <u>not</u> deal with how photons propagate; "*The position operator for the photon simply does not exist.*" [5].

The following is just a very general summary that identifies some aspects of EM radiation that are fundamentally different from photons. The only aspect that we know photons and EM radiation have in common is they both travel at "c".

Maxwell's equations show that EM radiation is created when charged particles are accelerated. The most common charged particles are free electrons (not bound in an atom) and the free electrons generally need to be in an electrical conductor called an "antenna", so only that case will be used.

The acceleration of free electrons in an antenna creates time-varying interconnected electric and magnetic fields that radiate away from the antenna at speed "c". The energy used to generate EM radiation is always greater than the energy radiated. The shape of radiated EM waves varies with antenna length and can be modified using reflectors and other devices, but always spreads out as it travels away from the antenna. Because the wave spreads out, it gets continuously weaker the further it travels. The energy of an EM wave that arrives at a receiver is much less than the energy transmitted. The energy of the received EM wave is completely independent of its frequency. The same EM wave can be simultaneously received at many receivers, and the received signal is a time-varying signal.

Photons are quite different; they are generated by quantum events. A common example is a bound electron (part of an atom) jumping from some quantum energy level to a lower quantum energy level. The difference in energy is emitted as a photon. The energy of the emitted photon is exactly the same as the energy lost by the atom. The photon travels away from the atom at speed "c". The energy does not spread out and it does not diminish with distance. A photon emitted from a distant star, billions of light years away, arrives at your eye with the exact same energy that it had when it was emitted[10]. The energy of the photon is determined by its frequency. A photon is a pulse of energy that can only be received at one point (one atom or molecule); it does not produce a time-varying signal.

For EM radiation, antenna size is very significant. Different antenna sizes are used but the basic antenna is called a "dipole" (two poles). Each pole is typically ¼ of the wavelength, so the full antenna is ½ of the wavelength[11] of the EM radiation being transmitted or received.

Photons by comparison are emitted by atoms that are only a tiny fraction of the photon wavelength. The hydrogen atom, for example, emits and absorbs photons of four visible-light wavelengths. One of those is red colored (designated "H-alpha") and has a wavelength of 656.28 nm (10^{-9} m). The size of the hydrogen atom varies depending on how it is defined, but the Bohr radius of 53 pm (10^{-12} m) is the most appropriate for this example. That makes the diameter of the hydrogen atom 106 pm (10^{-12} m), which means the red colored (H-alpha) photon is being emitted and absorbed by an object that is more than 6,000 times smaller than one wavelength of the photon. Ignoring the question of how an atom can emit a photon with a wavelength that is 6,000 times larger than the atom, how can an atom absorb <u>all</u> of it? EM waves spread out as they propagate and an antenna only absorbs the energy of the EM wave that intersects with the antenna.

There is an even more extreme example that will be discussed in more detail later. That is that case of the 21 cm emission from a hydrogen atom. A wavelength of 21 cm makes the photon wavelength 2 billion (2,000,000,000) times larger than the atom that emits and absorbs it.

It should also be noted that the size in the previous examples is the size of one wavelength not the size of an entire photon.

2.4. How big is a photon?

If the question "How big is an EM wave?" is asked, the answer would be that the electric and magnetic fields extend as far as is possible traveling at the speed of light "c". But EM waves spread out as they travel, can be simultaneously received by multiple receivers, and the energy at each receiver is a tiny fraction of what was transmitted.

Photons do not spread out, the energy received is exactly the same as was emitted. If they do not spread out, how big are they? Text books typically avoid such questions by presenting the photon not as a physical entity but as a mathematical object that has only certain definable properties such as wavelength, energy and momentum – but not size. But if a photon has a definable wavelength and frequency bandwidth we can at least calculate the minimum number of wavelengths that must be present.

In 1807 Jean-Baptiste Joseph Fourier presented his theory that any signal in the time domain (such as a pulse) is composed of a weighted set of different frequencies and vice-versa. The Fourier transform can be used to relate the width of a pulse in the frequency domain (bandwidth) to the width in the time domain. A pulse that is very narrow in one of

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[10] Ignoring energy changes due to such things as doppler shifts and expansion of the universe.

[11] Antennas can be made with only one "pole" so they are ¼ λ.

these domains must be wide in the other. For any given width in one domain there is a minimum width required in the other domain. The product of the widths in both domains is called the Fourier "time-bandwidth product" (TBP). Pulses that are constrained to a minimum width in either domain (frequency or time) are called "Fourier-limited".

For different pulse shapes the TBP varies slightly. Gaussian-shaped pulses are very common and the theoretical minimum TBP is approximately 0.44 [6]. If the BW of a Gaussian-shaped pulse is 1 Hz, it must be at least 0.44 seconds wide. If it is 1 sec wide, it must have a BW of at least 0.44 Hz.

A 2007 study of the spectral-temporal (frequency-time) properties of Fourier-limited single photons, using the chronocyclic Wigner function[12] found TBPs ("$\Delta t \Delta \omega$" in the quotes), were all much larger (up to 40x larger) than the theoretical limit.

> *The generated single photons are studied within the framework of the chronocyclic Wigner function, from which the single photon spectral width and temporal duration can be computed. … Our approach is rather to use the Gaussian approximation in cases where it yields essentially the same chronocyclic Wigner function.*
>
> *… we present the chronocyclic Wigner function (calculated numerically from Eq. 13) for a specific collinear, degenerate type-I example. … we obtain Δt = 288.01fs and $\Delta\omega$ = 61.4THz, corresponding to $\Delta t\Delta\omega \approx 17.7$[18] which suggests a large departure from the transform limit.*
>
> *… The resulting single photon duration obtained numerically is Δt = 205.7fs while the single photon bandwidth is $\Delta\omega$ = 50.1THz, yielding $\Delta t\Delta\omega \approx$ 10.3[18], which suggests a substantial deviation from the Fourier transform limit.* [7]

For a specified BW and wavelength (λ), the minimum number of wavelengths, that must be present, can be calculated.

The time-width of a pulse is: $time = \frac{time\ x\ BW}{BW} = \frac{TBP}{BW}$

The length of a pulse is: $time\ x\ c = \frac{TBP}{BW}\ x\ c$

The number of wavelengths in a pulse is the length of the pulse divided by one wavelength, so the minimum number of wavelengths that must be present is:

$$\boldsymbol{N_{\lambda_{MIN}} \geq \frac{TBP\ x\ c}{BW\ x\ \lambda}}$$

For Gaussian-shaped photons: $N_{\lambda_{MIN}} \geq \frac{0.44\ x\ 3\ x\ 10^8\ m/sec}{BW\ x\ \lambda}$ or $N_{\lambda_{MIN}} \geq \frac{1.32\ x\ 10^8\ m/sec}{BW\ x\ \lambda}$

12 The "chronocyclic Wigner function" is a common method of analyzing spectral-temporal (frequency and time) characteristics of photons.

A 2017 experiment on the generation of heralded[13] single photons from an SPDC[14] source measured the BW of single photons.

> *The type-II SPDC emits signal and idler photons, at 852nm central wavelength ... To extract the single photon bandwidth ... we assume again a Gaussian pulse spectrum ... to give the FWHM[15] spectral bandwidth of the heralded single photons ... We obtain a single photon spectral bandwidth of ... 1.78 ± 0.06 GHz.* [8]

The signal and idler photons have BW = 1.78 GHz and wavelength = 852 nm. A wavelength of 852 nm is a frequency of 351,869 GHz, which makes a BW of 1.78 GHz very narrow, so time, and the minimum number of wavelengths, will be proportionally large.

$N_{\lambda_{MIN}} \geq \dfrac{1.32\,x\,10^{8}\,m/sec}{\left(1.78\,x\,10^{9}\,Hz\right)x\left(852\,x\,10^{-9}\,m\right)}$ = **87,039** wavelengths

A 2016 experiment also used an SPDC source to measure the BW of single photons.

> *We demonstrate such an interface by converting single photons from 1,545nm and a bandwidth of 1 THz to 550nm and a bandwidth of 129 GHz ... we conclude that the bandwidth (full-width at half-maximum) of the idler photon is 963±11 GHz at 1,545 nm central wavelength.* [9]

The signal photon after compression has BW = 129 GHz and wavelength = 550 nm.

Signal photon: $N_{\lambda_{MIN}} \geq \dfrac{1.32\,x\,10^{8}\,m/sec}{\left(129\,x\,10^{9}\,Hz\right)x\left(550\,x\,10^{-9}\,m\right)}$ = **1,860** wavelengths

The idler photon has BW = 963 GHz and wavelength = 1545 nm.

Idler photon: $N_{\lambda_{MIN}} \geq \dfrac{1.32\,x\,10^{8}\,m/sec}{\left(963\,x\,10^{9}\,Hz\right)x\left(1545\,x\,10^{-9}\,m\right)}$ = **89** wavelengths

There is a large variation in these examples, but these numbers are the minimum number of wavelengths that must be present. The above calculations are also based on a theoretical minimum TBP = 0.44. Calculated TBPs using the chronocyclic Wigner function are more than an order of magnitude larger, so all of the photons in these examples likely have many more wavelengths present.

These examples do not show how big any photon is, but do show photons are much bigger than a few wavelengths. This also shows that the many diagrams that appear in textbooks, and other documents, that show the photon as a "wave packet" with just a few (5 to 10) wavelengths are quite incorrect.

13 "Heralded" means a second photon has "announced" the first photon is coming.

14 "SPDC" = Spontaneous Parametric Down Conversion.

15 FWHM = Full Width at Half Maximum.

2.5. Anti-photon

Willis E. Lamb, a 1955 Nobel Prize winning physicist, published an article in 1995 with the title "Anti-photon"[10].

> *It should be apparent from the title of this article that the author does not like the use of the word "photon",which dates from 1926. In his view, there is no such thing as a photon. Only a comedy of errors and historical accidents led to its popularity among physicists and optical scientists.*
>
> *The photon concepts as used by a high percentage of the laser community have no scientific justification.*
>
> *It is high time to give up the use of the word "photon", and of a bad concept which will shortly be a century old. Radiation does not consist of particles, and the classical, i.e., non-quantum, limit of QTR* [Quantum Theory of Radiation] *is described by Maxwell's equations for the electromagnetic fields, which do not involve particles.*

2.6. Quantum mechanics terminology

Quantum mechanics (QM) is the area of physics that deals with all sub-atomic entities. It provides a set of rules (the mechanics) for precisely calculating the expected results of experiments with quantum entities such as photons, but does not provide any sense of what a photon actually is.

QM is generally considered to have started with Max Plank in 1900, gained momentum with Albert Einstein's 1905 paper on the photo-electric effect, and Neils Bohr's 1913 atomic theory that explained electron orbitals and line-spectra, and really picked up speed in the 1920's with Erwin Shrödinger's quantum wave function, Max Born's probability interpretation of the wave function, and Werner Heisenburg's uncertainty principle. It was also in the 1920's that the term "photon" was introduced by Gilbert Lewis to replace Einstein's "light-quanta". Louis de Broglie in 1924 proposed that not only light had both a wave and a particle nature, but so do all sub-atomic particles. There have been refinements over the years but the mathematical formalism of QM was more or less established by 1930. That formalism has provided tremendous success in predicting the results of numerous experiments.

QM uses equations called "wave functions" to describe quantum systems. The tradition is to represent the wave function with the Greek letter psi:"Ψ". Wave functions are complex[16] functions that can have positive and negative values and can interact with themselves and produce interference patterns. There is a lot of debate about wave functions; some believe the wave function is a real thing, others believe it is just a mathematical tool for making calculations.

[16] "Complex" means the square root of -1 ("i") is involved.

A common equation in quantum mechanics is the Schrödinger equation[17].

$$\hat{H} \cdot \Psi = i\hbar \frac{\partial \Psi}{\partial t}$$

This equation defines how a system, defined by the wave function "Ψ", evolves (changes) with time.

Quantum calculations only provide probabilities. The probability of an event is calculated by adding up the contributions from all the different paths the wave function "Ψ" can take. The amplitude of the wave function, for each possible path, is a complex number called the "probability amplitude" for that path. All of the probability amplitudes for the different paths are added[18] together to get an overall probability amplitude at some location, which is then squared[19] to determine the probability[20] of an event at that location. It was Max Born that first proposed the idea that the square of the amplitude of the wave function for an entity at some location, determined the probability of finding it there, so this is known as the "Born rule".

The amplitude of the wave function is called a "probability amplitude", because it is used to calculate probability, but the wave function "Ψ" is not a wave <u>of</u> probability. The number "X" and the square root of "X" can have very different properties; a perfect example is the number -1 and $\sqrt{-1}$.

Richard Feynman did not like the name probability amplitude: "*which we call a probability amplitude because we don't know what it means*" [11]

If we accept that "Ψ" is real, it should be called a "wave" not a "wave function". Adding the word "function" implies it is just a mathematical entity not something real. In their 2012 paper, Roger Colbec and Renato Renner argue the wave function must be real and cannot be a mathematical entity (*interpreted subjectively*).

> *Here we show, based only on the assumption that measurement settings can be chosen freely, that a system's wave function is in one-to-one correspondence with its elements of reality. This also eliminates the possibility that it can be interpreted subjectively.* [12]

Others agree that "Ψ" is a real wave, but a very unusual kind of wave. "*The wave-function is real but nonphysical."*[13] *"Does the wave function correspond directly to some kind of physical wave? If so, it is an odd kind of wave."* [14]

If we call "Ψ" a "wave" and not a "wave function", we also should not call the amplitude of the wave a "probability amplitude", it is simply the amplitude of the wave "Ψ" at any point. But what names would be more appropriate?

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17 This is the "time dependent" version.

18 The "probability amplitudes" are vectors so they are added using vector addition.

19 It is actually the product of the amplitude and its complex conjugate, or the square of the magnitude.

20 It is actually "probability density" as you must integrate over some interval to determine the probability for that interval.

In many papers and texts the wave function "Ψ" is described as containing all possibilities, and it is also described as containing information about everything that can be known about the system.

> *However, there is a long history of suggestions that a quantum state (even a pure state) represents only knowledge or information about some aspect of reality.* [14]

The information aspects (what can be known) seem somewhat independent from the possibility-probability aspects. The two aspects may be orthogonal[21] as certain features, such as quantum spin, seem quite independent. So the name of the wave should include both "information" and "possibility". Both words also have no specific meaning in physics so we can assign aspects, both mathematical and conceptual, to both words as required by quantum mechanics.

The name "Possibility-Information" would be shortened to "PI" - so not a good choice. The name "Information-Possibility" becomes "IP" so (ignoring the overlap with Internet technology) seems a reasonable choice.

The wave function (Ψ) for a light-quantum is then a complex-valued "Information-Possibility" (IP) wave. Restating the Born rule – the probability of an event is the square of the amplitude of the IP-wave.

$$\Psi = Information - Possibility$$

$$|\Psi|^2 = Probability$$

2.7. The Feynman path integral

In 1948 Richard Feynman introduced what is called the "path integral" also called "sum over histories" to quantum mechanics. [16][17][18]

The anecdotal story is that Feynman, as an undergrad, was attending a lecture on Young's double-slit experiment. When told that the interference pattern was created by a photon going through both slits he asked "what if there were three slits?" and was told the interference pattern would then be the result of the photon going through all three slits. He of course then asked "what if there were ten or a thousand slits?". The answer was that the interference pattern would then be the result of the photon going through all ten or all one thousand. He realized that the situation with no slits was actually the same as an infinite number of slits; so many slits that there was nothing between them. So the task was to develop a mathematical way to add up the contribution from every possible path a photon could take; hence the term "path integral".

All classical aspects of optics, such as light traveling in a straight line, and the way lenses focus light, are explained by the path integral.

[21] Independent, or in more rigorous terms: the dot product is zero.

As previously stated, quantum mechanics adds values (amplitudes) of the wave function that are called "probability amplitudes". The path integral has two basic principles [17]:

1. The probability for an event is the square of the magnitude of the total probability amplitude.
2. The total probability amplitude is calculated by adding together the contributions of the individual probability amplitudes for every possible path.

Feynman used vectors[22] to represent the probability amplitudes for each path the wave function could take because the wave function is a complex wave and the probability amplitude for each path has both magnitude and phase. The total probability amplitude is the vector sum of the individual vectors for each path.

If the wave function is a complex-valued IP-wave, the probability amplitude vectors represent the magnitude and phase of the IP-wave, at every location, for each path. A water wave going through two slits, generates an interference pattern because the single wave takes multiple paths. The variation of total probability amplitudes for different locations is just the interference pattern of a single IP-wave that takes multiple paths.

Re-stating the path integral principles replacing "probability amplitude" with magnitude of the IP-wave:

The path integral has two basic principles:

1. The probability for an event at any location is the square of the magnitude of the total IP-wave at that location.
2. The magnitude of the total IP-wave at any location is the superposition of the IP-waves for every path.

The path integral is significant because it highlights a major inconsistency with the current conceptual model of the photon. If there are many possible paths, how can a photon, a localized packet of EM energy, take every path? It is clear that "something" is taking every possible path because we can selectively block certain paths and get very different results. Results that are in complete agreement with QM and the path integral. QM says that an IP-wave is taking each path. QM is correct; we simply need to re-conceptualize what a light-quantum is, so it aligns with what QM is telling us.

If photon detectors are placed in some of the paths, only one detector ever registers a photon, and it registers an entire photon. So how does a photon split itself up to take every path but somehow deposit all of its energy on one detector that is located in a single path?

As previously stated, QM is not the problem. The mathematics is correct – it provides very accurate and consistent predictions. The problem is that QM requires light-quanta to have qualities that are inconsistent with light being a localized form of EM radiation.

We need a conceptual model of light-quanta that embraces what QM is saying and what is experimentally verified.

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[22] Feynman called them "arrows" in case the term "vector" was unknown to some of the audience.

2.8. Object permanence

For the first few months of a human baby's life, when an object is out of sight it ceases to exist. Which is (probably) why the game of "peek-a-boo" is popular with infants; when you put your hands in front of your face you cease to exist, when you move your hands away, you suddenly appear from nowhere. Infants gradually learn object permanence and, by about 18 months, they are aware that objects continue to exist even when out of sight. [19]

Consider a ball initially at location "A", that rolls and disappears behind a wall. Sometime later, what looks like the same ball, emerges from behind the wall and stops at location "B". Because the ball at B looks the same as the ball that left A, and because of object permanence, we instinctively assume that the ball, now at B, is the same ball that was at A, and that it must have travelled, behind the wall, from A to B. The ball that left location A may be a completely different ball that arrives at B, but because we have learned that objects do not cease to exist when out of sight, and the balls look the same, we instinctively assume it is the same ball.

The same cognitive bias is always influencing how we interpret what we observe. If we observe that an atom at location "A" loses energy and sometime later we observe an atom at location "B" gains the exact same amount of energy, we instinctively assume that the energy must have travelled from A to B, even though we cannot detect it traveling.

2.9. A monetary analogy

The following analogy shows how object permanence can bias perception.

There was a time, not long ago, when we used money in the form of gold and silver coins to purchase goods and services. (For simplicity just gold will be used.) If you lived in town "A" and wanted to buy something from a vendor in town "B", you would travel to town B with your gold coins, exchange the gold coins for the goods, and travel back home. Needing to carry large amounts of gold presented serious impediments to trading over large distances.

Back in the 1100's, shortly after the first crusade, the "Knights Templar" created what is considered to be the first international banking system[20]. You could take a bag of ten gold coins to a "Templar bank" in your town and exchange it for a piece of paper - a "letter-of-credit" (or other similar document). You could then travel to town B with just your piece of paper. The paper was much easier to carry and was of no value to the various brigands you may encounter on the way. When you arrived at town B, you could go to the Templar bank there, exchange your piece of paper for a bag of ten gold coins, then go to the vendor in town B and exchange the gold coins for the goods.

Imagine a group of aliens from another planet observing the entire procedure from space and unaware of the Templar's banking system. They could see that you had a bag of ten gold coins when you were in town A. They could not see you traveling between towns (you were under trees), but sometime later they could see you with a bag of ten gold coins in town B. The bag of ten gold coins in town B would appear identical to the bag of ten gold coins in town A, so object permanence would make the aliens instinctively assume that the bag of ten gold coins had travelled with you from town A to town B.

3. What are Light Quanta?

We know that a light quantum is a wave; many experiments including Thomas Young's double-slit experiment confirm that. The assumption that a light quantum is also a particle "*localized in space"* started with Einstein's explanation of the photo-electric effect, and is wrong; a light quantum is a wave[23]. The apparent particle nature of light quanta is an emergent property of how light quanta are emitted and absorbed. QM says it is a wave (a wave function), and the path integral only makes sense if it is a wave that takes every path. QM says light quanta are waves. If we accept that they are information-possibility waves, and discard the idea of little bundles of localized EM energy, we have a simpler conceptual model that is consistent with QM theory and with observation.

We know that specific amounts of energy are emitted by a light source and absorbed by a destination. The source and destination are locations, such as individual atoms, that are tiny compared to the size of the light quantum. The source emits and the destination absorbs 100% of the energy. The proposed model is that light-quanta do not carry energy but they do contain information that allows energy to be transferred from an energy field to the destination. A light quantum is analogous to the "letter-of-credit" described in the monetary analogy, and the gold coins are analogous to energy. What travels between the source and the destination is information, not energy.

The proposed model of light quanta requires the existence of a **quantum energy field** that functions like the Templar's bank in the monetary analogy; energy is deposited by the source and withdrawn by the destination.

When an atom[24] "emits" a light-quantum, the atom is actually interacting[25] with the quantum energy field (QEF). The atom transfers energy to the QEF, and a light-quantum (IP-wave) is created by the QEF; not by the atom. That allows light-quanta to be much larger than atoms because light-quanta are not created by atoms. That also allows 100% of the energy to be transferred because it is an interaction between the atom and the QEF.

The light-quantum spreads out, which it can easily do because it is a wave of information-possibility not energy. The IP-wave takes all paths and interferes with itself. The probability the energy will be deposited at some location is the square of the amplitude of the total IP-wave at that location.

At some location where possibility is not zero, there is an interaction between the IP-wave, the QEF, and the atom that will receive the energy. When an atom "absorbs" a light-quantum, it is actually interacting with the QEF and the IP-wave. The energy is transferred from the QEF to the atom, not from the IP-wave, that is orders of magnitude larger than the atom receiving the energy. The IP-wave collapses.

23 Other quantum entities do have wave-particle aspects because they also have rest mass. The light-quantum has zero rest mass so it is only a wave.

24 An atom is just used as an example.

25 As mentioned earlier, it is actually the various quantum fields that are interacting.

3.1. Non-locality and entanglement

The light-quantum, IP-wave, must be "non-local"; meaning the wave is spread out and communication within the wave is "super-luminal" (faster than light). This is necessary for the IP-wave to collapse when the energy it represents is transferred from the QEF to a quantum entity such as an atom. It must also be non-local to support entanglement.

The non-local nature of QM was evident quite early in the development of quantum theory, because QM requires the wave function to collapse when observed or measured[26]. A quantum entity evolves according to Schrödinger's wave equation until it is observed. When evolving, the quantum entity is spread-out and has the possibility of being at many different locations. When it is observed, it must be at one specific location; the many possible locations must instantaneously "collapse" into one actual location. The transition from a spread-out wave of possibilities, to something at a specific location, is called the "collapse of the wave function". For a spread-out wave of possibilities to instantaneously transition to be something at a specific location, there must be some sort of communication within the wave, so all the spread-out parts know the collapse has occurred.

The non-local aspects of QM become more apparent when "entangled" particles are involved. Orthodox QM theory says there are quantum events that can produce pairs of particles that are described by a single wave function; they do not have individual wave functions. Because there is only one wave function for the pair, their aspects are connected. Shrödinger coined the word "entangled"[27] to describe this connected state.

One common example, used in many quantum optics labs, is "spontaneous parametric down conversion" (SPDC). Type-II SPDC produces a pair of photons that are polarization entangled with complimentary polarizations; if one photon has vertical polarization the other photon must have horizontal polarization. A key aspect of entanglement is that neither photon actually has vertical or horizontal polarization until one of them is measured. According to orthodox QM theory, before measurement, there is only one wave function and both photons exist in a superposition of having both horizontal and vertical polarization. The instant one of them is measured the other instantaneously changes from a superposed polarization state to being in a definite and complimentary polarization state.

This apparently impossible situation was challenged by a now famous paper written by Albert Einstein, Boris Poldolsky and Nathan Rosen in 1935, and now simply called the "EPR" paper. In this paper they showed that QM requires this "spooky action at a distance" (their term) and made the case that QM must be incomplete because this requires a signal to travel from the first photon being measured, to the other photon, at super-luminal speed. They argued that super-luminal communication was not possible, so polarization information must actually be carried with each photon, even if it is not detectable. Because the information is carried by each photon, and not communicated at super-luminal speed, it is called "local". Because the information is not detectable, it is called "hidden". So theories of this type are called "local hidden-variable" theories.

[26] In orthodox quantum terminology "observed" and "measured" mean the same thing.

[27] He actually used the German word "Verschränkung".

Not much happened to address this mystery until John Stewart Bell published a paper in 1964 in which he showed that no "local hidden-variable" theory could explain the strong correlations that quantum entanglement predicted. Since Bell's paper many experiments have been performed that confirm his predictions. The unavoidable conclusion is that entanglement and "spooky action at a distance" are real. QM is non-local; information is sent at super-luminal speed.

> *This communication must be faster than light if the outcome at one station is space-like separated from all relevant events at the other station.* [21]

This totally agrees with the proposed model that light-quanta are IP-waves and that communication within the IP-wave is non-local (super-luminal).

The proposed model that light-quanta are IP-waves has a significant implication for entangled light-quanta. QM requires the entangled pair to be described by a single wave function because they are created by a single quantum event. The proposed model of light-quanta agrees completely. A single quantum event creates a single IP-wave; there are not two separate photons. There is only one IP-wave and it carries information that allows the single IP-wave to interact with the QEF at multiple locations, making it appear as if there were two separate photons.

The orthodox QM explanation says an SPDC-Type II source produces a pair of entangled photons that are each in a super-position of being both vertically and horizontally polarized. The proposed conceptual model of light-quanta says there is a single quantum event that creates a single IP-wave that contains information that allows two connected interactions with the QEF. When the IP-wave interacts with the first destination and the QEF, a random choice is made (a coin is flipped) that the interaction will be horizontal, so the interaction between the destination, the IP-wave, and the QEF results in the detection of a horizontal photon. The IP-wave is non-local and it communicates the event to all parts of the wave. The IP-wave interacting with the second destination "knows" (has information), that only vertical is now possible. The IP-wave interacts with the second destination and the QEF, and a vertical photon is detected.

The non-locality and the single wave ideas are essential features of QM theory. The proposed conceptual model, the concept that light-quanta are IP-waves, is just embracing the existing requirements of QM. Light-quanta are IP-waves that have no mass or energy or momentum; they could not spread out and take every path if they did. Energy and momentum are transferred by the source to the QEF, and from the QEF to the destination.

3.2. Is information a fundamental aspect of nature and reality?

John Archibald Wheeler, possibly the most influential physicist since Einstein, clearly thought that information might be a very fundamental aspect of nature and reality.

> *I suggest that we may never understand this strange thing, the quantum, until we understand how information may underlie reality. Information may not be just what we 'learn' about the world. It may be what 'makes' the world.* [22]

There are many current quantum theories that suggest that information is something quite fundamental to quantum mechanics and nature. In a poll conducted at a 2011 conference on "Quantum Physics and the Nature of Reality", many respondents favored an information-based/information-theoretical interpretation of quantum mechanics.

> *Evidently, there is broad enthusiasm or at least open-mindedness about quantum information, with three in four respondents regarding quantum information as "a breath of fresh air for quantum foundations." Indeed, it is hard to deny the impact quantum information theory has had on the field of quantum foundations over the past decade. It has inspired new ways of thinking about quantum theory and has produced information-theoretic derivations (reconstructions) of the structure of the theory.* [23]

In a 2005 article in Nature "The message of the quantum", Anton Zeilinger seems to be agreeing with what John Wheeler proposed:

> *Maybe this suggests that reality and information are two sides of the same coin, that they are in a deep sense indistinguishable. If that is true, then what can be said in a given situation must, in some way, define, or at least put serious limitations on what can exist.* [25]

In a 2006 paper "The Information Interpretation of Quantum Mechanics and the Schrödinger Cat Paradox", Kofler and Zeilinger state that reality and information are deeply connected.

> *The quantization of nature is a consequence of the quantization of information. Moreover, reality and information are two sides of the same coin.* [24]

4. The Proposed Conceptual Model Explains Different Phenomena

Many existing situations are difficult, if not impossible, to explain assuming the current conceptual model of photons. They are very easy to explain using the proposed model of light-quanta.

4.1. Young's double-slit experiment

The "double-slit" experiment is often cited as the prime example of the conflict between the current concept of the photon and what QM says. Richard Feynman said "*In reality, it contains the only mystery.*" [15]

The orthodox QM view is that the wave function is in a superposition of having gone through both slits. From a conceptual view that means a photon (a localized bundle of EM energy) magically goes through both slits, then the waves from each slit interfere and manage to recombine somehow, so all of the energy shows up at a single spot. If detectors are placed so they can tell which slit the photon went through, they always detect a complete photon but never at the same time.

Young's double-slit experiment presents no mystery if light-quanta are considered IP-waves that do not carry energy. An atom in the light source interacts with and transfers energy to the QEF. The QEF creates a light-quantum, an IP-wave. The IP-wave spreads out, passes through both slits and interferes with itself. At some location, where the amplitude of the IP-wave is not zero (so probability is not zero), there is an interaction between the IP-wave, the QEF, and an atom that can receive the specific amount of energy. The atom at the chosen location receives energy from the QEF, and the IP-wave collapses.

If detectors are placed so they can tell which slit the IP-wave went through, they always detect a complete photon because the IP-wave interacts with the QEF and the atoms in the detectors. If the choice of location is the detector (based on the amplitude of IP-wave), the QEF transfers the energy to an atom in the detector. If the IP-wave does not choose to transfer energy at the detector, the non-local communication within the IP-wave means all parts of the wave still "know" the detector is present[28] so there is no interference pattern on the detection screen.

The question "which slit?" is irrelevant as the IP-wave always takes all possible paths.

4.2. The Standard Model and the force carrier for the EM field

The Standard Model is a theory that describes three of the four fundamental forces in the universe: the strong force, the weak force, and the electromagnetic force. It does not explain gravity. Each fundamental force has its own corresponding force-carrying particle and the electromagnetic force is carried by the "photon".

The Standard Model has been remarkably successful. Complex equations have been developed that allow the theory to make predictions that agree[29] with virtually every experiment. The Standard Model predicted the "Higgs boson". It does however have problems. Some problems are complex and largely mathematical, but some are very fundamental. The Standard Model does not include gravity, and it predicts the existence of gravitons and magnetic monopoles.

> *We may have confirmed our theory again and again but, increasingly, we've also gathered evidence that it isn't right, that it isn't the last word. The Standard Model simply can't explain some of the most prevalent and fundamental features of the universe ...*
>
> *These observations make us suspect that there must be a better, more fundamental, extensive description of the universe. We just don't know what it is yet. There are hundreds of ideas out there, ranging from gentle extensions of the Standard Model to frankly freaky bizarreness.* [26]

In the Standard Model, the photon is the "force carrier" for the electromagnetic field. Electric and magnetic fields can repel (push) and attract (pull), and the Standard Model explains the repulsive and attractive forces as resulting from the exchange of force-carrier particles - photons. The repulsion is understandable because photons carry momentum so

[28] This also explains why the interference pattern disappears even if the detectors are turned off.

[29] Within acceptable errors margins.

(conceptually at least) they can exert a "push" on an object, but how does a photon exert a "pull" on an object?

Mathematically an attractive force appears if one just adds a minus sign to the momentum, but that makes no sense; how does any object have negative momentum? Existing theory cannot explain how it all works. Even for a repulsive force, which is acceptable conceptually, normal photons do not work because sources would have to be constantly emitting photons that have energy and momentum, and that would violate energy and momentum conservation laws.

The solution was "virtual" photons. Virtual photons do not have the characteristics of real photons; they are "virtual". They do not have the energy and momentum that real photons have, and are mathematically only allowed to exist, as long as they do not exist for very long[30]. They are an invention that makes the mathematics work but they make no sense from a conceptual viewpoint.

There is a lot of debate about virtual photons. Some say they are not real and are just a mathematical tool to make calculations work, others argue they must be real because of the measurable effects they have. The idea that virtual photons, that can only exist for an instant, are responsible for both an attractive and repulsive force, that in theory extends to infinity, may work mathematically, but it presents an absurd conceptual model. Inventing virtual photons, that are called "virtual" because they don't really exist, to explain EM forces, seems a bit like Ptolemy's "epicycles" and "deferents"; they just make the math work.

A simpler answer is that light-quanta are IP-waves. Sources can interact with the QEF and EM fields, to generate IP-waves, that have no energy or momentum, but contain information that will cause the QEF and EM fields, to interact with some destination to push or pull on the destination. The light-quanta are not pushing or pulling on the destination, the QEF and EM fields are. The reverse process is also happening, so the system is always in balance and conservation laws are obeyed. There is no need to invent virtual photons. The conceptual model of light-quanta as IP-waves explains normal light (events involving energy transfer) and EM forces.

4.3. Partial reflection

Feynman's favorite example of partial reflection, was the image of the moon reflecting (partially) from the surface of water at night[16].

QM has difficulty explaining why light partially reflects when traveling from air to water (or any medium change) if light is composed of little bundles of EM energy called photons.

The proposed model that light-quanta are IP-waves, provides a simple explanation. The IP-wave has no energy so it can spread out, take every path, and reflect and refract[31] the same way other waves do.

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30 Heisenburg's uncertainty principle allows virtual particles to exist as long as they exist so briefly they cannot be observed.

31 Refraction is the change in direction of a wave when it enters a different medium.

The IP-wave from the light source, both reflects from the air-water interface and refracts (enters) into the water. The reflected path through the air and the transmitted path through the water, are just different paths the IP-wave takes – it takes all paths. At some location where the amplitude of the IP-wave is not zero, so probability is not zero, there will be an interaction between the IP-wave, the QEF and the atom receiving the energy. The chosen location will be more likely where the IP-wave has larger amplitude. The ratio of light transmitted or reflected is contained in the IP-wave amplitudes at every location.

If the chosen place is an atom in the water, all of the energy is transferred from the QEF to that atom and the IP-wave collapses. The photon appears to have not been reflected. If the chosen place is an atom in a camera, or the eye of the person viewing the partial reflection, the QEF transfers all of the energy to that atom, the IP-wave collapses, and the photon appears to have been reflected.

4.4. The Mach-Zehnder interferometer

This is a very common device in optics labs that produces an interference pattern based on length differences in two optical paths.

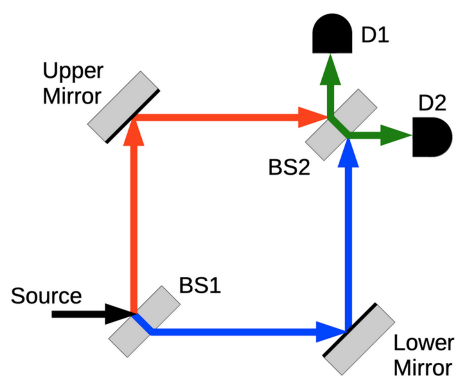

Figure 1: Mach-Zehnder Interferometer

When the source of light is a "beam" of light containing many photons, the interference can be explained classically. Some photons are reflected at beam splitter BS1 and take the upper (red) path, the rest are transmitted at BS1, and take the lower (blue) path. Photons from the upper and lower paths combine at beam splitter BS2, and interfere constructively or destructively depending on differences in the two path lengths. This explanation however does not actually make sense because photons do not interfere with other photons[32].

When the source is a single photon the orthodox QM explanation is that the one photon is in a superposition state of having taken both paths. Like the double-slit case, the implication is that the photon splits itself in two at the first beam splitter, travels both paths, then interferes with itself at the second beam splitter. If detectors are placed in each

32 There are special cases where separate photons do appear to interfere, but the photons have to be virtually "indistinguishable".

path they detect a complete photon, but never at the same time. The implication from that, should be that the photon only takes one path, but if that was true, how would it interfere with itself at the second beam splitter?

The simpler explanation is that a single light-quantum, an IP-wave, reflects and transmits at both the first and second beam splitters. It combines and interferes with itself at the second beam splitter and continues on to both detectors. The IP-wave interacts with the QEF at both detectors. The amplitude of the IP-wave, which can be zero because of interference, determines how often each detector receives the energy from the QEF. The same is true if detectors are placed in one or both of the two paths; the IP-wave takes both paths and selects one location, one detector, to transfer energy from the QEF.

There is nothing mysterious or confusing. All the equations of quantum mechanics still work the same. The superpositions of the photon are just the different paths taken by the IP-wave, currently called the wave function Ψ.

4.5. Bubble chamber tracks

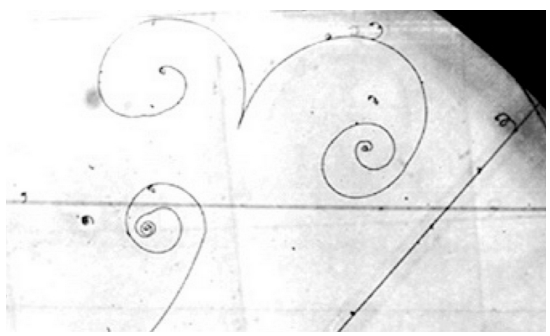

Figure 2: Bubble Chamber Tracks [27]

The top half of the above image shows the tracks of two particles[33], curling in opposite directions, that were created by a photon that leaves no track. Why do photons not leave tracks in bubble chambers[34]? Why can a passing photon not give up a little bit of its energy (like the other particles do) to make a track, and just drop in frequency a bit (to adjust to the lower energy)? Why does the energy exchange have to be "all-or-nothing"?

The orthodox photon concept has difficulty explaining this. A passing photon that is a little bundle of EM energy should be able to give up some energy and continue at a lower frequency but it cannot. In the above image the incoming photon had enough energy to create two entire particles, each of which left a track, but the photon left no track.

"Compton scattering" is the scattering[35] of a photon (in Compton's case, high energy x-rays) by a free charged particle, usually an electron. This is a situation where the photon does (appear to) loose some energy. It comes out of the "collision" with slightly less energy

[33] An electron-positron pair.

[34] Or cloud chambers.

[35] "Scattering" just means it collided and bounced off.

(lower frequency) because the photon looses some energy to the electron[36]. This was used as an argument that photons had particle aspects. This shows photons can give up some energy – so why can't they do the same in situations like bubble chambers?

A light-quantum, IP-wave, conceptual model, explains the situation easily. The light-quantum is not a little bundle of energy, it contains no energy. It is like the "letter-of-credit" from the monetary analogy. You cannot tear off a piece of the letter-of-credit and exchange it for gold. You can only exchange the letter for the full amount; it is an all-or-nothing situation. In Compton scattering, the "collision" between the photon and the electron is really an interaction between the IP-wave, the QEF, and the electron. The original IP-wave collapses, the QEF transfers energy (momentum) to the electron, and a completely new IP-wave is created.

5. Technologies That Involve Quantum Events at RF Frequencies

There are technologies that involve quantum events at frequencies that are considered radio frequencies (RF). If light quanta are not EM waves there should be obvious conflicts between theory and experimental measurements.

5.1. Nuclear magnetic resonance

The conflict is very evident with nuclear magnetic resonance (NMR). The controversies come from the fact that there is no consistent theory that can be used. Different situations require the use of different equations. Some solutions are quantum-mechanical but others are largely classical (Maxwell's equations).

A 2009 paper by David Hoult presents the various controversies and shows that there is little or no connection between EM waves (radio waves) and NMR signals.

> *The origins, history, and present status of the controversy surrounding a quantum description of the NMR signal as being due to radio waves are traced. With the Principle of Relativity and Coulomb's Law as formal starting points and the minimum of mathematics needed for understanding, the derivation of a classical electromagnetic theory of signal reception is first given. The agreement between that classical theory and a recent NMR experiment is then presented, leading to proof that, except for the highest field imaging experiments, there is no significant contribution of radio waves to the signal.* [28]

36 There is also "reverse" Compton scattering where the photon gains energy, but that is less common.

5.2. The 21 cm hydrogen line and the cosmic microwave background

When the electron in the hydrogen atom changes its spin direction, from the same direction as the nuclear spin to the opposite direction, the atom is in a slightly lower energy state and the energy difference is emitted as a photon. The energy difference is quite small[37] so the equation E=hf, gives a frequency for the emitted photon of approximately 1420 MHz and corresponding photon wavelength of 21 cm. Hydrogen exists in vast clouds throughout all galaxies so this signal is very important to radio astronomy.

The "cosmic microwave background" (CMB) is the spectrum of photons that are detectable today at a black-body temperature of approximately 2.7 °K. They were (according to theory) created about 380,000 years[29] after the Big Bang when the universe was about 3000 °K. Black-body radiation at 3000 °K produces a spectrum of photons with a peak color of orange (high frequency and short wavelength). As the universe expanded these photons got stretched, and longer wavelength means lower frequency. The universe has expanded tremendously, so the frequency of the "stretched" photons is now down in the microwave range – hence the label.

The CMB was discovered by Arno Penzias and Robert Wilson in 1965. They were taking measurements with a microwave horn antenna and discovered an unexplainable noise, a background hiss.

The 21 cm hydrogen signals are received by radio telescopes. The CMB signals[38] were initially detected by a radio receiver as noise, a background hiss. The 21 cm hydrogen and CMB signals, are light-quanta because they are created by quantum events, but they are received by what are called "radio receivers", not by optical telescopes. That seems to be clear evidence that light-quanta are EM waves, but a closer examination shows they are not.

Radio telescopes are called "radio" telescopes but they receive in virtually all EM frequencies. Most of the EM signals received by radio telescopes are received by antennas. An EM wave received by an antenna produces a time-varying signal, and the time-varying signals, from multiple antennas in multiple radio telescopes, can be combined to create a larger time-varying signal, which is the equivalent of a larger virtual radio telescope called a base-line array.

The 21 cm and CMB signals are <u>not</u> received by antennas. They do <u>not</u> produce time-varying signals. These signals cannot be combined with signals from other antennas. These signals are received by sensors called bolometers[39] that measure received energy as an increase in the temperature of the sensor. This is precisely how light-quanta are received, it is not how EM radiation is received. The receivers are only called "radio receivers" because they receive signals in the "radio" range.

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37 Energy is approximately 5.9 x 10^{-6} eV

38 CMB signals are now mainly received by the Planck Satellite which was specially designed to receive this signal – but the type of receiver is still a bolometer.

39 Also called "radiometers" but still measure impulse noise not a time-varying signal.

A bolometer is more sensitive than an electrical antenna, and these signals are very weak. However the original detection of the CMB by Penzias and Wilson was with a radio antenna and the signal was loud enough to be a problem, so these signals can be received by antennas, but they are not really "signals", they are not time-varying. The CMB signal originally received by Penzias and Wilson was just constant noise, a background hiss; which is precisely how light-quanta would behave. The light-quanta depositing energy on the antenna would be like raindrops hitting a tin roof; they do not create a time-varying signal.

How can equipment designed to receive EM waves, receive light-quanta that are not EM waves? The answer is that the receiving equipment is just waveguides and resonant chambers leading to a bolometer sensor. The equipment is designed to receive a particular wavelength and EM waves and light-quanta have the same wavelength.

5.3. Terahertz radiation

The terahertz (THz) region of the electromagnetic spectrum lies between the microwave and far-infrared frequencies, so approximately 0.3 to 10 THz frequency or 1.00 to 0.03 mm wavelength and often called the "sub-millimeter" wavelength band.

This band marks the transition from what we know is EM radiation (radio waves) and the beginning of the optical frequencies that current theory says is just higher frequency EM radiation. There has been little development in this frequency band because the generation and detection of EM radiation at these frequencies is very difficult. With the higher speed electronics being developed and micro-fabrication technology (for very tiny antennas) that is starting to change.

Because this frequency range will allow the transmission and reception of EM radiation that has historically been considered light, development of this technology may accelerate the realization that light and EM radiation are not the same phenomena.

Terahertz transmitters do not use quantum events to generate signals, they use very tiny dipole antennas and generate EM radiation by accelerating free electrons in the dipole antenna; the way EM radiation is always generated. The typical argument is that signals at these frequencies cannot be generated by quantum events because the energy levels of the quantum events are too small.

There are terahertz transmitters that use lasers with "photoconductive antennas" and that seems to imply that EM radiation is being produced by quantum events. A closer examination however shows that in every case there is an actual dipole antenna and EM radiation is produced by the acceleration of free electrons in the antenna. The use of optical technology, such a lasers, is just to create the free electrons in the antenna. [30]

6. Is Nature Quantized?

The simply answer is “no” - nature is not quantized. There is a lot of confusion about this because quantum mechanics says that everything down at the atomic level is quantum mechanical and Einstein said that light is quantized so the implication is that quantization is a fundamental aspect of nature and everything comes in little chunks. That is not true.

Part of the confusion comes from the term “quantum mechanical”. The term implies that things are quantized (little chunks) but that is not what it means. It means that things are wave functions (or at least they are described by wave functions) and wave functions are continuous. There are situations where the only allowable values are discrete but that is because the particular events, such as electrons changing orbitals, only allow specific energies; specific solutions to the wave equations.

Planck applied quantization to blackbody radiation to get the equations to fit the observed data. At any given frequency, light comes in little chunks, not a continuous stream. The incorrect conclusion, that many seem to make, is that light only comes at certain frequencies, so you can only get certain energies. That is not the case. The blackbody radiation spectrum is continuous, so light is emitted at all frequencies in the spectrum. The light at any one frequency is a quantized amount of some basic energy, but any frequency, so any energy, is possible. Energy is not quantized, just the emission and absorption of energy, which is precisely what Planck originally said.

Schrödinger’s famous equation is continuous; there is nothing discrete about it.

$$\widehat{H} \cdot \Psi = i\hbar \frac{\partial \Psi}{\partial t}$$

The apparently discontinuous, discrete, quantum appearance, is an emergent quality – nature is not quantized.

From “Quantum Fields: The Real Building Blocks of the Universe – with David Tong”.

> *Question: At a fundamental level is nature discrete or continuous?*
>
> *Answer: I see no evidence whatsoever for discreteness. All the discreteness that we see in the world is something that emerges from an underlying continuum ... the quanta are emergent.* [31]

Light-quanta emitted from distant stars, for example, are quantized at specific energies because of the underlying quantum events that created them. Those light-quanta also experience red or blue shifts (changes in energy) due to doppler shifts and expansion of the universe. The red or blue shifts are continuous, not quantized, so light-quanta are not “quantized oscillations” they are just oscillations, of an IP-wave.

Using a monetary analogy; it is only transactions with the bank that are quantized. If you were withdrawing money from a bank machine that could only dispense $10, $20 and $50 bills, every transaction would be “quantized” at $10. Every transaction would be a multiple of $10, and the minimum amount you could withdraw would be $10.

7. Summary

There are many assumptions behind the current conceptual model of the photon:

- Photons are assumed to be localized packets of EM energy
- Energy is assumed to travel from the source to the destination
- An atom[40] is assumed to emit and absorb 100% of the energy carried by a photon

These assumptions have existed for a very long time. Many related conceptual and mathematical theories have been developed that support these assumptions[41] but there have been many cases of theories that supported incorrect concepts.

What gets us into trouble is not what we don't know.
It's what we know for sure that just ain't so.[42]

In the proposed conceptual model:

- Light-quanta:
  - Are non-local waves of information-possibility
  - Do not have energy so they can go everywhere, take every path
  - Wave amplitude at any location determines the probability of an interaction at that location
  - Energy and frequency are related by Planck's constant (E=hf)
- A quantum energy field:
  - Exchanges energy with quantum entities[43]
  - Interacts with other quantum fields
  - Creates and destroys light-quanta

Why has so much theory and related mathematics been developed on the assumption that light is EM energy?

- Many equations are actually wave equations. Light and EM radiation both travel at the same speed "c", so they are both waves and they have the same frequency and wavelength. As with the radio-telescope receiving equipment, the design equations and equipment work because the wavelengths are the same.
- We tend to see what we expect to see and what we are looking for. A very good example is the "Selective Attention Test" by Simons and Chabris [32]
- Much of what has been developed is very selective and does not work for all situations.

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[40] Or other quantum entity.

[41] If they did not agree with existing assumptions they would have been discarded long ago.

[42] Source unknown but often attributed to Mark Twain (Samuel Clemens).

[43] Quantum entities are quantized disturbances of a quantum field.

The often excessive focus on mathematics and the belief that the answers lie in the mathematics, even though the mathematics often requires absurd conceptual issues such as “virtual photons”, has caused many to expressed concern.

One of the founders of Quantum Mechanics - Paul Dirac, had this to say:

> *Some physicists may be happy to have a set of working rules leading to results in agreement with observation. They may think that this is the goal of physics. But it is not enough. One wants to understand how Nature works.*
>
> *Mathematics is only a tool and one should learn to hold the physical ideas in one's mind without reference to the mathematical form.* [33]

Richard Feynman when presenting quantum electrodynamics (QED) theory to a general audience commented:

> *Mathematics is just tricky ways of doing something that would be laborious otherwise … students take four years of undergraduate work plus four years of graduate work to learn how to add these arrows*[44] *cleverly and quickly … that’s all they learn is how to add the arrows … the more accurately they can do it adds nothing to their understanding of it.* [16]

Sabine Hossenfelder’s recent book “Lost in Math – How Beauty Leads Physics Astray”, addresses the current state of theoretical physics and how efforts to make the math more “beautiful” are leading the research in the wrong direction. A bigger issue is not the effort to make the math more beautiful – it is simply the focus on the math, too often at the expense of sensible conceptual models.

J.B.S Haldane is quoted as saying:

> *Theories have four stages of acceptance:*
> 1. *This is worthless nonsense.*
> 2. *This is an interesting, but perverse, point of view.*
> 3. *This is true, but quite unimportant.*
> 4. *I always said so.*

There is a tremendous amount of theoretical and mathematical analysis regarding light and electromagnetic theory. Anyone with a basic education in physics “knows” that light is electromagnetic radiation. Challenging such a well known “fact” is not just silly or even insane; it is ludicrous! So this paper is submitted with the certain knowledge that, in the opinion of many, it achieves Haldane’s stage 1.

[44] The “arrows” are the vectors representing complex probability amplitudes.

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Appendix: Cosmic Implications of a Quantum Energy Field

If a quantum energy field (QEF) exists, stars are constantly "depositing" very large amounts of energy into that field. Energy is not being radiated away as photons, made of electromagnetic energy, it is going into the QEF. IP-waves, that contain no energy, are radiating away. Energy is equivalent to mass ($e = mc^2$ so, $m = e/c^2$). How much equivalent mass would the energy in the QEF contain on a galactic scale?

The following is an estimate, using our star (the sun) and our galaxy (the Milky Way), of how much energy, and the mass-equivalent of that energy, that would exist in the galaxy given the rate at which stars are generating energy, the number of stars in the galaxy, and the age of the galaxy.

- The mass-equivalent of the energy our sun produces ($m = e/c^2$) is 4.26 million metric tons per second [35], which is 4.26×10^9 Kg/sec
- At 31557600 seconds per Julian astronomical year, our sun produces the energy mass-equivalent of:
  4.26×10^9 Kg/sec x 3.15×10^7 sec/year = 1.34×10^{17} Kg/year
- Assuming our sun is close to average for the galaxy, and that there are approximately 250 billion stars in the Milky Way galaxy, the combined energy mass-equivalent produced by all the stars in the galaxy is:
  1.34×10^{17} Kg/year x 250×10^9 stars = 335×10^{26} Kg/year
- Our galaxy is considered to be 13.6 billion years old[36]. That gives a total energy mass-equivalent over the age of the galaxy of:
  335×10^{26} Kg/year x 13.6×10^9 years = **4,556 x 10^{35} Kg**

The mass of the Milky Way galaxy is approximately 890 billion solar masses[37]. The mass of our sun (one solar mass) is 2×10^{30} Kg, so the galaxy weighs about:
$890 \times 10^9 \times 2 \times 10^{30}$ Kg = **1,780 x 10^{39} Kg**

The mass of the Milky Way galaxy is almost 4,000 times greater than the total energy mass-equivalent contribution of all the stars in the galaxy over the entire age of the galaxy. So the total potential contribution to galactic mass by a QEF seems to be quite insignificant.