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# The Light in a New Light: Always a Wave, Never a Particle

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**Abstract:** Though it has been widely viewed that the light consists of quantum particles known as photons, the light is not made of quantum particles or photons, and the light is always a wave. What is quantized in the light is the frequency. The electromagnetic frequency is always quantized due to the quantized nature of the electromagnetic energy; the quantum energy results in quantum frequency. The light is made up of many discrete electromagnetic wave bursts of constant durations; each burst consists of an electromagnetic wave of a single frequency determined by an integer multiple of the indivisible quantum energy units. The quantum energy and frequency are synonymous; they are one and the same. The duration of a wave burst is a universal constant, and it is the same for all the wave bursts irrespective of the frequency of the electromagnetic wave they contain. Since the quantum energy is in the frequency of the electromagnetic wave in a wave burst, the light can be propagated unlimited distances with the quantum energy intact, without which, the evolution of life would not have occurred. The quantum energy is not affected by any gradual path degradation even after the propagation of light for billions of light years since the quantum energy is the frequency; this would have been an impossible task by any other means such as carrying the quantum energy in a particle or photon on a wave. The light is always a wave, and never a particle; there is no wave-particle duality. There is absolutely no need for an unrealistic, artificial quantum light particle, or photon hypothesis. The hypothetical mass-less particles only exist in human imagination; they do not exist in the nature.

**Keywords:** Photon, Light, Quantum-Light, Quantum-Frequency, Maxwell-Equations, Quantum-Energy, Quantum-Particles

## 1. Introduction

Several centuries ago, Newton believed the light to be consisted of particles; however, he did not mean indivisible quantum particles. Later, based on the interference pattern generated when the light is passing through two narrowly spaced slits, it was well established the wave nature of the light. The Maxwell's equations clearly and unequivocally demonstrated that the light consists of electromagnetic waves. In 1900, when it was discovered that the electromagnetic energy itself is quantized in nature, the quantum light hypothesis was born indicating that the light consists of quantum particles or photons with quantum energy $e = hf$, where, $e$ is the indivisible quantum energy, $f$ is the frequency, and $h$ is the Plank constant [1, 2, 5].

Since 1905, it has always been a widely accepted notion that the light consists of quantum particles known as photons [1, 3, 6]; the energy of a photon, the indivisible quantum energy $e$ is given by, $e = hf$. The idea that the photons are real is so ingrained in human mind that even a slightest hint against its existence will be met with a fierce resistance, or the indifference; the resistance may be so great that not many even care to glance at a paper that denies the existence of quantum light particles or photons, not to mention the difficulty the author has to face to get it published. In fact, sending an article that denies the very existence of photons to a Photonic Journal (there are plenty) for a publication is the same as sending an article that denies the existence of a divine power to a Vatican Journal; the outcome is obvious. So, the Science Discovery is the right place to publish it. Although everyone seems to take the existence of photon for granted, there are some important questions still need to be answered.

What made the people to believe the existence of photons in the first place? It is the indivisible nature of quantum electromagnetic energy that led to the belief that the light must be made of indivisible quantum light particles, or photons. If the light is made of indivisible quantum particles, or photons, how do these particles travel billions of light years without being subjected to the gradual degradation in a hazardous environment that the light has to travel? By its very nature, the quantum particles cannot be subjected to gradual attenuation or decay. When it comes to photons, it is all or none deal; a photon either travel as a single entity, or lose it as a single entity; no gradual decay along the path is allowed. Why should the natural environment obey the self enforced by-laws of photons? Whatever the case, the path degradation is ever present and does not care about the need of others such as photons. The path degradation is indiscriminately; it does not know the photon is indivisible; it does not give any favors to the indivisible quantum particles of light, photons, if they exist. If the quantum light particles or photons do exist, they have to suffer slow and gradual path degradation or attenuation along the path like everything else; there is no escaping.

Further, in the derivation of the existence of quantum light particles or photons, Einstein assumed that the positions of photons in space are random and independent; this assumption is absolutely crucial and necessary for the derivation. The Einstein's derivation does not work without this assumption. What this means is that there will be no photons, if the photons are not allowed to have random and independent positions in space. If the light is made of photons, and their positions in space are random and independent, why should the light travel in straight lines as coherent rays of light? Why shouldn't they spread out uniformly in the vast space instead of travelling as coherent rays of light directionally? Shouldn't the photons' random and independent positions in space prevent having night and day, or even a constant speed of light, due to their natural tendency to spread out uniformly? If the light consists of photons, the universe should be in a uniform glow. The behavior of the photons that are expected from the assumption that the positions of photons are random and independent in space seems to contradict the very physical nature of light itself. Therefore, if light is made of photons, and photons in a ray of light can have any location in space randomly and independently as it was assumed in Einstein's derivation of photons, the light cannot travel coherently in a direction at a constant speed; impossible.

If the photons are real, how do they travel? Though photons are defined based on the frequency, the frequency cannot withstand alone without the time; the frequency always co-exists with time. So, where does the time fit in with the so-called photon? What is the time signature of a photon? Does a photon have an infinite time signature or limited time signature? If a photon has a limited time signature, how much is that limit? If the light behaves as particles at high frequencies, and as waves at low frequencies, where is the frequency boundary? Who determines the boundary? What happens at the boundary? How does the propagation of photon differ from the propagation of the electromagnetic waves? Nobody seems to know.

So, without a question, it is not possible for light to be made of quantum particles or photons. Now, the question is: how does the light carry indivisible quantum energy $e$? The light in a new light presented in this paper answers that question. It is in fact the way that the ubiquitous quantum relationship $e = hf$ is expressed that lead to the mistaken belief that the light consists of quantum particles or photons. Instead of hypothesizing the quantum particles in the reverse direction through the blackbody radiation to understand the nature of electromagnetic energy, if we had used the quantum energy jumps of an electron in an atom in the generation of light, there would have been no need for quantum light or photon hypothesis; we would have never come to believe in quantum light or photons. The light is always a wave and never a particle; there is no wave-particle duality.

## 2. The Genesis of Photon

The idea that the energy comes in discrete quanta given by $e = hf$ was first proposed using blackbody radiation by Max Plank in 1900, where, $e$ is the indivisible quantum energy, $f$ is the frequency of the electromagnetic wave, and $h$ is the Plank constant. In 1905, Einstein used this idea in blackbody radiation to propose that the light itself is made of quantum particles. Einstein used the following relationships in the derivation that led to the quantum particles of light, which later came to be known as photons [1, 3, 6]:

(i) The entropy, $S$ of a blackbody cavity radiation,

$$S = V\int_0^{\infty} \phi(\rho, f)df \tag{1}$$

where, $V$ is the volume of the cavity, $\phi(\rho, f)$ is the entropy per unit volume at frequency $f$, $\rho$ is the energy density function in the cavity.

(ii) The Wien's Principle,

$$\frac{\partial\phi}{\partial\rho} = \frac{1}{T} \tag{2}$$

where, $T$ is the temperature of the cavity.

(iii) The Wien's energy density function, $\rho$ inside the cavity for high frequencies,

$$\rho = \alpha f^3 e^{-\beta f/T} \tag{3}$$

where, $\alpha, \beta$ are constants.

(iv) The positions of photons in space are assumed to be random and independent. Then, the probability, $p$ of finding all the $n$ photons in a sub-volume $v$ of the cavity of volume $V$ is given by,

$$p=(v/V)^n$$

The derivation that led to the belief that the light is made of quantum particles is given in the Appendix-1.

### *2.1. The Concerns over the Einstein's Photon Derivation*

(a) Discrete Spectrum:

In the equation, $S = V\int_0^{\infty} \phi(\rho, f)df$, it was assumed that the frequency spectrum inside the cavity is continuous; this is not so. Inside a cavity, frequencies are not continuous; only the fundamental frequency determined by the dimensions of the cavity and its integer harmonics can exist inside a cavity.

(b) Photons Catastrophe:

If the frequency spectrum is continuous, as it was assumed, then, there are infinite numbers of discrete frequencies in the light spectrum; this is the case even for a narrowest band of electromagnetic spectrum. Now, if the light consists of quantum particles or photons, when the energy of a single photon for each frequency are added up, it will lead to an energy catastrophe due to infinite frequencies present in a continuous spectrum. This itself prevents light from being consists of particles.

*Mass Catastrophe:*

If the Einstein's mass-energy relationship is true, even though photon is mass less, the equivalent mass of the energy of a single photon for each frequency will add up to an infinite mass, due to the infinite number of discrete frequencies present even in a narrowest continuous band of frequency spectrum, leading to a mass catastrophe. However, as it is shown in [10], Einstein's mass-energy relationship does not hold true in the nature.

(c) Wien's Energy Distribution Limitations:

The Wien's energy distribution $\rho = \alpha f^3 e^{-\beta f/T}$ is only applicable in a blackbody cavity at high frequencies. Hence, the derivation of photon has validity only at high frequencies inside a blackbody.

(d) The Non-Extendibility to the Low Frequencies:

The energy density function inside a blackbody for low frequencies is given by [1],

$$\rho = \frac{\alpha}{\beta} f^2 T \quad (4)$$

However, the use of energy density function, $\rho = \frac{\alpha}{\beta} f^2 T$ in place of the Wien's energy density function $\rho = \alpha f^3 e^{-\beta f/T}$ in the Einstein's derivation does not lead to the same results [Appendix-2]. The derivation does not show any quantum particle nature of the radiation inside a blackbody at low frequencies when the same methodology is used; Einstein's derivation is not extendable to low frequencies inside a blackbody. There is no reason to assume that the particle behavior is only at high frequencies. What happens at the boundary that separates the high and low frequencies? What determines the high and low frequencies?

(e) The Non-Extendibility to the Whole Spectrum:

The energy density function inside a blackbody cavity for the whole spectrum is given by the Plank's distribution,

$$\rho = \alpha f^3 / (e^{\beta f/T} - 1) \quad (5)$$

The use of the energy distribution function $\rho = \alpha f^3 / (e^{\beta f/T} - 1)$ in place of Wien's energy density function, $\rho = \alpha f^3 e^{-\beta f/T}$ in Einstein's derivation does not lead the same result [Appendix-3]. The derivation does not show any quantum nature of the radiation inside a blackbody cavity for the whole frequency range; the Einstein's derivation is not extendable to the whole range of frequencies inside a blackbody.

(f) The Random Probability Assumption:

In the Einstein's photon derivation, it was assumed that the probability of the locations of photons in the space are random and independent; the photons have equal probability for being anywhere in the space. If this is true, how can there be any coherent directional light traveling in space at a constant speed? If the locations of the photons in space are random and independent, eventually, all the photons will be distributed homogeneously in space, which results in a uniform glow preventing the day and night as we know of. There would be no rays of light traveling at constant speed, because the photons distributed in space randomly and independently cannot produce coherent light rays that travel at a constant speed, the speed of light.

(g) The Application Limitations of Photons:

Einstein's derivation of photons has shown that the electromagnetic waves consist of quantum particles or photons in blackbody cavity only for high frequencies. The derivation does not show if the electromagnetic waves at low frequencies consist of quantum particles or not. Further, the radiation inside a blackbody cavity is quite different from radiation outside a blackbody; the Wien's energy distribution, the derivation so heavily rely on, does not apply outside a blackbody. So, the results obtained for high frequencies inside a blackbody cavity cannot be used to make a general statement that the light in general consists of quantum particles or photons.

### *2.2. Is the Photon a Result of a Rare Mathematical Coincidence*

So, what do all these mean? Most probably, Einstein's quantum light derivation for a limited frequency range in a blackbody cavity could simply be a rare mathematical coincidence due to the very special nature of the Wien's energy distribution function and its entropy relationship, to the discrete probability distribution of presumed quantum particles in the space and its entropy based on Boltzmann principle. Although there has not been a definite proof to show that the light consists of quantum particles or photons, it has always been assumed, across all the disciplines, for the light to be consisted of photons. However, even for the dedicated believers of the photons, some questions still remain: What are photons? Is light really made of photons? How do the Maxwell's equations, a wave theory, deal with the photons or particle nature of light? How do indivisible light quanta or photons propagate unimaginable distances without subjected to unavoidable gradual degradation along the path? Do lower frequencies in a blackbody cavity consist of photons? Einstein himself spent a considerable part of his life unsuccessfully to extend his photon derivation to lower frequency range. At the end, near the end of life, in a letter to his friend Besso [4], Einstein demonstrated his suspicions about the existence of the photons by asking the same question we all have been asking quietly: "What are the light quanta?" Seriously, what are the light quanta? Does anybody know?

## 3. The Light in a New Light

Let us consider the quantum energy relationship,

$$e = hf \quad (6)$$

where, $e$ is the indivisible smallest quantum electromagnetic energy, $h$ is the Plank's constant, and $f$ is the frequency of the electromagnetic wave.

One quantum of light with energy $hf$ is considered to be a photon. Though it is not known how light quanta or photons travel, it is assumed that a photon travels as a single unit, and gets absorbed as a single unit.

The notion of a photon is a misconceived concept. The ubiquitous equation *e=hf* has a subtle representation error that led to the idea that the light is made of quantum particles or photons. In fact, the relationship *e=hf*, as it is, does not exist in reality. It is not possible to write an arbitrary number for frequency *f* on the blackboard and ask to calculate quantum energy; that frequency may not even exist in reality. So, what does exist in reality?

### 3.1. Atomic Origin of Light

In an atom, the electrons are bound to the nucleus through electromagnetic field, and the electrons are in discrete energy levels or quantum levels. When an electron moves from one higher quantum energy level to the next lower energy level, in the presence of an electromagnetic field, an indivisible quantum energy $e$, that is the smallest energy unit that cannot be divided any further, is freed as a burst of an electromagnetic wave of a single frequency, $\frac{e}{h}$. The electromagnetic wave of single frequency, $\frac{e}{h}$ in the burst is propagated according to Maxwell's equations.

If an electron moves from higher energy state to a lower energy state by *n* quantum levels, then, the energy *ne* is freed as a burst of electromagnetic wave of a single frequency $\frac{ne}{h}$, where *n=1, 2, 3,...*. It is the quantum energy that determines the frequency of an electromagnetic wave present in a burst. So, the correct relationship is,

$$f_n = \frac{ne}{h},\ \forall n \tag{7}$$

Though, this seems the same as the relationship *e=hf* for *n=1*, they are naturally not the same. The equation *e=hf* may not exist in reality. It is not possible to write down a value for *f* and calculate the quantum energy; that *f* may not exist in nature. Further, $f_n = \frac{ne}{h}$ is unidirectional and discrete. The quantum energy *e* is a fundamental building block of the universe. The quantum energy determines the frequency of an electromagnetic wave in a wave burst; not the other way around. The nature has no idea what *f* is; *f* has a meaning only for human; it is just a human label. The quantum energy is the independent variable. The dependent variable is the frequency *f*. The nature understands frequency as quantum energy *ne*, $\forall n$. The quantum energy and frequency are synonymous. So, there is no need for a separate quantum particle to carry quantum energy as a single unit on a wave; the quantum energy is already there in the frequency of an electromagnetic wave burst. What is frequency to human is quantum energy to the nature; there is absolutely no need for a separate quantum particle or photon hypothesis.

Since the quantum energy level of an electron in an atom represents the potential energy of an electron, it is the potential energy change of an electron that determines the frequency of an electromagnetic wave in a wave burst. The strength of an electromagnetic wave burst is determined by the kinetic energy of an electron and the strength of the electric field inside an atom.

The duration of an electromagnetic wave burst is a universal time constant, $\tau$ and it remains the same for any burst independent of the frequency of the electromagnetic wave it contains. Since the location of an electron in an atom can be anywhere in a given energy level at any given time, the direction of electromagnetic wave burst emission may appear to be random. Every time there is a quantum energy level drop of an electron in an atom, there will be a release of a wave burst; the direction of the wave burst depends on the location of the electron at that moment.

The light is a collection of electromagnetic wave bursts of constant duration; each wave burst consist of an electromagnetic wave of a single frequency, $\frac{ne}{h}$, $\forall n$. A single colour laser beam also consists of a stream of discrete electromagnetic wave bursts, but each burst contains an electromagnetic wave of a single frequency, $\frac{ne}{h}$, where $n=n_o$. Different $n_o$ give rise to different color or frequency laser beams. If a light beam is slowed down dramatically, it is possible to observe the individual electromagnetic wave bursts of constant duration; this is one way to determine the universal time duration, $\tau$ of an electromagnetic wave burst due to quantum energy $ne$, $\forall n$.

*The Duration Theorem:*

The duration, $\tau$ of an electromagnetic wave burst is a universal constant given by, $\tau = \frac{h}{e}$.

Proof:

The duration of an electromagnetic wave burst has to satisfy the conditions;

i) The duration of any wave burst must be large enough to contain an integer number of whole waveforms or periods for all frequencies, i.e. $\frac{ne}{\hbar}\tau = k(2\pi)$, $\forall n$, where *k* is an integer, and $\hbar = \frac{h}{2\pi}$.
ii) The duration has to be an absolute minimum for all frequencies, $\frac{ne}{h}$, $\forall n$.

Both these conditions are met only when, $\tau = \frac{h}{e}$. Since both $h$ and *e* are universal constants, τ is also a universal constant.

So, any point along a path of light experiences a wave bust for the time duration of τ. This also indicates the fact that the time is absolute; the time is not relative [10].

### 3.2. Reversibility: Law of Quantum Symmetry

When an electron moves from a higher energy state to a lower energy state by *n* quantum energy levels, then the quantum energy *ne* is freed as an electromagnetic wave burst of duration equal to the universal time constant τ; the electromagnetic wave in a wave burst has a single frequency, $\frac{ne}{h}$.

Similarly, in reverse, when an electron is subjected to an electromagnetic wave burst consisting of an electromagnetic wave of frequency, $\frac{ne}{h}$ for the duration of the universal time constant, τ, then the electron will be moved to a higher energy state by *n* quantum energy levels.

*Photoelectric Effect:*

According to the law of quantum symmetry or reversibility, if an electron in an atom requires quantum energy *ne* for it to be freed, and if the electron is exposed to an electromagnetic wave burst consisting of an electromagnetic wave of frequency $f_n \geq \frac{ne}{h}$, for the duration τ, then, the electron will be freed; this is the photoelectric effect.

For an electron to be freed, the frequency of the electromagnetic wave, $f_n$ in the burst that the electron is exposed to has to match the quantum energy levels $n$ the electron has to jump in order to be freed. In other words, $f_n \geq \frac{ne}{h}$.

It is not the strength of an electromagnetic wave burst that liberates an electron from an atom; it is always the frequency of an electromagnetic wave that releases an electron, provided that the frequency matches the quantum energy required for the electron to be freed and the duration of the exposure is at least τ. If the quantum energy required for an electron to be freed is not matched by the frequency of the impinging electromagnetic wave for the duration of at least τ, then the electron will not be freed irrespective of the strength of the burst.

# 4. The Nature of Light

It has always been the belief that the spectrum of light is continuous. In fact, the genesis of the quantum light or photon derivation is based on the assumption that the spectrum of light is continuous. This is indeed not the case for light.

### *4.1. The Spectrum of Light*

The electromagnetic wave due to quantum energy $ne$, $\forall n$, in a wave burst can be written as,

$$A(t,r)=A(r)\exp(-j\frac{ne}{\hbar}t) \qquad (8)$$

where, $|A(r)|$, the amplitude of the wave, depends on the kinetic energy of an electron and the strength of the electromagnetic field inside an atom, $e$ is the indivisible quantum energy, $\hbar=\frac{h}{2\pi}$, and $r$ is the distance wave have traveled.

*What is Light?*

The light is a collection of discrete electromagnetic wave bursts; each burst consist of an electromagnetic wave of a single frequency, $\frac{ne}{h}$, $\forall n$. Since at any given time, an electron can be anywhere in an energy level, the direction of each electromagnetic wave burst, carrying an electromagnetic wave of single frequency, $\frac{ne}{h}$, $\forall n$, can be considered to be random. Hence, the radiation is Omni-directional. The appeared randomness of a location of an electron in a quantum energy level in an atom prevents any favored direction of a wave burst. The strength, $|A(r)|$ of an electromagnetic wave burst deteriorates with the distance, but the quantum energy $ne$ will be secured, unaffected by the gradual path attenuation, and remains intact since it is the frequency of the wave. This is the very reason that we are able to receive light from stars that are billions of light years away. The sunbathers exposed to electromagnetic radiation get sun burns from the quantum energy in the frequency of the wave bursts, not from the strength of the wave bursts. A single ray of light contains many discrete wave bursts, each burst containing an electromagnetic wave of a single frequency, $\frac{ne}{h}$, $\forall n$.

*Theorem: Spectrum of Light*

The frequency spectrum of light is discrete.

Proof:

A macro electromagnetic source such as the sun is a source of discrete electromagnetic wave bursts. Each burst consists of an electromagnetic wave of a single frequency, $\frac{ne}{h}$, $\forall n$. These wave bursts emanate from every direction; the wave bursts are Omni-directional. Each burst is of the duration, $\tau = \frac{h}{e}$ which is a universal constant. The frequency spectrum of light is the plot of the strength of electromagnetic wave bursts against the frequency of the wave, $\frac{ne}{h}$, $\forall n$, which is discrete. If there are more bursts of the same frequency, the strength at that frequency will be stronger. The frequency spectrum of light is always discrete. The light can only consist of discrete frequencies, $f_n= \frac{ne}{h}$, $\forall n$. So, the spectrum of light represents the nature of the atoms; that is why we can use the light spectrum to obtain the information regarding the atoms, as well as the concentration of different elements in a light source or a star. This is the very reason why the frequency spectrum of the light is so valuable in determining the atomic constituents of stars and the other celestial bodies.

The conventional wisdom has always been that the spectrum of light is continuous. However, this view is not correct. The spectrum of light is not continuous; it is discrete. It is even more appropriate to call the spectrum of light 'quantum spectrum' since the quantum energy is the frequency; the frequency is just a label for the quantum energy, $\frac{ne}{h}$, $\forall n$.

*Theorem: Frequency Resolution*

The frequency resolution, $\Delta f$ of light is bound by,

$\Delta f = \frac{e}{h}$, where $\Delta f$ is the difference between any two adjacent frequencies.

The proof follows directly from the fact that the quantum energy $e$ is indivisible.

### *4.2. The Nature's Wonder*

Since the quantum energy is carried as the frequency of an electromagnetic wave in a burst, its authenticity and well being are always protected; most of all its indivisibility is respected. Whether it is a dust storm, snow storm, rain storm or any other hazard along the path that an electromagnetic wave burst has to go through, the quantum energy is carried securely in the frequency of the electromagnetic wave in a burst without the effect of gradual fading that the strength of an electromagnetic wave burst has to endure along the path. The light can travel billions of ears, yet the fidelity of quantum energy will be in tack since the frequency is the quantum energy. Could nature find any better mechanism than this to radiate the indivisible quantum energy? Not by any other mean could the quantum energy be carried for billion's of light years for unlimited vast distances with its authenticity and fidelity intact; wondrous nature!

### 4.3. The Laws of the Nature of Light

Unlike many inconsistencies in nature, the nature seems to have gotten everything right in the case of light. The nature of light conforms to the following laws:

*The Law of the Harmony:*

Electromagnetic frequencies in nature are quantized, and limited to, $\frac{ne}{h}$, $\forall n$, where $e$ is the indivisible quantum energy. In other words, all the electromagnetic frequencies present in the universe are constrained to the fundamental frequency, $\frac{e}{h}$ and its integer harmonics; the nature's harmony.

*The Law of the Frequency Limits:*

The highest electromagnetic wave frequency present in the vast universe is restricted by the energy levels of the smallest, the atoms. The highest electromagnetic frequency is constrained by the maximum quantum energy difference that an electron in an atom can jump down to.

The highest frequencies present in light are $\gamma$-rays; the highest frequency present in atomic radiation are also $\gamma$-rays.

*The Law of the Number of Frequencies:*

The number of discrete electromagnetic frequencies present in light is limited by the maximum number of quantum energy levels in an atom.

### 4.4. The Doppler's Effect

The Doppler's effect does not change the spectrum of light; it merely shifts the spectrum one way or the other; toward the red, a red shift, or toward the blue, a blue shift.

Consider a wave burst consisting of a wave of the frequency, $\frac{ne}{h}$, $\forall n$. When the source moves, the shift of a frequency can only take place in discrete steps, $\frac{e}{h}$. So, the quantum energy $e$ remains unchanged; the only thing that changes is the $n$, in $\pm i$ discrete steps creating a frequency shift, where $i$ is an integer.

The Doppler's effect is not continuous; it is discrete, and the frequency shift takes place in quantum steps, $\frac{e}{h}$.

### 4.5. Prism: A Wave Burst Sorter

As we have seen, a ray of light is not continuous; it is discrete. It contains many electromagnetic wave bursts of constant duration that is equal to the universal time constant, τ. Each burst contains a single frequency, and each frequency can take any value $f_n = \frac{ne}{h}$, $\forall n$. So, a ray of light is a stream of electromagnetic wave bursts that are travelling according to the Maxwell's equations at a constant speed determined by the medium (or lack of it). What happens when this stream of electromagnetic wave bursts hit a surface of a prism? The prism becomes a wave burst sorter according to the frequency of the wave in a burst. The wave bursts of different frequencies in a single ray of light are sent to different directions in different streams or rays according to their frequencies; of course, this happens because the velocities of different bursts inside the prism differ due to their different frequencies. The separation of each ray further widens at the exit surface of the prism. Each ray of light that exits the prism only contains a sequence of bursts of a single distinct frequency; one exit ray may contain a sequence of bursts of frequency, $\frac{ne}{h}$, where $n=n_o$, while another exit ray may contain a sequence of bursts of frequency, $\frac{ne}{h}$, where $n=n_1$, and $n_o \neq n_1$. A rainbow is a result of this wave burst sorting according to frequency, $\frac{ne}{h}$, $\forall n$; we only see the visible region.

### 4.6. Two-Slit Interference

In the two-slit experiment, a beam of light is directed to two slits on a board and then on to a screen. This was used to show that the light is a wave. When a ray of light passes through two slits, each electromagnetic wave burst creates an interference pattern on the screen since each burst is a wave. What we see on the screen is the superposition of all the interference patterns created by all the electromagnetic wave bursts of different frequencies.

## 5. The Maxwell's Equations and the Quantum Energy

As we have seen, the light is a collection of electromagnetic wave bursts of constant duration τ. Each burst consists of an electromagnetic wave of a single frequency, $\frac{ne}{h}$, $\forall n$. So, there are two aspects of energy in the light:

i) The energy associated with the power or the strength of an electromagnetic burst.
ii) The quantum energy, which is the frequency of the electromagnetic wave in a burst.

The Maxwell's equations deal with the propagation aspect of an electromagnetic wave. It treats the frequency of an electromagnetic wave as a number. It has no concern over what is represented by the frequency; in the case of light, the frequency is the quantum energy. The power of a wave calculated using the Maxwell's equations tells us the strengths of the wave bursts. The quantum energy is the frequency of the electromagnetic wave in a burst and has nothing to do with the power of a wave burst. The power of an electromagnetic wave diminishes gradually as it travels, but the quantum energy is not. This is the secret to the success of the light in transporting the quantum energy without which the life would not have evolved. It is this quantum energy that plants use to generate carbohydrate. It is also this quantum energy that solar cells use to generate electricity. It is this quantum energy that the human skin uses to make vitamin D. It is this quantum energy that burns the skin, and causes skin cancer. It is this quantum energy that may create DNA mutations, and shortens the telomeres and hence the life-span; the list continues.

## 6. Properties of Light

a) The light consists of discrete electromagnetic wave bursts of constant duration.
b) The propagation of wave bursts takes place according to the Maxwell's equations.
c) The duration of wave bursts, $\tau = \frac{h}{e}$ is a universal constant; this indicates that the time is absolute; the

time is NOT relative.

d) The frequency is quantized.
e) Each wave burst contains a wave of a single frequency.
f) Frequency can only takes values, $\frac{ne}{h}$, $\forall n$, where $n$ is an integer.
g) The number of discrete frequencies in the light is finite and limited by the maximum number of quantum levels in an atom.
h) The frequency spectrum is discrete; it is more appropriate to call the frequency spectrum, “the quantum energy spectrum”.
i) The frequency resolution is $\frac{e}{h}$.
j) Since the quantum energy $e$ is represented in the frequency, it can be transmitted as a single unit for any distance for billions of light years without subjected to gradual path degradation.
k) By slowing down a ray of light dramatically, it is possible to see individual wave bursts; these bursts are waves, not particles.
l) The duration of wave bursts can be measured by slowing down a ray of light.
m) When an electron in an atom is subjected to a wave burst of frequency $\frac{ne}{h}$ for the duration of the universal time constant, τ, that electron will be moved to a higher energy level by $n$ quantum levels or by quantum energy $ne$.
n) The frequency of light is synonymous with quantum energy of an electron in an atom; the frequency is the quantum energy.
o) There are two aspects of energies in light: one is the power of a wave burst; the other is the quantum energy which is the frequency of the wave in a burst.
p) There is absolutely no quantum spookiness to the light. In the absence of the complete knowledge of the underline physics, we use the probabilistic modeling (a simplistic view) to get, at least, some understanding in to the working of natural processes including the working of the elementary particles. Nothing in the nature is probabilistic; probability is a human creation. The nature does not understand probability. The nature does not take decisions based on probability.
q) Each discrete wave burst of light is independent of the other.
r) Each wave burst travels in a straight line in a vacuum.
s) Once a wave burst is out of a source, the direction is determined by the density gradient (or the lack of it) of the medium.
t) The gravity has no effect on a wave burst in a vacuum.
u) Gravity creates a density gradient in the presence of a medium which affect the direction of a wave burst; the effect of gravity on light is always indirect, and it is through the medium. In the presence of a medium, the gravity creates a lens around the gravitational object which diffracts light; the gravitational lensing.
v) A single color laser beam is a sequence of discrete wave bursts of constant duration; each wave in all the bursts consist of a single frequency, $\frac{ne}{h}$, where $n=n_o$.
w) There are no quantum particles or photons.
x) There are no mass-less particles.
y) There is no wave-particle duality.
z) The light is always a wave.

# 7. The Old in the New Light

Consider the well known decay of a neutron [7, 8, 9]. When a neutron combines with an electron-neutrino, the neutron is known to mutate into a proton while releasing an electron and a presumed photon. What exactly is this photon? It is not a quantum particle that is freed. What releases in this reaction is an electromagnetic wave burst of duration τ, the universal time constant; this wave burst consists of a wave of a single frequency, $\frac{ne}{h}$, where $e$ is the quantum energy, i.e.

$$N + \nu_e \rightarrow P + electron + W(\frac{ne}{h}),$$

where, $W(\frac{ne}{h})$ is an electromagnetic wave burst of the universal time duration $\tau$, consisting an electromagnetic wave of a single frequency $\frac{ne}{h}$, $N$ is a neutron, $P$ is a proton, and $\nu_e$ is an electron-neutrino. The wave burst $W(\frac{ne}{h})$ propagates according to Maxwell’s equations.

So, we do not need a mysterious, non-existent, hard to explain, never seen, a hypothetical photon that we have no idea how its propagation takes place, to explain the quantum phenomena and the light in the nature. A discrete wave burst of constant universal time duration, consisting of an electromagnetic wave of a one single frequency, $\frac{ne}{h}$, $\forall n$ explains every phenomena regarding the light in the nature. The light is made of discrete wave bursts of constant time duration. As it is the case with electromagnetic energy, the electromagnetic frequency is quantized.

# 8. The Force-Particle Duality

The false idea that the light consists of quantum particles or photons had been widely used to explain the electromagnetic force.

*Electromagnetic Force:*

It has become a common belief that the electromagnetic force is a result of exchanging photons or quantum light particles. The photons have no mass; this makes electromagnetic force a long range force. There is no validity to this idea when there are no quantum light particles or photons. There are no mass-less particles.

The same idea, that the electromagnetic force is a result of an exchange of the quantum particles or the photons, has been extended to explain the weak force, the strong force, as well as the omnipresent gravity.

*The Weak Force:*

The weak force or $\beta$-radiation is a nuclear force that results in the decay of the nucleus. It is considered to be negotiated by very short lived $W^+$, $W^-$, and $Z^o$ particles that bear a mass. These relatively massive particles make the weak force a short range force.

*The Strong Force:*

The strong force is responsible for holding the positively charged particles, protons together in the nucleus. The strong force binds the quarks together. The strong force is considered to be negotiated by the particles, gluons. The greater mass of the gluons makes the strong force extremely short range; the gluons have never been found.

*The Gravity:*

Ubiquitous, ever-present gravity keeps the galaxies together, planets together, and more importantly, everything including us on a solid ground. It has been speculated that the gravity is a result of exchanging the particles gravitons which are mass-less. It is believed to be the mass-less nature of gravitons that makes gravity an extremely long range force; the gravitons have never been found.

### *8.1. The Validity of Force-Particle Duality*

The genesis of the force-particle duality or the particles creating the forces of nature, electromagnetic force, weak force, strong force, and gravity goes back to the photons. It all started with the misconceived foundation of the mysterious photons, and the idea that the electromagnetic force is created by exchanging the quantum particles or photons.

Now, we know that there are no quantum light particles or photons. So, electromagnetic force can't be a result of the exchange of the non-existent photons. The idea, that the electromagnetic force is a result of the exchange of photon, is no longer true. Then, what about the whole notion of particles creating forces of nature; this is questionable, no longer a general statement that applies to all the forces of nature. Can the each force-particle duality hold for specific forces on their own merits even when the electromagnetic force-photon duality no longer presents or holds? One thing is certain; there are no mass-less particles and hence gravity can't be a result of a particle.

### *8.2. Probability and the Nature*

Nothing in the universe is random. Everything in the universe, from the elementary particles to the galaxies, has underline physics that describe the processes. However, we either do not have all the knowledge of the underline physics or the process is too involved that it is impossible to carry out the calculations. This led to the modeling of certain processes using probability. Probability is a human creation; it is not a characteristic of the nature. The ubiquitous phrase "The nature does not throw dies in its decisions" is indeed true.

It is our lack of knowledge of the underline physics of the quantum particles that led to the use of probabilistic approach. We are able to explain certain natural processes using probability does not mean that the process itself is random in the nature; it only means that we have no true knowledge of the underline physics, and the process seems to agree with the probabilistic modeling to a good approximation. An observer's ignorance of the state of the Schrödinger's cat does not in any way mean that the cat's fate or state is not determined or in limbo; the cat's state is determined independent of the observer. There is no need for an observer for a robbery to take place. A robbery can take place irrespective of whether there is someone to observe it or not; in fact, most of the robberies take place in the absence of observers.

The universe is deterministic; our lack of the knowledge leads us to make probabilistic approximations to make predictions, or to explain the natural processes. The nature does not know what probability is; only human knows. Though we may choose to describe an electron's location in an energy level using probability, electron itself may have a physical deterministic reason for where it wants to be at any moment in time.

We use the probability do analyze lottery winnings even though the process is deterministic; if we know the initial state of all the 49 balls in the drum, their elasticity, all the forces involved, lottery outcome is certain. However, it is impossible to carry out the calculations. So, we use the easy way out, the probabilistic approach. It is the same with the weather prediction. It is the same with the cell division. When living cells duplicate or copy themselves, the copying of Deoxyribonucleic Acid (DNA) is not exact; the Single Nucleotide Polymorphism (SNP) of the DNA takes place. We do not know what causes these mutations; so, we consider them to be random. Just because we call them random mutations of the DNA does not mean that they are random occurrences in the nature; the nature's purpose is unknown to us.

Probability is a human mathematical tool to at least achieve a partial understanding of the unknown natural processes without which it is impossible to obtain any understanding at all. The manner in which the probability had been use to justify the existence of photons is completely unrealistic and against the very natural behavior of the light. How did such a false notion of photon survive for so long?

### *8.3. The Effect on de Broglie and Schrödinger*

In 1924, Louis de Broglie thought the idea that the energy of a light particle or a photon is proportional to the frequency of the electromagnetic wave could be extended to matter particles. He erroneously assumed that the electromagnetic energy $e$ in the quantum relationship $e=hf$ is the same as the kinetic energy of a matter particle, and obtained the relationship for the momentum of a matter particle, $p=\frac{e}{u}$, where $u$ is the speed of the particle, and $p$ is the momentum of the particle. He further conjectured that the matter particles have a wave behavior and substituted $u=f\lambda$ to obtain the momentum and wavelength relationship for a particle, $\lambda=\frac{h}{p}$, where λ is the wavelength of the matter particle, and $f$ is the frequency of the wave that results from the wave behavior of the matter particle. He used this relationship to proclaim that every particle, no matter how big or small, behaves like a wave; a flawed concept from the very beginning.

The energy $e$ in the $e=hf$ relationship is the electromagnetic energy, not the kinetic energy of a particle. Only the electromagnetic energy is proportional to the frequency and can be represented as $f=\frac{e}{h}$ or $e=hf$; the kinetic energy of a matter particle is not equal to $hf$. The electromagnetic energy and the kinetic energy of a particle are not the same; they can be converted to each other, but they are not equal. Therefore, the quantum energy or electromagnetic energy $e$ in the $e=hf$ relationship cannot be substituted by the kinetic energy of a matter particle, $pu$. It is not possible to substitute $hf$ for any form of energy, wherever, whenever, or whatever form the energy appears. The $hf$ is only applicable for electromagnetic energy or quantum energy, nothing else. The kinetic energy of an electron determines the strength of an electromagnetic burst, not the frequency of the wave in a burst; the frequency of the wave in a burst is determined by the quantum energy $e$. Further, as we have seen, there are no light particles or photons; the relationship $e=hf$, or more appropriately $f=\frac{e}{h}$ does not constitute a particle. Therefore, it is clear that the relationships $p=\frac{e}{u}$, and $\lambda=\frac{h}{p}$ derived for matter particles by de Broglie do not hold, and the particles do not have wave behavior. Wave-particle duality does not exist.

In 1926, build upon the de Broglie's false concept that the matter particles behave as waves, Erwin Schrödinger came up with a wave equation for electrons. However, as we have seen, de Broglie's derivation is based on the wrong assumption that the electromagnetic energy and the kinetic energy of a matter particle are the same; they are not the same. There is no relationship between a mass of a particle and the universal Plank constant $h$. The particles, small or large, do not have wave behavior. This makes ubiquitous Schrödinger's equation that provides the probability distribution of an electron, or the probability of finding an electron at a given location at a given time questionable. There is no quantum spookiness after all.

## 9. Conclusions

The fact that the electromagnetic energy appears in discrete quanta in nature does not require light to be quantized; it does not require light to appear in light quanta or photons. The light does not consist of quantum light particles or photons. The light is always a wave, and the electromagnetic waves have an inherent ability to handle the quantum nature of energy. The light does not have to be made of quantum particles or photons to deal with the quantum nature of the electromagnetic energy. The quantized nature of the electromagnetic energy, however, requires the electromagnetic frequency to be quantized; it is essential and necessary.

The indivisible quantum energy unit $e$ is one of the building blocks of nature; it is inherent in an atom. When an electron in an atom moves from a higher energy level to a lower energy level by and $n$ quantum energy steps, the quantum energy $ne$ is freed as an electromagnetic wave burst of universal time duration consisting of a single frequency, $\frac{ne}{h}$. So, it is the frequency of an electromagnetic wave that carries the quantum energy. It is the quantum energy that defines the frequency; not the other way around. The frequency and the quantum energy are one and the same; they are synonymous. There is no need to send the quantum energy in a packet, a particle, or in a photon. There is absolutely no need for a particle hypothesis for the light. The frequency is the quantum energy.

Since it is the quantum energy that determines the frequency of an electromagnetic wave burst, it is more accurate to represent the quantum relationship as $f_n=\frac{ne}{h}$, $\forall n$, where $n$ is an integer. This is a unidirectional relationship in nature where the quantum energy $e$ is the independent variable, one of the fundamental building blocks of the universe; $f$ is the dependent variable, which is just a human label. As far as the nature is concern, the frequency is the quantum energy.

The quantum law of symmetry clearly explains the mechanism of the photoelectric effect; it shows why the strength of an electromagnetic wave has no effect on liberating an electron from an atom. To liberate an electron from an atom, what is needed is the quantum energy $ne$ with the appropriate $n$. The quantum energy is the frequency of an electromagnetic wave. So, it clearly testifies to the fact that the frequency of an impinging electromagnetic wave alone determines the liberation of an electron from an atom giving rise to the photoelectric effect.

The time duration of a wave burst is a universal time constant $\tau$ given by $\tau = \frac{h}{e}$. This testifies to the fact that the time is absolute; time is not relative. Each wave burst has an electromagnetic wave of a single frequency, $\frac{ne}{h}$, $\forall n$. The duration of a wave burst, which is the universal time constant, $\tau$, is independent of the frequency of the wave in a burst. It is possible to measure the duration of a burst by slowing down a laser beam or a ray of light. A single color laser beam is a stream of discrete wave bursts of constant duration, $\tau$; each wave burst consists of an electromagnetic wave of a single frequency, $\frac{ne}{h}$, where $n=n_o$ ; different $n_o$ leads to different color beams.

Our conventional wisdom has been that the light spectrum is always continuous; this is not true. The spectrum of light is always discrete. The light spectrum contains the fundamental frequency, $\frac{e}{h}$ and its harmonics, $\frac{ne}{h}$ $\forall n$. So, the lowest frequency of the light is, $\frac{e}{h}$. The highest frequency of light is determined by the highest number of quantum levels of an electron in an atom. So, what light has is a "discrete quantum energy spectrum" that we have labeled as a frequency spectrum.

The Doppler's effect of light is not continuous; it is discrete. The Doppler's effect shifts the spectrum of light in quantum steps, $\pm\frac{e}{h}$. The Doppler's effect respects the indivisible nature of the quantum energy $e$.

When a ray of light is directed to a prism, the prism becomes a wave burst sorter, separating the wave bursts according to the frequency of the wave in a burst. The prism directs each wave burst in different directions in different streams according to the frequency. So, each ray inside a prism has a stream of bursts of a single frequency. These wave bursts in different streams can be recombined at the exit surface of an inverted prism in the first come first serve basis to form a single ray of light containing a sequence of discrete wave bursts of different frequencies, the original ray of light. A ray of light is separated according to the frequency, burst by burst, first come first serve basis, at the surface of the prism; similarly at the exit surface of an inverted prism, a ray of light is reassembled, burst by burst, first come first serve basis.

When light is directed to two closely separated slits, each burst creates an interference pattern on a screen since they are waves. What we see is the superposition of the interference patterns created by individual wave bursts of different frequencies.

In one of the well known particle decaying process, when a neutron is combined with an electron-neutrino, the outcome is a proton, an electron, and the release of an electromagnetic wave burst of constant duration, given by the universal time constant, τ; the burst consists of an electromagnetic wave of a single frequency, $\frac{ne}{h}$, where $e$ is the indivisible quantum energy. It is not a mythical photon that is released; it is simply a wave burst of frequency, $\frac{ne}{h}$, that is released. This wave burst is not a particle; it is a wave that propagates according to the Maxwell's equations. The frequency of the wave in the burst is the quantum energy released during the collision or the reaction.

There are absolutely no particles of light, light quanta or photons. The light is always a wave, and the propagation of the wave bursts takes place according to the Maxwell's equations. The frequency of the light is the quantum energy; the frequency and the quantum energy are synonymous. We understand the light in terms of frequency; the nature generates and treats the light in terms of the quantum energy. The power of an electromagnetic wave we obtain from the Maxwell's equations tells us the strength of the wave bursts; it has nothing to do with the quantum energy. The light is a collection of electromagnetic wave bursts of constant duration; each burst contains a wave of a single frequency from a set of available discrete frequencies, $\frac{ne}{h}$, $\forall n$.

The electromagnetic frequencies present in light are the same as the radiation frequencies of atoms. The high frequency $\gamma$-radiation in an atom is the $\gamma$-radiation present in the light. Highest frequency of light is determined by the highest frequency of the radiation in an atom.

In addition, the customary quantum relationship $e=hf$ will make a better realistic sense without leading to a mistaken belief of the light quanta or photons, if it is expressed as $f_n = \frac{ne}{h}$, $\forall n$. It is the quantum energy that generates the frequency, not the other way around. The quantum energy $e$, one of the building blocks of the universe, is the independent variable; $f$ is the dependent variable. It is not possible to write down a number for $f$ on a blackboard and ask to calculate the quantum energy $e$; that $f$ may not even exist in the nature. However, it is always possible to write down $\frac{ne}{h}$ on a blackboard and say confidently: here is a frequency of a discrete wave burst in the light.

There is absolutely no need for a quantum particle or photon hypothesis for light. The light is always a wave and never a particle. There is no wave-particle duality. There are no mass-less particles. The mass-less particles are present only in the human imagination, not in the nature. In the absence of photons, the idea that "a force is a result of exchanging particles" is questionable. One thing is certain, as with the electromagnetic force, the gravity is not a result of a particle since the mass-less particles are not a reality in the nature. The ubiquitous saying, "nature does not throw dies", attributed to Einstein, although in a slightly different and unrealistic variation is indeed true; it is only the human who throws the dies, not the nature. The particles, whether they are small or big, do not have a wave behavior; there is no quantum spookiness.

# Appendix-1

***Einstein's Derivation of Quantum Light Particles Using Blackbody Cavity Radiation at High Frequencies and Apparent Problems***

At high frequencies, the energy density function, $\rho$ of a blackbody cavity is given by Wien distribution [1],

$$\rho = \alpha f^3 e^{-\beta f/T} \tag{1}$$

where, $\alpha, \beta$ are constants, and T is the temperature.

This leads to,

$$\frac{1}{T} = \frac{-1}{\beta f}\, ln(\rho/\alpha f^3) \tag{2}$$

Using Wien Principle,

$$\frac{\partial\phi}{\partial\rho}=\frac{1}{T} \tag{3}$$

where $\phi$ is the entropy per unit volume for frequency $f$, we get,

$$\frac{\partial\phi}{\partial\rho} = \frac{-1}{\beta f}\, ln(\rho/\alpha f^3) \tag{4}$$

$$\text{i.e., } \phi = \int \frac{-1}{\beta f}\, ln(\rho/\alpha f^3)\partial\rho \tag{5}$$

From eqn. (5),

$$\phi = -\frac{\rho}{\beta f}[\, ln\ (\rho/\alpha f^3)\text{-}1] \tag{6}$$

The entropy $S$ of a sub-volume $v$ in a blackbody cavity of volume $V$ at frequency $f$ is given by, $S=\phi v$

$$S=-\frac{\rho v}{\beta f}[\, ln\ (\rho v/v\alpha f^3)\text{-}1]. \tag{7}$$

If the total energy $E$ of the cavity at frequency $f$ is concentrated in the sub-volume $v$, then,

$$E=\rho v.$$

Substituting in eqn. (7), we get,

$$S=-\frac{E}{\beta f}[\, ln\ (E/v\alpha f^3)\text{-}1] \tag{8}$$

Similarly, consider that the total energy $E$ is in the whole cavity of the blackbody of volume $V$. Then, the entropy, $S_o$ of the whole blackbody cavity of volume $V$ at frequency $f$ is given by,

$$S_o=-\frac{E}{\beta f}[\, ln\ (E/V\alpha f^3)\text{-}1] \tag{9}$$

From equations (8) and (9), we get,

$$S\text{-}S_o=\frac{E}{\beta f}\ln\frac{v}{V} \quad (10)$$

Now, assume that the energy in the cavity is a result of *n* discrete quantum particles or photons. Under the assumption that the locations of photons in space are random and independent, the probability *p* of having all the *n* particles in a sub-volume *v* of the blackbody cavity of volume *V* is,

$$p=\left(\frac{v}{V}\right)^n \quad (11)$$

This leads to the entropy change,

$$S-S_o=kn\ \ln\left(\frac{v}{V}\right) \quad (12)$$

where, *k* is the Boltzmann constant.

*Note: If the position of photons in the volume is random and independent as it was assumed to be the case, then, the electromagnetic waves or light ceases to have any coherent directional properties normally the light seems to possess; this leads to a uniform glow in the space preventing day and night. Random and independent photons also prevent propagation of light at a constant speed.*

The equations (10) and (12) gives, $n=\frac{E}{hf}$, where $h=k\beta$, the Plank constant.

*Note: This derivation is only applicable to high frequencies in a blackbody cavity.*

Now, we are going to use the same approach with the energy density function of the cavity at low frequencies [Appendix-2], and also with the energy density function for the entire range of frequencies in the cavity [Appendix-3]. If the above proof is true and the light or electromagnetic energy consists of quantum particles or photons, then the methodology above should be extendable to the whole range of frequencies in the cavity. There is no reason to believe it is only the energies at higher frequencies that are quantum particles, and the energies at the lower frequencies are not. If the method is not extendable to the lower frequencies to show that the energies at the lower frequencies also consist of quantum particles, then the methodology used in the proof could simply be a mathematical coincidence rather than the nature of electromagnetic energy, or light.

# Appendix-2

***Can We Extend the Einstein's Photon Derivation to Lower Frequency Range in a Blackbody Cavity?***

For low frequencies, the energy density function in a blackbody cavity is given by [1],

$$\rho=\frac{\alpha}{\beta}f^2T \quad (1)$$

where, $\alpha,\beta$ are constants, $T$ is the temperature of the blackbody cavity, and *f* is the frequency.

Both $\rho=\frac{\alpha}{\beta}f^2T$ for low frequencies, and the Wien's distribution $\rho=\alpha f^{3}e^{-\beta f/T}$ for high frequencies for a blackbody cavity can be obtained using the Plank's distribution, $\rho=\alpha f^3/(e^{\beta f/T}-1)$.

If the entropy distributions function in the cavity per unit volume for frequency $f$ is given by, $\phi$, then, the Wien's Principle gives,

$$\frac{\partial\phi}{\partial\rho}=\frac{1}{T} \quad (2)$$

Now, we follow the exact derivation procedure that is used for the high frequency region in the blackbody cavity using the energy density function for low frequencies, $\rho=\frac{\alpha}{\beta}f^2T$ in place of the Wien's density function, $\rho=\alpha f^3e^{-\beta f/T}$ in the Einstein's derivation.

Equations (1) and (2) gives,

$$\frac{\partial\phi}{\partial\rho}=\frac{\alpha}{\beta}f^2\,\frac{1}{\rho} \quad (3)$$

By integrating, we get,

$$\phi=\frac{\alpha}{\beta}f^2\ \ln\rho \quad (4)$$

If $v$ is a sub-volume of the cavity of volume *V*, then the entropy, *S* of the sub-volume *v* at frequency *f* is given by,

$S=\phi$ v.

Using equation (4), we get, $S=\frac{v\alpha}{\beta}f^2\ln\frac{\rho v}{v}$.

If the whole energy *E* of the cavity is confined to the sub-volume *v*, then, $E=\rho$v.

Hence,

$$S=\frac{v\alpha}{\beta}f^2\ln\frac{E}{v} \quad (5)$$

If the energy *E* is contained in the entire volume *V* of the cavity, then, the entropy $S_o$ is given by,

$$S_o=\frac{V\alpha}{\beta}f^2\ln\frac{E}{V} \quad (6)$$

Then, the change of entropy, $S-S_o$ is given by,

$$S-S_o=\frac{\alpha}{\beta}f^2\ln\left[\left(\frac{E}{v}\right)^v/\left(\frac{E}{V}\right)^V\right] \quad (7)$$

Now, assume that the electromagnetic energy *E* is made of *n* quantum particles, or photons. Under the assumption that the locations of photons in space are random and independent, the probability *p* that all the *n* particles will be in the sub-volume *v*, is given by,

$$p=\left(\frac{v}{V}\right)^n \quad (8)$$

The entropy change $S-S_o$ is given by the Boltzmann relationship,

$$S-S_o=kn\ \ln\left(\frac{v}{V}\right) \quad (9)$$

Equations (7) and (9) lead to,

$$\frac{\alpha}{\beta}f^2\ \ln\left[\left(\frac{E}{v}\right)^v/\left(\frac{E}{V}\right)^V\right]=kn\ \ln\left(\frac{v}{V}\right) \quad (10)$$

Since, $\alpha f^3\ln\left[\left(\frac{E}{v}\right)^v/\left(\frac{E}{V}\right)^V\right]\neq E\ln\left(\frac{v}{V}\right)$, it is clear that,

$\frac{E}{hf} \neq n$, where $h=k\beta$.

So, unlike the case for the higher frequency region in a blackbody cavity, for the low frequency region in a blackbody, the derivation does not lead to the relationship, $\frac{E}{hf} \neq n$, where $h=k\beta$. Einstein's photon derivation cannot be extended to the lower frequency region in a blackbody cavity. If the light is made of quantum particles or photons, the derivation should be true for both the high frequency and the low frequency regions. In the Appendix-3, we consider if the derivation can be extended to the entire frequency region of a blackbody.

## Appendix-3

***Can We Extend Einstein's Photon Derivation to the Entire Frequency Range of a Blackbody Cavity?***

The Plank's energy distribution function, $\rho$ for a blackbody cavity for the entire frequency range is given by,

$$\rho=\alpha f^3/(e^{\beta f/T}-1) \tag{1}$$

$$\text{i.e., } \frac{1}{T} = \frac{1}{\beta f}\ ln\ (\ \frac{\alpha f^3}{\rho} + 1) \tag{2}$$

From the Wien's Principle, we get,

$$\frac{\partial\phi}{\partial\rho} = \frac{1}{T} \tag{3}$$

where, $\phi$ is the entropy distribution function inside a blackbody cavity per unit volume at frequency *f*.

From equations (2) and (3), we get,

$$\frac{\partial\phi}{\partial\rho} = \frac{1}{\beta f}\ ln\ (\ \frac{\alpha f^3}{\rho} + 1) \tag{4}$$

$$\text{i.e., } \phi = \frac{1}{\beta f}\ [(\alpha f^3 + \rho)\ ln\ (\alpha f^3 + \rho) - \rho\ ln\ \rho)],$$

$$\phi = \frac{1}{\beta f}\ ln\ [(\ \eta + \rho\ )^{(\eta+\rho)}\ /\ \rho^{\rho}\ )] \tag{5}$$

where, $\eta = \alpha f^3$.

If *v* is a sub-volume of the blackbody cavity of volume *V*, then the entropy of the sub-volume *v* at frequency *f* is given by,

$$S = \phi v$$

$$\text{i.e., } S = \frac{v}{\beta f}\ ln\ [(\ \eta + \rho\ )^{(\eta+\rho)}\ /\ \rho^{\rho}\ )] \tag{6}$$

The entropy $S_o$ of the black body cavity of volume *V* is given by,

$$S_o = \frac{V}{\beta f} ln\ [(\eta + \rho)^{(\eta+\rho)}\ /\ \rho^{\rho}\ )] \tag{7}$$

From equations (6) and (7), we get the entropy change, $S{-}S_o$,

$$S{-}S_o = \frac{1}{\beta f} ln\{[(\eta + \rho)^{(\eta+\rho)}/\ \rho^{\rho}]^{v}\ /[(\eta + \rho)^{(\eta+\rho)}/\ \rho^{\rho}]^{V}\} \tag{8}$$

Assume that the total energy of the cavity is due to *n* quantum particles or photons. Under the assumption that the locations of photons in space are random and independent, the probability *p* that all the particles will be in a sub-volume *v* of the blackbody cavity of volume *V* is given by,

$$p\ =\ (\ \frac{v}{V}\ )^{n} \tag{9}$$

Using the Boltzmann relation, the entropy change $S{-}S_o$ is given by,

$$S{-}S_o = kn\ \ ln\ (\ \frac{v}{V}\ ) \tag{10}$$

where, *k* is the Boltzmann constant.

From equations (8) and (10), we get,

$$kn\ ln\ (\frac{v}{V}) = \frac{1}{\beta f} ln\ \{[(\eta + \rho)^{(\eta+\rho)}/\rho^{\rho}]^{v}\ /\ [(\ \eta + \rho\ )^{(\eta+\rho)}\ /\ \rho^{\rho}\ ]^{V}\}.$$

Since, $E\ ln\ (\ \frac{v}{V}) \neq ln\ \{[(\eta + \rho\ )^{(\eta+\rho)}\ /\ \rho^{\rho}\ ]^{v}\ /\ [(\ \eta + \rho\ )^{(\eta+\rho)}\ /\ \rho^{\rho}\ ]^{V}\}$,

we get, $\frac{E}{hf} \neq n$, where $h=k\beta$.

The Einstein's derivation of photons for the high frequency range in a blackbody cavity cannot be extended to the entire frequency range of a blackbody cavity by using the same approach. Therefore, the Einstein's photon derivation is simply a mathematical coincidence due to the special nature of the Wien's energy density distribution function at the high frequency region rather than the photons a natural phenomenon of light.

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