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Research Article

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Impossibility of Determining the Electric Field Strength of Electromagnetic Wave. Correction of Energy Density Equation

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Abstract
This article addresses and corrects a major misconception about the energy density of electromagnetic wave that has become prevalent in electromagnetic wave theory. The author derives and proves the correct formula for energy density based on principles of energy conservation and the corpuscular theory of radiation. The article also demonstrates the impossibility of determining the electric field strength of electromagnetic radiation without first determining the area of individual photons.

Keywords: Electromagnetic Wave Theory, Energy Density, Electric Field Strength, Photon, Electromagnetic Wave

1. Introduction

Electromagnetic (EM) radiation is a fundamental form of energy that pervades various aspects of life and technology. EM radiation can be perceived either as electromagnetic waves or as individual particles of energy (photons), as manifests due to the particle-wave duality of matter.

Despite significant achievements in the fields of photonics, optics, photophysics and quantum computing, our understanding of light remains incomplete. Various models have been developed to describe light [1,2], yet most are either incomplete or fail to consistently align with experimental data. Consequently, a comprehensive and universally accepted model of light has yet to be established.

One of the most pressing questions in the field of photonics is the nature of the photon itself: its shape and size [3], how it is formed, and its interactions with matter. Understanding these characteristics is crucial for advancing our knowledge of light, impacting broad areas ranging from fundamental physics to practical applications in communication technologies and optics.

In this paper, I focus on the Electric field strength (E_0) property of EM waves and single photons. I will show the challenges and issues related to this model of describing light, aiming to contribute to the broader understanding of electromagnetic radiation and its fundamental properties.

2. State of Problem

The primary objective of this paper is to demonstrate the impossibility of determining the electric field strength (E_0) of an EM wave.

The most common and generally accepted representation of light, as a possible solution to Maxwell's equations, involves sinusoidal, orthogonal in-phase (harmonic) oscillations of electric and magnetic fields [4] (Figure 1).

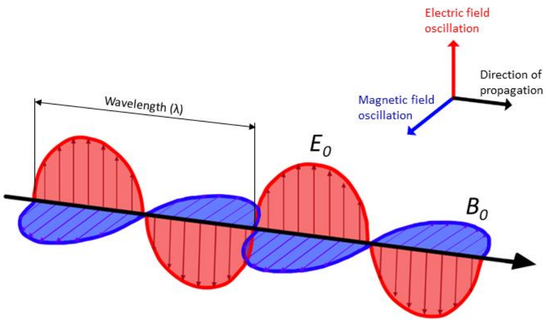

Figure 1: Most Common Presentation of EM Radiation as Sinusoidal EM Wave

Such a description of light highlights a major feature: its sinusoidal nature, which leads to phenomena such as interference and defines the wavelength of radiation.

The energy density of EM wave in such model is determined by Equation (1) [4]:

$$u_{EM} = \varepsilon_0 E_0^2 \cos^2(wt - kx) \qquad (1)$$

where E_0 is the amplitude of the electric field strength, ε_0 is the permittivity of free space, w is radial frequency of EM wave, t is time, k is wavenumber, x is the position.

The energy flow of such EM radiation is characterized by the Poynting vector [4, 5]:

$$S = u_{EM} * k \qquad (2)$$

Although this concept is highly visual and useful, I have found out that it is not possible to determine the electric field strength (E_0) of such oscillations in an EM wave.

Indeed, there is no data or literature that provides the electric field strength for different types of EM radiation across the spectrum.

It is peculiar that this widely used representation lacks specific quantities and values of Electric field strength (E_0), which is the fundamental property of such model.

Initially, I was both surprised and intrigued by this discrepancy. However, I eventually discovered the underlying reason. This article aims to explain it.

3. Problem of Energy Density of Electromagnetic Radiation and Its Solution

The only way to determine the electric field strength (E_0) of an EM wave is by using the concept of energy density. As mentioned before, the energy density of an EM wave is determined by Equation (1).

To highlight and prove that this equation is incomplete, let us examine the energy density for EM radiation from two perspectives: wave and particle. Suppose we are working with two coherent photons. Since photons are bosons, from the EM wave point of view, the model will appear to us as identical EM wave (phase and wavelength), but with the field vectors multiplied by a factor of two (Figure 2).

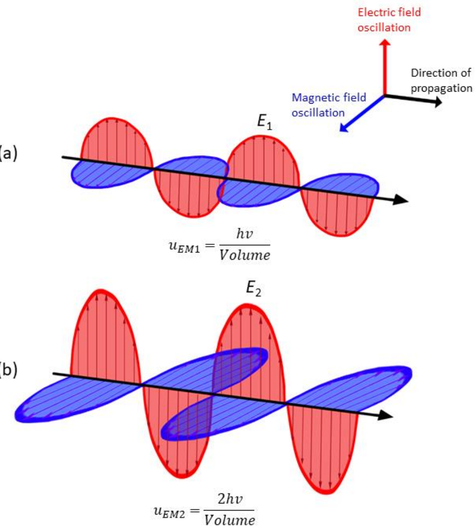

Figure 2: a) EM Wave Consistent From Continuous Radiation of Single Photons. b) EM Wave Consistent from Continuous Radiation of Coherent Two Photons

Photons are coherent, and electric and magnetic field vectors are additive, so:

$$\bar{E}_2 = 2\bar{E}_1 \qquad (3)$$

According to the standard Equation (1), the energy densities of EM waves for one and two photons should be equal:

$$\textit{single photon}: \quad u_{EM1} = \varepsilon_0 E_1^2 \cos^2(wt - kx) \qquad (4)$$

$$\textit{two coherent photons}: \quad u_{EM2} = \varepsilon_0 (E_2)^2 \cos^2(wt - kx) = \varepsilon_0 (2E_1)^2 \cos^2(wt - kx) = 4\varepsilon_0 E_1^2 \cos^2(wt - kx) = 4u_{EM1} \qquad (5)$$

We see, that increasing energy of EM wave by factor of 2, standard **Equation (1)** leads in increase of energy density of factor of 4. This discrepancy is inconsistent with theoretical expectations. If we consider particle point of view, energy density of such EM wave should just increase by factor of 2 (because we are working with 2 coherent photons instead of just one):

$$E_2 = 2E_1 \qquad (6)$$

$$u_{EM2} = 2u_{EM1} \qquad (7)$$

$$u_{EM1} = 1\varepsilon_0 E_1^2 \cos^2(wt - kx) \qquad (8)$$

$$u_{EM2} = 2\varepsilon_0 E_1^2 \cos^2(wt - kx) \qquad (9)$$

Now if we compare both Equation (8) and (9), we see that the equality is only possible, if we introduce a factor of 2 (some N) in Equation (1), the factor of amount of photons in EM wave:

$$u_{EM} = N\varepsilon_0 E_0^2 \cos^2(wt - kx) \qquad (10)$$

where N is amount of photon in EM wave, and E_0 is electric field strength of individual photon.

Another way to represent energy density is depicted in Figure 3. Area of square in case a represents energy density of individual photon. Two coherent photons should have twice large energy density, depicted in case b.

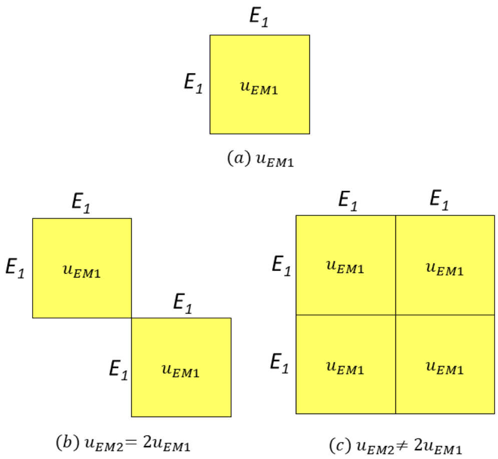

Figure 3: Simplified Presentation of Energy Density of EM Wave Containing: a) One Photon. b) Two Coherent Photons. c) Four Coherent Photons

In other words, we have discovered that the energy density of an EM wave is actually the sum of the energies of individual photons that share the same volume and each have its own electric field strength (E_0). In such case of matter, it is pointless to work with electric field strength of EM wave as entity of photons. Whenever someone measures energy density, they are actually measuring the sum of the energy densities of individual photons that constitute the radiation, rather than energy density of entire radiation. This is a novel finding that has not been previously reported or observed.

4. Impossibility ff Determination of Electric Field Strength of Electromagnetic Radiation

Now we address the main problem: how can one find and derive the electric field strength (E_0) of an EM wave? The energy in an EM wave is described through the energy density concept, as given by Equation (1). Energy density has the units of energy per volume (J/m³). We need to define the volume in which a packet of individual radiation is stored (the volume of a photon). Suppose that photons are located in a cylindrical volume with a length equal to the wavelength and a cross-sectional area corresponding to the circular area of the photon (**Figure 4**). Photons are bosons, allowing any number of them to occupy the same cylindrical space.

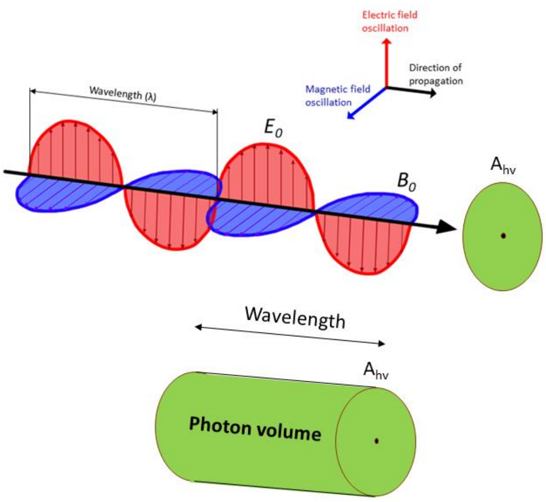

Figure 4: Supposed Volume of Individual Photon

In this case, from derived Equation 10 we can obtain the following equations:

$$\frac{Energy}{Volume} = u_{EM} = N\varepsilon_0 E_0^2 \cos^2(wt - kx)$$

$$= \frac{Nhv}{Volume} = \frac{Nhv}{Area * \lambda} = \frac{Nhv^2}{Area * c} \quad (11)$$

$$c\varepsilon_0 E_0^2 \cos^2(wt - kx) = \frac{hv^2}{Area} \quad (12)$$

From which we can find E_0:

$$E_0 = \sqrt{\frac{hv^2}{Area * c\varepsilon_0 \cos^2(wt - kx)}} \quad (13)$$

We see, that to determine the electric field strength (E_0) of EM wave, the missing parameter is the area of the photons (*Area*, Equation (13)). Until we find a way to determine the shape and area of photons, it is impossible to determine E_0 for any EM wave or photon.

One obvious point is that shorter wavelength photons should carry more energy, encapsulated in a shorter path. However, the function of the area of these photons remains unknown. It is still possible that shorter wavelength photons have a larger area. Without a definitive understanding of the photon's area and shape, determination of the electric field strength (E_0) remains unresolved.

One might think that the simplest experiment to determine the electric field strength and area of a photon would involve recording a beam profile using a laser pulse of known power and calculating the area of an individual photon.

Let's suppose we have a rectangular beam profile with the same intensity across the detector, for simplicity, not varying with time (Figure 5).

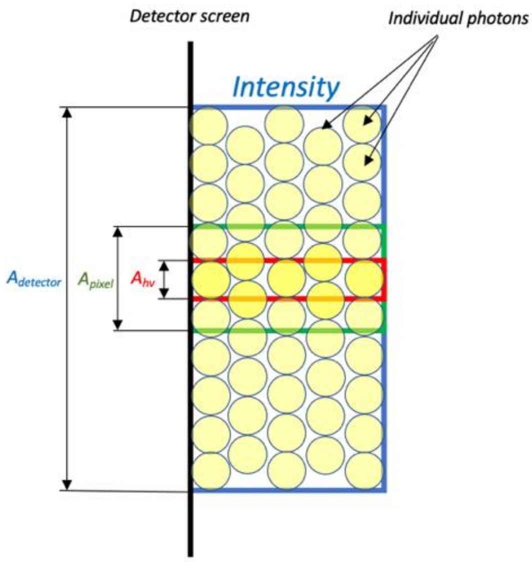

Figure 5: Supposed Beam Profile Experiment for Determining A_{hv}

The detector measures the number of photons (N) that hit each pixel area across the detector (Equation 14). Intensity is constant across the detector for our model, so we can write next:

$$I = \frac{Nhv}{Area} = \frac{N_1 hv}{A_{hv}} = \frac{N_2 hv}{A_{pixel}} = \frac{Nhv}{A_{detector}} \quad (14)$$

The detector counts the number of photons per pixel, not per area of photon [6]. Both the area of an individual photon (A_{hv}) and the number of photons per that area (N_1) are unknown values. Consequently, the area of a single photon cannot be determined from such an experiment when working with a collection of photons.

This fundamental challenge of measuring the area of an individual photon underscores the difficulty in pinpointing the electric field strength and area of single photons. The result is clear: to obtain values of E_0, one must find a way to determine the shape and area of photons. However, determining the area of an individual photon, which should be precisely located in space and time, presents a formidable task. Most experiments involving light entail working with a high number of particles. Nevertheless, there remains hope that someone will develop a method to overcome this challenge, leading to a breakthrough in determining the electric field strength of individual photons.

5. Conclusion

In summary, through this investigation, I explored the feasibility of determining the electric field strength of individual photons. I started by employing the commonly accepted sinusoidal representation of light, which lacked specific values for electric field strength. Despite conducting theoretical analysis and considering photon characteristics, I concluded that determining the electric field strength (E_0) of EM radiation is impossible without determining the area of individual photons. Unless a convenient method for determining the area of individual photons is developed, the values of electric field strength (E_0) of EM radiation remain unknown.

6. Acknowledgment

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