

Research Article

The Electric Field and the Size of the Thermal Photons

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Abstract

The size and shape of photons are still unknown. Due to their dual wave–particle quantum nature and recent discoveries related to entanglement, photons continue to surprise the scientific community. The ability to generate single pure photons opens up many potential applications, particularly in information technology. On the other hand, thermal photons are encountered in everyday life. Environmental effects, material reliability, and aging under high temperature are all areas where thermal photons play an important role. Engineers must understand better the effects of these photons. By applying Einstein's law relating photon energy to frequency, using Maxwell's classical electromagnetic laws and the Poynting theorem concerning electric fields, it becomes possible to link the wave and particle aspects of photons. These relations suggest that a photon's volume (considered as semi-classical volume) is proportional to the cube of its wavelength. By combining Planck's law, the Poynting power law, and Bose–Einstein statistics, one can estimate both the volume and electric field of thermal photons as functions of frequency. These values can then be correlated with the physical effects photons have on matter.

Keywords

Photon, Electric Field, Dimensions

1. Introduction

The size and shape of photons remain unknown, but recent studies have attempted to estimate them through various theoretical approaches [1-6]. The quantum nature of the photon—being both a wave and a particle—and the recent discoveries regarding the entanglement between two photons continue to surprise the scientific community, giving several Nobel Prizes [7] as a result of highly sophisticated experimental research [8-10].

The generation of single photons one by one opens the door to many potential applications, particularly in information technology. Meanwhile, thermal photons are ubiquitous in our daily environment. Research into material reliability and aging under high temperatures must account for the effects of

thermal photons.

By applying Einstein's law, which relates photon energy to frequency linearly, along with the classical laws of electromagnetism formulated by Maxwell and the Poynting theorem regarding energy flow in electric fields [11], one can link the wave and particle characteristics of photons. These laws suggest that a photon has an effective volume proportional to the cube of its wavelength.

According to the Poynting theorem, energy is proportional to both the square of the electric field and this effective volume. If a photon is electromagnetic, its field energy would therefore scale with the fourth power of the frequency. Yet Einstein's formula shows that total energy is proportional to

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the frequency, Maxwell's equations applied to electromagnetic waves show that the electric field is proportional to the second power of frequency. Thus, the effective volume (semi-classical) must be inversely proportional to the cube of the frequency, or proportional to the cube of the wavelength.

The electric field is proportional to the square of the frequency, as seen, for example, in dipole antenna radiation. By adding Planck's law [12], the power formulation from the Poynting theorem, and Bose-Einstein statistics [12, 13], it becomes possible to evaluate the effective volume and electric field of thermal photons as functions of frequency. These values can then be correlated with their physical effects on matter.

2. The Electric Field of the Thermic Photons

We begin with a current model: an Electric field and a magnetic field at angular delay of $\pi/2$ turning at the frequency f perpendicular to the z axis (spin) and moving to c speed following this z axis.

For a constant electric field E the classic volumic density

$$-dPP/d\lambda = 2 \pi h c^2 / ((\lambda^5) (\text{Exp} (h c / (k \lambda T)) - 1) \text{ in watt/m}^2\text{m} \quad (2)$$

This law in $(1/\lambda)$ - empiric at the beginning but well justified after- was modified by the statistic Bose-Einstein of physical states. This last quantity is the rate between N_i / G_i , N_i number of photons which occupy the sites and G_i the total number of sites. We have:

$$N_i/G_i = 1 / (\text{Exp} (h c / (k \lambda T)) - 1)$$

With k = Boltzmann constant

If λ tends to 0 or infinity, $-dPP/d\lambda$ tends to 0. So, $-dPP/d\lambda$ has a maximum for λ_m such as $\lambda_m T = 0.298 \cdot 10^{-3}$.

On the other side the Poynting law gives the power by m^2 :

$P = \epsilon E^2 c$, in the case where the electric and magnetic energy are equal.

But with the spin this law becomes [4]

$$P_s = 2 \epsilon E^2 c \quad (3).$$

Following the Maxwell laws, the E electric field $E = k_e f^2$, k_e constant: this relation is conform to the the values of electric field in the electromagnetic waves [11].

In reporting in Poynting law:

$$P_s = 2 \epsilon c k_e^2 (f^4) = 2 \epsilon k_e (c^5) (1/\lambda^4)$$

Derive this relation with λ in the case of emission of power radiations:

$$-dP_s / d\lambda = 8 \epsilon k_e^2 (c^5) (1/\lambda^5) \quad (4)$$

The relations (2) and (4) are in $(1/\lambda^5)$

energy or pressure is: $0.5E^2\epsilon$, with ϵ the vacuum permittivity. The electric and magnetic densities are the same here, therefore the total bulky density is $E^2 \epsilon$. More the spin double this energy following specialist quantic author [3]:

$$W = 2 \epsilon E^2 V \quad (1)$$

E = constant electric field rotating, ϵ = dielectric constant of void, V the photon volume.

The Einstein energy of this photon is $W = hf$, h Planck constant.

The Maxwell law and the applications to electromagnetic waves said that the electric field is proportional to the squared frequency therefore the E^2 is proportional to f^4 and the volume is proportional to f^{-3} or to λ^3 to satisfy Einstein law (λ wave length).

Now we try to evaluate the electric field E .

For thermic photons at absolute temperature T , the Planck law gives the total radiation emission in watt by m^2 m: it can be obtained by deriving the power by m^2 following λ (wave length) on semi space:

The difference is coming from the statistic Bose-Einstein.

Poynting formula is due to classical assumptions.

Historically, Bose-Einstein have introduced this statistic law to correct and give perfect the Planck formula. It concerns the probability to have a certain number of photons in the given energy state. In fact, it corresponds to the numerous of photons in a certain state and not their electric field. Therefore it is normal to generalize this formula giving k_e to all thermal photons.

So, in removing the Bose-Einstein law, to have the electric field this law becomes

$$dPPL/d\lambda = 2 \pi h c^2 / (\lambda^5) \quad (5)$$

By identifying (4) and (5) we obtain ke^2 :

$$ke^2 = \pi h / (4 \epsilon c^3)$$

and

$$ke = \sqrt{\pi h / (4 \epsilon c^3)} = 1.47 \cdot 10^{-24} \text{ Volt Sec}^2 / m \quad (6)$$

The equation (1) becomes:

$$W = 2 \epsilon ke^2 f^4 V = hf$$

Or

$$V = h \lambda^3 / (2 \epsilon ke^2 c^3)$$

With the value of ke^2

$$V = (2/\pi) \lambda^3 \quad (7)$$

This value does not depending of h and conform to the classic assumptions to the electromagnetic waves concerning the volume.

3. Try of Simple Model

The simple model of photon is a radius R wearing the electric field E turning at angular speed w and advancing at speed c .

Its angular momentum is $M = I w$, I inertial momentum. Here, $I = 0.50 m R^2$ (homenous fields, m =equivalent mass= hf/c^2) [11]

The angular momentum equation is

$$h/(2\pi) = I w = (hf/c^2) R^2 0.5 2\pi f \quad (8)$$

This equation gives

$$R = \lambda / (\pi\sqrt{2}). \quad (9)$$

If we consider the volume as cylindrical the section πR^2 and of length $n \lambda$, its value is:

$$V = \pi R^2 n \lambda \quad (10)$$

In using equation (9):

$$V = (n / 2\pi) \lambda^3 \quad (11)$$

In comparing (7) and (10) $n=4$.

4. Discussion and Applications for Engineers

The above calculations pertain to thermal photons as described by Planck's law, which has been extensively validated. However, it is important to note that the behavior of a large ensemble of photons does not perfectly represent the behavior of individual photons. This is due to factors such as random orientation and possible coupling between photons. As a result, the electric field values estimated here may be lower than those of single isolated photons. In fact, several authors [1-5] have found smaller volumes and stronger electric fields for single photons by using different assumptions.

We now explore several numerical examples based on our results.

As an example, take the case of solar photon at $\lambda = 0.40 \mu$, $f = 7.50 10^{14}$ Hertz.

Its energy is $h f = 4.96 10^{-19}$ j or 3.10 eV.

After our formula (6) the Electric field $E = k e f^2 = 0.83 10^6$ V/m.

To fix ideas, the ionization of air is $3.0 10^6$ V/m in normal

conditions.

Even with the coupling of 2 photons this electric field $<$ to $2.0 10^6$ V/m.

Following their spectra (0.2 micron to 4 microns) the visible radiations cannot ionize the air directly.

But for $\lambda < 0.1$ micron waves have an electric field up to $16 10^6$ V/m and become more and more dangerous (UV).

The authors [1-4] concerning one single photon found in the visible (0.4 micron) electric field found electric field greater than our values.

5. Try on Electric Field in Single Photon

Another application is the possible extension in electromagnetic waves. For example the works made by Haroche (Nobel Price) and by his team [7]. The experiments made at $f = 50 10^9$ Hertz the authors think to get the measurement of Electric Field after several reflections on perfect mirrors about some 10^{-3} V/m. With our formula (6) we found $E_{90} = 3.7 10^{-3}$ V/m. This value is coherent with the values found by Haroche team [7].

6. Conclusion

The estimations of electric field and volume presented in this paper—derived from Planck's law—allow a connection to be made between quantum and classical physics. They provide a coherent framework to understand the dual nature of photons, which has been debated for centuries.

Although it is difficult to directly extrapolate these results to individual photons—due to the random orientation and potential coupling among thermal photons—this estimation suggests that the notion of photon may extend over a large spectrum of wavelengths. In essence, the "entity" photon seems linked with a quantum of energy due to the electromagnetic fields amplitudes.

For engineers who work regularly with thermal photons, such as in the fields of materials science, electronics, and reliability engineering, the calculations and insights provided here can contribute to a better understanding of aging processes in materials and components, and offer a useful perspective on the physical phenomena involved.

Author Contributions

Alain Toureille is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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