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Comparative Analysis of The Photon Density Measurement Processes Using Planck's and E-Goen's Constants

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Abstract

The photon density measurement processes are able to measure number of photons contained in the energy density of an unit volume of the electromagnetic fields at a certain point location. The process of measuring photon density can be done with two basic concepts. First, the basic concept of quantized energy using the Planck's constant. Second, the basic concept of an amplitude of the electric field is quantized, so that in a photon it will contain an elementary electric field. The amplitude of an elementary electric field in a photon is proportional to the square of the measured electromagnetic wave frequency whose exact value is calculated by the E-Goen's constant (k_E = 2.624777975 × 10-23 V • s^2 / m). In this study will compare the process of photon density measurement, with the same final result. The measurement process with the concept of quantized energies using the Planck's constant, done step by step, while with the concept of quantized electric fields using the E-Goen's constant, done directly.

Keywords: *Photon, Electromagnetic, Density, Energy, Discrete*

1. Introduction

In the Maxwell's Electromagnetic Wave Field Theory has been proven that electric fields can induce magnetic fields, and vice versa magnetic fields can induce electric fields [6], which results in the Maxwell's electromagnetic wave equation [4], [11], [14]. Futhermore, through the theory of Einstein's electric photo effects, it turns out that light which is part of the electromagnetic waves also has properties as particles because it turns out that the energy is quantized [1]. Therefore, since that time began to be known that lights or electromagnetic waves have the nature of dualism [2], [9], namely as waves and as particles [3], [7].

Photons are the concept of electromagnetic waves as particles. The concept of photon was interpreted as the smallest energy unit of an electromagnetic wave, the method used to measure the photon density of an electromagnetic wave at a particular location needs to first determine the amount of the energy density per unit volume of electromagnetic waves. In order that the measurement data of the magnitude of the electric field at a particular location by an electric field sensor needs to be changed first to get the energy density per unit volume of electromagnetic waves [5].

This study aims to analyze the comparison of the photon density measurement process, which is to first calculate the amount of the energy density per unit volume of electromagnetic waves [8], with the basic concept of photons being the smallest energy unit of electromagnetic waves using Planck's constant [10]. Second, the process of measuring the density of a photon without first doing the calculation of the amount of the energy density per unit volume of electromagnetic waves. This second measuring process relates to a process of measuring the density of photons in electromagnetic waves at a particular point location using the help of the E-Goen's constant [17], with the basic concept of a photon containing the elementary amplitude of an electric field.

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2. Basic Theory

As discussed in the background above that in order to measure the density of photons, the magnitude of the electric field captured by the sensor used to find the amount of the energy density per unit volume of electromagnetic waves. But with another concept that a photon also contains elementary electric fields, the search for the amount of the energy density per unit volume of electromagnetic waves is no longer needed to measure the photon density of electromagnetic waves at a particular location.

The technique of measuring photon density using the Planck's constant is a photon as the smallest unit of energy from an electromagnetic wave [13]. In the process of measuring photon density, it is necessary to know in advance the density of electromagnetic wave energy measured at a certain distance, for example, from a transmitter station. Meanwhile, to determine the amount of the energy density of electromagnetic waves cannot be directly from a sensor, but first need to find the value of the electric field strength through an electric field sensor.

To search Densitas Photon that is scalar quantities of large number of photons contained in energy density of the unit volume of electromagnetic fields (n) is to divide the energy density of the unit volume of the electromagnetic field (u), with the energy density of the unit volume of the one photon (u_{photon}), Mathematically it can be written as: $n = u/u_{\text{photon}} = (\varepsilon_o E_{\max}{}^2)/(E_f\, k^3)$, where $u = \varepsilon_o E_{\max}{}^2$ is the energy density per unit volume [8] and $\varepsilon_o = 8.854187817\times10^{-12}$ $C^2/N{\cdot}m^2$ is the electrical permittivity in vacuum or the absolute permittivity [11]. $u_{\text{photon}} = E_f/(1/k^3)$ is the energy density of the unit volume of one photon and $1/k^3$ is a unit volume of one or more photons *also* $k = 2\pi/\lambda$ is the wave number [6]. $E_f = h{\cdot}f$, is the amount of energy of the one photon [20], where $h = 6.6260755\times10^{-34}$ J·s is Planck's constant [12] and f is the magnitude of the frequency of the electromagnetic field.

While the basic concept used in the second method using the E-Goen's constant is the process of measuring photon density using the basic concept of a photon as the smallest unit of electric field amplitude of an electromagnetic wave. So that the measurement process of this second method aims to measure the density of the photon without first doing the calculation of the amount of the energy density per unit volume of electromagnetic waves. To achieve these objectives the basic concept is used that the strength of the electric field is quantized and has the smallest unit of amplitude. From this basic concept, the formula for photon density measurement can be obtained, namely [17]:

$$n = \left(\frac{E}{k_E \cdot f^2} \right)^2 \qquad (1)$$

Which consists of:

- measure the frequency *(f)* of electromagnetic waves by using a frequency sensor,
- measure the electric field strength *(E)* of an electromagnetic wave using an electric field sensor,
- determine the photon density using the E-Goen's constant (k_E = 2.624777975 × 10-23 V·s2 / m).

3. Methodology

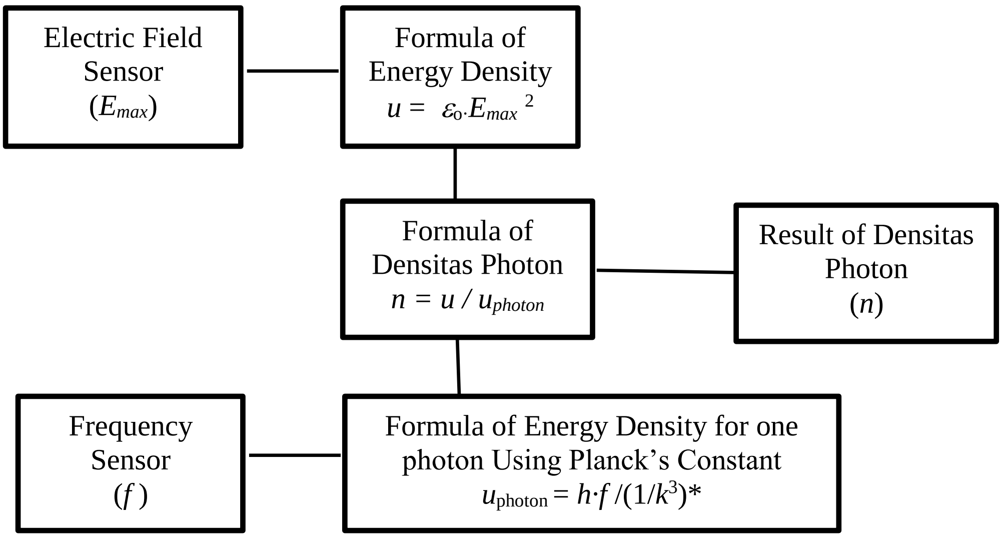
First, the method of measuring photon density with Planck's constant using the basic concept of a photon as the smallest unit of energy of an electromagnetic wave is to be described through Figure 1. Figure 1, is a scheme of the process of measuring photon density using sensors that measure:

a. The frequency of an electromagnetic wave that is used to find the value of the energy density of the unit volume of one photon (u_{photon}).

b. The strength of the electric field of an electromagnetic wave that must be changed first, that is to find the value of the magnitude of the energy density of the unit volume of the electromagnetic field (u).

Referring to Figure 1, the stage of the photon density measurement process is a frequency sensor measuring the magnitude of the frequency of an electromagnetic wave *(f)*. Then through the frequency data, the value of the energy density of the unit of volume of one photon is calculated using the formula $u_{\text{photon}} = h\cdot f/(1/k^3)$, where h is the Planck's constant and $k = 2\pi/\lambda$ is the wave number.

Furthermore, the electric field sensor simultaneously measures the strength of the electric field at the measured frequency of an electronic wave (E_{max}). Then the value of the electric field strength is used to find the energy density per unit volume, $u = \varepsilon_o E_{\max}^2$. Finally, to determine the photon density value, the division operation can be done between the energy density per unit volume (u) and the energy density of the unit volume of one photon (u_{photon}) [8].



* $1/k^3$ is a unit volume of one or more photons and $k = 2\pi/\lambda$ is the wave number

Figure 1: Schematic of Photon Density Measurement Process Using Planck's Constant

Second, the method of measuring photon density with the E-Goen's constant uses the basic concept that a photon has an amplitude as the smallest unit of electric field of an electromagnetic wave, which will be described through Figure 2. Figure 2, is a scheme of measuring photon density using a sensor that measures the frequency and strength of the electric field of an electromagnetic wave.

Referring to Figure 2, the stage of the photon density measurement process is a frequency sensor measuring the magnitude of the frequency of an electromagnetic wave *(f)*. Then the electric field sensor simultaneously measures the strength of the electric field at the measured frequency of an electronic wave (E_{max}). Furthermore, the two data can be used in calculating the magnitude of the photon density of an electromagnetic wave at a particular location. Stages that need to be done in math-processor is first to calculate the amplitude of the elementary electric field ($E_{\text{max-e}} = k_E\cdot f^2$) by multiplying between the E-Goen's constant ($k_E = 2.624777975\times10^{-23}$ V·s^2/m) with the square of frequency *(f)*. After that, the division between the strength of the electric field signal (E_{max}) and the amplitude of the elementary electric field ($E_{\text{max-e}}$). The final step is to calculate the photon density or the number of photons contained in energy density of the unit volume of electromagnetic fields (n) by squaring the result of the division value between the strength of the electric field signal (E_{max}) with the amplitude of the elementary electric field ($E_{\text{max-e}}$).

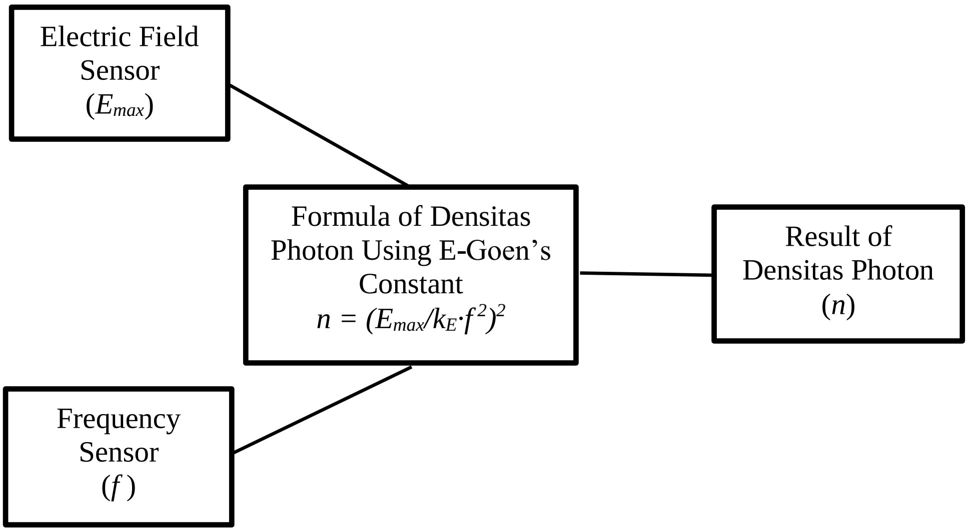


Figure 2: Schematic of Photon Density Measurement Process Using E-Goen's Constant

4. Comparative Analysis of Photon Density Measurements

After the photon density measurement process is done in two different concepts. The first method to use the concept of a photon as the smallest unit of energy of an electromagnetic wave is needed the Planck's constant. While the second method uses the concept of a photon as the smallest unit of electric field amplitude of an electromagnetic wave is needed the E-Goen's constant. In the experimental data that can be seen in table 1, there is a 100 Watt radio transmitter with a frequency of 14.15 MHz and at three different locations of the transmitter will be measured the strength of the electric field [15],[16], [18]. Then the process of measuring photon density at the three locations with the unit volume of photons is $1/k^3 \approx 38$ m^3. The final result of the photon density calculation obtained with the two different basic concepts is the same.

Analysis of photon density measurements using two methods with different basic concepts are:

First: The process of measuring photon density using the concept of a photon as the smallest unit of energy of an electromagnetic wave cannot be executed directly from primary data that is the frequency and strength of the electric field obtained from the sensors. Conceptually, the process must first be searched for the value of the energy density of the unit volume of one photon using frequency data and Planck's constant and the energy density per unit volume using the electric field strength data.

Second: The process of measuring photon density using the concept of a photon as the smallest unit of electric field amplitude of an electromagnetic wave can be executed directly from primary data, that is, the frequency and strength data of the electric field obtained from the sensors. This measurement can be executed directly because the concept of the value of the elementary amplitude of the electric field ($E_{\text{max-e}}$), the value depends only directly on the frequency of electromagnetic waves.

Below this is shown the results of calculating the density of photons at a certain distance from the source of the electromagnetic wave transmitter with a frequency of 14.15 MHz. The calculation process for photon density is two methods, the left column uses the help of the Planck's constant and the right column uses the help of the E-Goen's constant. The

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results of photon density are the amounts of photons (n) in the unit volume of electromagnetic fields which is $1/k^3 \approx 38$ m^3.

Table 1: The Measurement results of Photon density (n) using Planck's and E-Goen's Constants.

No.	Location $P_{Antenna}$ = 100 W and f =14.15 MHz	E (V/m)	n Using Planck's Constant	n Using E-Goen's Constant
1.	Near bedroom doorway appx. 3-5 m from closest section of antenna located above ceiling	14-17 (V/m)	$(7.10\text{-}10.46)\cdot 10^{18}$	$(7.10\text{-}10.46)\cdot 10^{18}$
2.	Above bedroom doorway near heating/cooling vent (localized) appx. 2-3 m from antenna	19 (V/m)	$13.07\cdot 10^{18}$	$13.07\cdot 10^{18}$
3.	Top of hall stairway & almost directly beneath antenna (appx. 1-2 m); localized near smoke alarm	75 (V/m)	$203.66\cdot 10^{18}$	$203.66\cdot 10^{18}$

5. Conclusion

The results of the photon density measurement process with two different concepts are the same. Measurements with the concept of a photon as the smallest unit of energy of an electromagnetic wave or quantized energies using the Planck's constant [13], the calculation is done in stages, while measurements with the concept of a photon as the smallest unit of electric field amplitude of an electromagnetic wave or quantized electric fields using the E-Goen's constant, the calculation is done directly. The calculation is done in stages, meaning that data of the two sensor, E and f, must be translated first in the form of the value of Energy Density and Energy Density for one photon. While the calculation is carried out directly, it means that data of the two sensor, E and f, can be directly used as the value of the electric field strength and the amplitude of the elementary electric field to find the photon density value.

Please note that the process of measuring photon density with a photometer is different. On the photometer measuring device according to patent: US1779574A is used to measure the strength of light with lumens units [19]. The strength of light is proportional to the number of photons, meaning that the greater the strength of light, the more the number of photons, but the measurement of photon density has a specific frequency that is the photons with the same frequency characteristics, whereas in photometer measurements the characteristics of a photon do not have to have a specific frequency there is a frequency spectrum.

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