International Journal of Scientific Research in Physics and Applied Sciences
Vol.**12**, Issue.**6**, pp.**36-39**, December **2024**
E-ISSN: 2348-3423
Available online at: www.isroset.org

Research Article

A Methodology for Obtaining the Effective Rest Mass of a Photon – A Focus on Radio Wave

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Received: 25/Oct/2024; **Accepted**: 26/Nov/2024; **Published**: 31/Dec/2024

Abstract — In recent times, there have been debates among modern scientists on whether photon has a mass or is mass less. This debate has lingered on for a while. This paper establishes that a photon has a discreet mass which is much smaller than that of an electron but is still significant. This paper also presents a methodology on how to mathematically compute the effective rest mass of the photon with a focus on Radio Wave signals. This work also reveals that photon mass is primarily dependent on it frequency which is the reason photon mass is varying. More so the investigation shows why Radio Wave signals which consist of photons as their electromagnetic field carriers are reflected by electrons and ions in the D, E and F layers of the Ionosphere during Radio wave transmission which enhances the aerial reach of radio Wave signal when propagated in the atmosphere.

Keyword — Photons, mass of photon, Reflection in Ionosphere, D, E & F Layers, Radio Wave.

1. Introduction

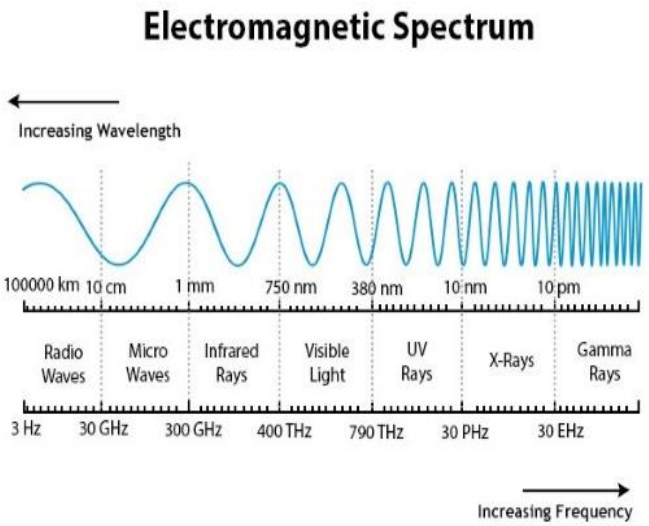

Figure 1: Showing the frequency and wavelengths of all constituents' waves in the electromagnetic spectrum.

Figure 1 shows the electromagnetic wave spectrum with increasing frequency from left to right with radio wave being wth least frequency and gamma rays with the highest frequency.

The full range of electromagnetic energy (figure 1) is represented by photons. This encompasses visible light, gamma rays, and radio waves [1]. Photons possess the properties of both waves and particles, just like a lot of other quantum-mechanical particles [2]. The local electric and magnetic fields fluctuate in strength as photons move in a wave-like pattern, frequently alternating between high and low energy levels. The kind of electromagnetic radiation that photons emit is determined by their energy. Thus, radio waves are carried by low-energy photons. Because the bottoms and crests of radio waves are comparatively far apart, they are referred to as long-wavelength waves. Gamma waves are carried by photons with high energy. Because the bottoms and crests of gamma waves are so near to one another, they are known as short-wavelength waves.

Generally, photons are referred to as he force carriers of the electromagnetic wave spectrum, these force carriers (photons) are said to have no electric charge and are also said to be mass less according to Einstein's theory in 1905 [3], their rest mass is said to be zero and since 1905, photons have been seen by scientists to be mass less. This implies that radio Wave which is part of the electromagnetic wave spectrum consist of particles called photons with a mass that is said to be zero, but this conception do not completely describe the interaction of radio Waves signals with electron and ions in the D, E and F layers of the Ionosphere. As a relief, in 2015, Agarwal.N published a paper where he proved experimentally that photons are not mass less but rather, they possess a finite mass [4].

In further view, Radio Waves interact with ions in the layers in the Ionosphere [5] as if they consist of minute particles which are smaller than the electrons with a minute's mass and charge. This personal observation/intuition led to the research and analysis carried out in this paper, which is to thoroughly and mathematically investigate if photon rest mass can be obtained mathematically no matter how small but not plainly equal to zero. With this study, it can be stated that body with mass (minute) can travel with the speed of light as we would see in the case of a photon. This investigation can be extrapolated to cover all other waves in the electromagnetic spectrum not necessarily only Radio Waves

2. Related Work

Nyambuya, G [6] conducted a study on the feasibility of massive bodies travelling at the speed of light. He argued that particles which have mass can still travel at the speed of light. Robles and Claro [7] investigated into if photons have mass. It was shown that there are some situations in which the light quanta exhibit behaviour consistent with having a finite mass. It starts with Maxwell's equations and go into how this occurs when light moves through a waveguide or interacts with charged plasma.

Goldhaber and Meto [8] underwent a study on photons and graviton mass limit. It was shown that historically, these studies have undergone three stages: (1) Verifying inverse-square laws of Newton and Coulomb by testing their power, (2) Investigating the possibility of a nonzero rest mass for photon or graviton, and (3) exploring additional degrees of freedom, that accommodate mass while maintaining explicit gauge or general-coordinate invariance.

Goray and Annavarapu [9] examined the rest mass of photons on matter surface. The investigation showed that according to experimental observations, the photon exhibits its imaginary rest mass within matter (dispersive). The reason why photons manifest themselves with variable mass was said to be a mystery.

Agarwal.N made an examination on the empirical basis for photon mass. The study examined the role of photon mass in producing a force during reflection, leading to a minor change in direction. It was shown that the only factor that can induce deviation because of inertial force is the photon's mass. A photon cannot stray if it has no mass. Additionally, it was discovered that this photon deviation is dependent on the laser light's polarization plane angle with regard to the reflecting mirror. This change in departure angle reveals an asymmetric mass distribution within the photon, rather than in the centre or equally distributed. This study demonstrates that photons have mass.

3. Theoretical Procedure

Table 1: Showing all Electromagnetic Waves with their Frequency band.

Electromagnetic Waves	Frequency Band
Radio Wave	3 kHz to 300 MHz
Microwave	300 MHz to 300 GHz
Infrared Ray's	300 GHz to 400 THz
Visible light	400 THz to 800 THz
Ultraviolet Ray's	800 THz to 30 PHz
X- Rays	3 x 10^16 Hz to 3 x 10^19
Gamma Ray's	3 x 10^19 Hz to 5 x 10^22 Hz

The frequency band of each wave in the electromagnetic wave spectrum is shown in table 1 namely Radio Waves, Microwave, Infrared ray, Visible ray, Ultraviolet ray, X-rays and Gamma rays as shown in table 1 were considered and noted then the energy (Eigen) value corresponding to each wave frequency band with a focus on Radio Wave signal will be computed using the Planck's formula

$$E = hf. \quad (1)$$

where, f= frequency of the wave measured in Hertz
h= the Planck's constant measured as $6.626 \times 10^{-34}\ Joule\ seconds$
After getting the lower and upper limit energy value of the Radio Wave of the electromagnetic spectrum of which consist of photons as carriers [10] whom value of rest mass we are interested to establish, we now use the Einstein's formula to compute the effective rest mass of the photon particle consisting of each wave as follows;

$$M = {}^{E}/_{c^2} \quad (2)$$

Where c = Speed of light in vacuum measured as 3×10^8 m/s,
E= Energy of the wave measured in Joules
and M = Effective rest mass of photons measured in kg
When the particle is in motion, it behaves as a wave but when it is at rest, the particle behaves as a particle itself. With this idea, we can calculate the rest mass of any wave by assuming it to be at rest.
From the analysis, it can be seen that the rest mass of photon is dependent on is energy, so the photon rest mass would vary since we know that the energy value is frequency dependent and frequency vary throughout the electromagnetic spectrum guided by photons.
The effective rest mass of the photons for the Radio Wave frequency band in the table 1 would be calculated using equation 2.

4. Results

We are to compute the effective rest mass of a photon for Radio Wave signal of the electromagnetic spectrum depicted by figure 1 by using equation 1 and 2. Radio wave has a frequency band of 3 kHz to 300 MHz as shown in table 1.
When f = 3 kHz which is the lower limit frequency band of the Radio Wave, we have our Energy value using equation 1 to be:

$$E = hf$$

$$E = 6.626 \times 10^{-34} \times 3 \times 10^3 = 1.988 \times 10^{-30} Joules$$

Working with equation 2, we evaluate the rest mass of a photon moving with frequency = 3 kHz and having the above energy,

$M = \frac{E}{c^2}$

$M = \frac{1.98\times10^{-30}}{9\times10^{16}} = 2.2 \times 10^{-47}\ kg$

This mass is the lower limit rest mass of a Photon of a Radio wave signal. This mass is relatively small when compared to the mass of an electron but it is still significant for radio wave propagation and can still cause scattering, absorption and reflection of radio wave signal when propagating in the higher atmosphere most especially in the Ionosphere.
For the upper limit frequency band of 300 MHz of the Radio Wave signal, we compute the corresponding rest mass of a photon with that frequency. First we calculate the energy of the photon wave with that frequency:

$E = hf$

$E = 6.626 \times 10^{-34} \times 300 \times 10^{6} = 1.988 \times 10^{-25}\ Joules$

now we obtain the rest mass;

$$M = \frac{E}{c^2} = \frac{1.988 \times 10^{-25}}{9 \times 10^{16}} = 2.2089 \times 10^{-42}\ kg$$

This is the effective rest mass of a photon of Radio Wave travelling at a frequency of 300 MHz

From the analysis and result shown, it can be seen that at a lower limit frequency of the radio wave which is 3kHz, the effective rest mass of the radio wave photon was $2.2 \times 10^{-47}\ kg$ while for the upper limit frequency of 300 MHz, the effective rest mass of the radio wave photon is $2.2089 \times 10^{-42}\ kg$ this mass is quite higher than that obtained for the lower limit frequency.

5. Discussion

It can be deduced that a photon has a discreet finite mass [4] which is much smaller than that of the mass of an electron but is still significant. Furthermore, from the result, it can be said that the rest mass of Radio Wave photon lies in the range limit $2.2 \times 10^{-47}\ kg\ to\ 2.2089 \times 10^{-42}\ kg$. Also, it can be deducted that because of this significantly small mass that a photon possess that causes Radio waves signals to be reflected by electrons and ions in the D, E and F Layers of the Ionosphere which enhances Radio Wave propagation and communication across points; a mass less particle cannot be reflected by the electrons and ions as such.

More so, It should be noted that, the rest mass of a photon is highly dependent on its frequency. A photon can be seen as a particle with a varying rest mass [9]; with each frequency of the electromagnetic wave spectrum having its own photon rest mass. The rest mass of a Radio Wave photon is different from the rest mass off a gamma ray photon because of difference in the frequency of the photon. It can also be concluded from this study that, particles with minute masses (like photons) can propagate at light's speed not necessarily only mass less particles as believed hitherto [6].

6. Conclusion and Future Scope

The rest mass of a Radio wave photon has been obtained and a methodology for obtaining the rest mass of other electromagnetic Waves photon has been shown. It is clear from the analysis presented by this paper that the rest mass of a photon is not zero but instead a photon assume a mass of finite discrete value which is smaller when compared to the rest mass of an electron notwithstanding but still significant. For a photon, its effective rest mass is dependent on the frequency of travel of the signal or radiation emitted, that is to say, each photon frequency has it own unique effective rest mass and a photon mass is not fixed instead it is a variable. More so, It is because of this minute mass of a photon that causes Radio Wave signal to behave the way it does in the Ionosphere causing it to be reflected by electrons and ions in the D, E and F layers in the Ionosphere thus improving radio Wave propagation in free space for communication purposes.
More so, it can be deducted from this paper that objects or particles with significantly small mass can travel at the speed of light just like photons which has been proven mathematically also experimentally to consist of discreet minute rest masses and with this significantly small mass also attain the speed of light during motion. Future computations can be made for the effective rest mass of a photon for the other waves in the electromagnetic spectrum and their practical implications stated.

Conflict of Interest
No conflict of interest

Funding Source
No funders

Author's Contribution
All research,ethical and writing work as it relates to this paper was carried out by the author Olusegun Eniola Ikuemuya

Acknowledgements
I want to acknowledge my creator for the uncommon insight and wisdom and also acknowledge all the staff and members of the Federal University of Technology Akure, Nigeria for making me the person I am today.

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