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Variation of Energy Density and Mass Density of Photon with Wavelength

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Abstract: ***The mass density and energy density of visible photon is calculated as*** $10^{-8}kg\,m^{-3}$ ***and*** $10^{9}Jm^{3}$***, respectively. Moreover it is also observed that mass density and energy density of photon depend upon photons mass, wavelength, volume and energy. This is clear from figure 1, figure 2 and literatures. Therefore the mass density and energy density of photon varies with masses of photon, wavelength, volume, etc.***

Keywords: Mass density, Energy Density, Wavelength, Volume and Energy etc.

I. INTRODUCTION

The formulations of the theory that assume the rest mass of photon is zero, failed to lead to a covariant description of the light wave. Moreover, it is also consider that the light wave is actually a coupled state of the field and matter with a small but finite rest mass. The rest mass is originate from the atomic mass density wave which is forward by the field-dipole forces [1]. On taking wavelength of 6328A^{0} emitted by He–Ne using relativistic equation of Einstein mass energy relation

$$E_{ph} = \frac{mc^2}{\left(1-\left(\frac{v}{c}\right)^2\right)^{\frac{1}{2}}} \qquad (1)$$

Pariser in 2012 calculated the mass of photon using relation

$$m_{ph} = \left(\frac{h}{\lambda c}\right) \times \left(1-\left(\frac{v}{c}\right)^2\right)^{\frac{1}{2}} \qquad (2)$$

He found the mass of photon approximate $8.56 \times 10^{-38}kg$ which is also considerable for mass of visible photon [2]. The rest mass of photon is zero suggest by different researcher and scientist. On using, uncertainty principle the upper limit of rest mass photon is estimated by equation $m_{ph} \approx \frac{\hbar}{(\Delta t)c^2}$ and given a numerical value $m_{ph} \approx 10^{-66}$ g at universe age 10^{10} years. This mass is extremely difficult to detect, therefore Coulomb's law and Ampere's law, longitudinal electromagnetic waves and Yukawa potential of magnetic dipole fields was studied seriously to find the mass of photon.

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To find the mass of photon an Particle Data Group, currently accepted upper limit rest mass of photon as $m_{ph} = 4 \times 10^{-49}g$ quoted by Hagiwara et al in 2002.

An improvement in rest mass of is made as $m_\gamma = 1 \times 10^{-49}g \equiv 6 \times 10^{-17}eV$ was reported in 2004 Eidelman et al. Variation of Lagrangian density with A_μ yields the Proca equation as

$$\frac{\partial F_{\mu\nu}}{\partial x_\nu} + \mu_{ph}^2 A_\mu = \mu_0 J_\mu \qquad (3)$$

Since, $F_{\mu\nu} = \frac{\partial A_\nu}{\partial x_\mu} - \frac{\partial A_\mu}{\partial x_\nu}$ therefore equation (3) become

$$\left(\square - \mu_{ph}^2\right)A_\mu = -\mu_0 J_\mu \qquad (4)$$

where $\square$ is d'Alembertian symbol and equivalence to $\nabla^2 - \partial^2/\partial(ct)^2$. In case of free space equation (4) become,

$$\left(\square - \mu_{ph}^2\right)A_\mu = 0 \qquad (5)$$

This equation is Klein–Gordon equation for the photon and μ_{ph} is parameters that interpreted the rest mass of photon as

$$m_{ph} = \frac{\mu_{ph}\hbar}{c} \qquad (6)$$

Hypothesis of Georgi et al. in 1983 and de Bernardis et al. in 1984 investigated the effects of photon mass on the spectral behaviour of the cosmic background dipole anisotropy. This hypothesis give the value of photon mass $2.9 \pm 0.1 \times 10^{-51}g$ with a confidence level of 68%. De Broglie in 1940 suggested the limit on the photon mass, from equation (6) on taking consideration of $\lambda_2^2 - \lambda_1^2 = 5 \times 10^{-13}m^2$ (for instance, red light of $\lambda_2 \sim 800\ nm$ and blue light of $\lambda_1 \sim 400\ nm$), $L = 10^3$ light years, and $\Delta t \leq 10^{-3}s$ Kobzarev and Okun in 1968 obtained as

$$m_\gamma = \frac{\mu_\gamma \hbar}{c} = \approx \frac{\hbar}{c}\sqrt{\frac{8\pi^2 c\,\Delta t}{L(\lambda_2^2 - \lambda_1^2)}} \leq 4 \times 10^{-40}g \qquad (7)$$

Gravitational deflection of massive photons also support the hypothesis for setting the limits of photon mass and from theory of general relativity for photon has a nonzero rest mass, deflection angle is given by

$$\theta = \theta_0\left(1 + \frac{m_{ph}^2 c^4}{2h^2 f^2}\right) \qquad (8)$$

Where $\theta_0 = \frac{4MG}{Rc^2}$ the deflection angle for a massless photon, M is the solar mass, G the Newtonian gravitational constant, R the photon impact parameter, and hf the photon energy. Lowenthal set the correction term $\Delta = \frac{\theta_0\left(m_{ph}^2 c^4\right)}{2h^2 f^2}$ equal to the difference between the measured deflection angle and the deflection angle calculated for photons with zero rest mass.

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The expression for setting an upper limit mass of photon as

$$m_\gamma^2 \le \frac{h\nu}{c^2}\sqrt{\frac{2\Delta}{\theta_0}} \qquad (9)$$

Lowenthal classified masses into three catagories that is mass of visible photon is $m_{ph} < 1 \times 10^{-33} g$ with $\nu = 5 \times 10^{15}\, Hz$ and $\Delta \approx 0.1\, arcsec$; mass of radio source photon $m_{ph} < 7 \times 10^{-40} g$ with $\nu = 3 \times 10^{9} Hz$ and $\Delta \approx 0.1\ arcsec$ and for intercontinental baseline interferometry mass of photon is $m_{ph} < 7 \times 10^{-41} g$ if the deflection measurement at radio frequencies could be improved to 0.001 arcsec [3]. De Broglie calculated photon mass by dispersion of optical light from stars and give limit to mass of photon as $m_{ph} \le 10^{-47} kg$ [4] with numerical error of $\approx\ 10^5$ [5]. Kroll also clauclate and give the limit mass of photon as $m_{ph}\ \le 4 \times 10^{-49}\ kg$. Moreover, Ryutov used fuller data on the plasma and magnetic field and make a dramatic further improvement on mass of photon as [6] $m_{ph}\ \le 4 \times 10^{-54}\ kg$ [7].

The behavior of a photon is strange as photon possesses both wave nature and particle nature. Electromagnetic theory assume that the rest mass of photon in free space is zero and also photon has non-zero rest mass, as well as wavelength-dependent. An experiment revealed its non-zero value as 10^{-54}kg (5.610 × 10^{-25} MeVc^{-2}). Rest mass of photon depends upon scalar curvature of the surface of matter and wavelength of the photon [8]. Numerous types of experiments have been done to show rest mass of photon example satellite measurement of earth's magnetic field is measure rest mass of photon as 4 × 10^{-51}kg (2.244 × 10^{-21}MeVc^{-2}), low frequency parallel resonance circuits measure the rest mass of photon as 10^{-52}kg (5.610 × 10^{-23}MeVc^{-2}) [9], solar wind experiment measure the rest mass of photon as 1.5 × 10^{-54}kg (8.414 × 10^{-25}MeVc^{-2}) [10], dispersion measures (DMs) meaure the rest mass of photon as 3.2 × 10^{-50}kg (1.795 × 10^{-20}MeVc^{-2}) [11] and 3.9 × 10^{-50}kg (2.188 × 10^{-20}MeVc^{-2}) [11]. Thes asll caluation of rest mass of photons is done indirectly. These all conclude that photon has nonzero real mass and depends on the wavelength of photon in free space [13, 14].

The probability density of a photon propagating with a Gaussian wave can be computed by the use of a Schrödinger equation. The changing propagation direction of the relativistic mass density propagating with the electromagnetic wave. Schrödinger equation allows to describe the transverse quantum mechanical motion of the photon by the use of matter wave theory, even though the photon has no rest mass [15]. The universe's length calculated from gravitational forces between the rest mass of all photons and each separated by Planck's length. The density of photons within a cross-section of unit space with a thickness that reflects the visible wavelengths as well as the shared metric of 10^{104}m^4 kg^{-2}. If we assume the minimal distance between two photons is Planck's length, a metric also suggested by some applications of Casimir interactions [16].

The dynamics ionized interstellar medium in the presence of hidden photon dark matter. The hidden photon mass is smaller than the plasma frequency in the Milky Way. Authors point out the Galactic plasma shielding direct detection of ultra-light photons mass range is especially challenging. The demonstrate of ultra-light hidden photon dark matter provides a powerful heating source for the ionized interstellar medium and hidden photons mass of order 10^{-20}eV [17]. Dark photon dark matter can be convert into visible photons and dark photon mass is equal to the plasma frequency. Dark photon dark matter in the presence of inhomogeneous structure and the masses of photons range $10^{-15} eV \le m_{A'} \le 10^{-12} eV$). The demonstration and experiment show photons masses near $\sim 10^{-14} eV$ [18].

II. MATERIAL AND METHOD

A. Submission of the paper

On observing approximate 40 data of each monochromatic spectrum, we found an average value in mV with the help of a sensor and voltage measuring device instantly. The average voltage observable value of considering spectrum is found for 400nm is 8.0125mV, 620nm is 5.3275mV, 650nm is 3.6025mV and 700nm is 2.7375mV. On taking this value we calculate the corresponding cross-sectional area and volume of the monochromatic spectrum, which give an approximate visualization of the photon, the calculated value is tabulated in table 2.

Table 1: Calculation of energy of the spectrum of the corresponding wavelength

⌖♋❖♏●♏■♑♦♒ □♐ ♎♒□♦□■ ♦	❄♒♏ ♏■♏❒♑⍓ □♐ ♎♒□♦□■ $\left(\frac{hc}{\lambda}\right)$
🗐▢▢■❍🖬 $400 \times 10^{-9} m$	$3.10 eV$
⌛🗎▢■❍🖬 $620 \times 10^{-9} m$	$2.00 eV$
⌛🗏▢■❍🖬 $650 \times 10^{-9} m$	$1.91 eV$
🖮▢▢■❍🖬 $700 \times 10^{-9} m$	$1.77 eV$

Table 1, is theoretically and experimentally calculated energy carried by corresponding monochromatic spectrum with specific cross-sectional area and volume of the photon. This table also helps to calculate the cross-sectional area of considering the monochromatic spectrum, which is tabulated in Table 2.

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Table 2: Cross-section area and volume of the corresponding monochromatic spectrum emitted from sources as sown in figure 1.

[illegible]	[illegible]	[illegible]
[illegible]	$0.11322309 \times 10^{-22}$	[illegible] $\times 10^{-28}$
[illegible]	$1.70286251 \times 10^{-22}$	[illegible] $\times 10^{-28}$
[illegible]	$2.50506666 \times 10^{-22}$	[illegible] $\times 10^{-28}$
[illegible]	$3.26918919 \times 10^{-22}$	[illegible] $\times 10^{-28}$

The calculated cross-sectional area and volume of the monochromatic spectrum are of the order $10^{-22}m^2$ and $10^{-28}m^3$, respectively. If we study deeply on the cross section area, it is observed from table 2 that cross sectional area and volume increases with an increasing wavelength of the spectrum. This nature of spectrum help to research, scientist and applied field to give the accuracy of the experiment [19, 20, 21].

The masses of visible photon is calculated by some authors like Tue et al., as $10^{-36}kg$ and Pariser by using He-Ne laser of wavelength 6328A^0 is $8.56 \times 10^{-38}kg$. Average mass of visible photon is $\frac{10^{-36}+8.56\times10^{-38}}{2} = \left(\frac{10^{-36}+0.0856\times10^{-36}}{2}\right) = 0.5428 \times 10^{-36}kg$.

Since we have density formula $\rho = \frac{Mass(M)}{Volume(V)}$, therefore the volume density of photon can be calculated with the help of table 2.

Table 3: Mass Density of Visible Photons with the help of table 2

[illegible]	[illegible]
[illegible]	[illegible] $\times 10^{-28}$
[illegible]	[illegible] $\times 10^{-28}$
[illegible]	[illegible] $\times 10^{-28}$
[illegible]	[illegible] $\times 10^{-28}$

Table 3 show the mass density of visible photon which is order of $10^{-8}kgm^{-3}$with increase the wavelength of photon mass density goes decrease. This mass density of photon varies with the mass of photon because different wavelength of photon has different masses as mention in literatures mention above. Therefore the mass density of the photon is not fixed and it varies with wavelength.

Table 4: Energy density of visible photons with the help of table 1 and table 2

[illegible]	[illegible]
[illegible] $\times 10^{-28}$	3.10
[illegible] $\times 10^{-28}$	2.00
[illegible] $\times 10^{-28}$	1.91

Table 4, show the energy density of visible photon which is order of $10^{9}Jm^{-3}$ with increase the wavelength of photon. This energy density of photon varies with the energy of photon because different wavelength of photon has different energies as mention in literatures mention above. Therefore the energy density of the photon is not fixed and it varies with wavelength. Both energy density and mass density are calculated goes deceases with increase the wavelength of the photons. This calculation is based on experimental observation data tabulated in table 2.

III. RESULT AND DISCUSSION

A. *Mass density of Visible Photon*

Here mass density means mass by volume where mass is mass of visible photon which is taken as average mass for our work. The representation shown figure 1 is to study the nature of photon volume and mass density of photon. In general one can say that with increase in volume or wavelength of photon mass density decrease and the order of mass density is $10^{-8}kgm^{-3}$. In similar way one can say that with increasing the wavelength of photon the volume of photon increase and hence density of photon decrease. The mass density of photon above 620nm is very sharp decreasing with volume of photon but after 620nm photons volume, mass density is slowly increases.

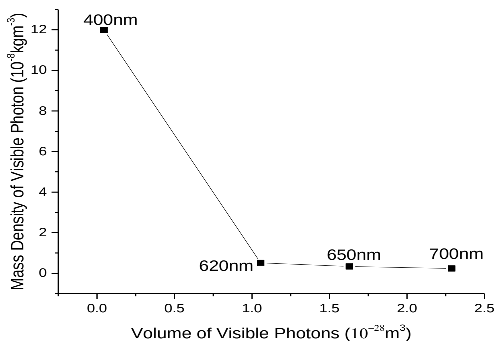

Figure 1: Volume of Visible Photon vs Mass density of Visible Photon

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B. *Energy Density of Visible Photon*

From the representation of figure 2, it is clear that the energy density of photon decrease with increases in wavelength and volume of visible photon. The energy density of a single visible photon is the order of $10^{9}Jm^{3}$. The energy density of photon above 620nm is very sharp decreasing with volume of photon but after 620nm photons volume, energy density is slowly increases.

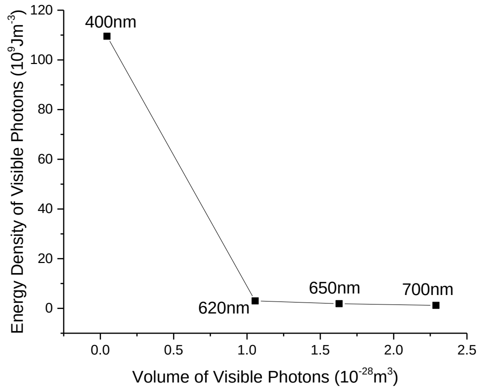

Figure 2: Volume of Visible Photon vs Energy density of Visible Photon

IV. CONCLUSION

To study the density of photon the experimental was observed to calculate the volume of photon and mass of visible photon was taken from the Tu et al. and Pariser. With the help of these data mass density and energy density of visible photon was calculated. The calculation show that the mass density is of order of $10^{-8}kgm^{-3}$ and energy density is of order of $10^{9}Jm^{3}$. Moreover it is also observed that with increasing the wavelength and volume of visible photon the mass density and energy density both goes decrease, detail in figure 1 and figure 2. Therefore in general one can say that mass density and energy density depend upon wavelength of photon. Also from literature there are numbers of masses calculated by different researcher for different wavelength of photon. So the mass density and energy density also depend upon the masses of photon.

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