

On the massive nature of photon

Author: Arka Dev Roy

Abstract: The idea drawn from Einstein's special Theory of Relativity, reveals that photons are mass less particles and that, every particle travelling at the speed of light must accordingly be mass less. This assumption gave an overview to the Neutrino Mass problem-If it has mass? Now, as we know, the values of the mass of electrons, protons, alpha-particles, etc. to a tremendous degree of accuracy, their velocities can also be changed by the application of electric and magnetic fields. Thus, we usually tend to visualize them as tiny particles. In presenting the present article, our hope is that this may aid or contribute significantly in solving the said problem of "How can a massive particle travel at the speed of light?" From different perspectives of existing knowledge in physics and the physical nature of particles it is generally assumed that the mass of the photon must be zero. Albeit, it has never been proven and it is never possible to prove innately that the photons are mass less it is generally accepted that photons travelling at the velocity of light must be mass less since they are long-ranged. Nevertheless, throughout the article we will endeavour to show about the history of light, types of masses and their intuition for the introduction of mass to the photon and some techniques for calculating the possible upper limits of mass of the photon.

Index Terms: Light History, introduction of Mass, Some Models for Calculating of Photon Mass. Discussion.

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1 INTRODUCTION

IN the latter half of seventeenth century Newton proposed the "Corpuscular theory" of light, assuming light consists of tiny billiard ball like particles which are given out by luminous light. These corpuscles travel in straight line when not acted upon by external forces. The fact that light seems to travel in straight line path and cast shadow behind the obstacles is the strongest evidence of particle nature of light. Different colours are due to different size of the corpuscles. Though this (1) model could explain many facts in geometrical optics, it failed to explain phenomena like interference, diffraction, polarization etc. The wave theory of light was put forward by Huygens considering that a luminous object sends out disturbances in the form of longitudinal waves, explaining reflection and refraction of light which was later decisively proved by Thomas Young and Fresnel to be correct by introducing the concept of transverse waves and his idea of half period zones. To explain the propagation of light through vacuum the supporters of this wave theory of light had to imagine the presence of all-pervading hypothetical medium ether prevailed by Huygen, through which light wave could pass. The energy of disturbances is transferred from one part of the medium to another part and the particles of the medium only oscillate about the mean position of equilibrium. Any part of the medium does not move, but the profile (1) of the waves move continuously and also the vibrations of the ether medium are similar to those produced by solids and liquids having the vibrations of the particles

is parallel to the direction of propagation of the wave. So the velocity of wave propagation is equal to the ratio of Elastic modulus to the density of that medium. Now light has enormous velocity. So ether must have very high modulus of elasticity and low density. Obviously, these two properties are contradictory to each other. So, the existence of ether was discarded. Maxwell's theory of light as electromagnetic waves was one of the greatest achievements of the 19th century which rejected the idea of ether concerning no material medium for propagation. According to him light is a transverse electromagnetic wave. A changing magnetic field produces a changing electric field and vice-versa. This makes both the field to be co-related and able to propagate even through vacuum as well. The existence of such electromagnetic waves was verified experimentally by Hertz (8). Maxwell's theory of light could explain rectilinear propagation, reflection, refraction etc. in addition to the phenomena like interference, diffraction and polarisation.

The history of the photon in the 20th century started in 1901 when the eminent physicist Planck [(2)] put forward the formula for radiation of a black body and introduction of what was called later the quantum of action 'h' (Planck's constant). The electro-magnetic theory failed to explain several phenomena like black body radiation, origin of line spectrum, photo-electric effect (where it is shown that light consists of quanta or packets of energy), Compton Effect etc, relating about the emission and

absorption of light. In 1902 Lenard [(3)] illustrate that energy of electrons in photoelectric effect is independent of the intensity of light, but depends on the wavelength of the latter.

In the year 1905 Einstein published fundamental article "On an Heuristic Point Of View Concerning the Production and Transmission of light" [(4), (5)]. Here he demonstrates that energy of light is distributed in space not uniformly, but in a form of localized light quanta. Einstein's light quanta behave as particles, it's carrying both the energy as well as momentum, was given in 1923 in the experiments by Compton [(6)] on Scattering of X-rays on electrons. The term 'photon' for particles of light was given by Lewis in 1926 in an article "The Conservation of Photons" considering photons to be "atoms" of interaction.

2 INTRODUCTIONS TO PHOTON MASS

. Professor Albert Einstein (1905's) energy-momentum dispersion relation, namely:

$$E^2 = p^2 c^2 + m_0 c^2 \quad (1)$$

Where E is the total energy of the particle, $|p|=p$ is this particle's momentum, m_0 is this same particle's rest mass and $c=2.99792458 \times 10^8$ m/sec is the speed of light in vacuum . The second fact is that due to SRT the energy of the photon has been found from our experience to be given by:

$$E = pc. \quad (2)$$

Now, neutrinos appear to travel at the speed of light and on account of the 'Special Theory of Relativity', they must be massless. Massless neutrinos have a problem to describe the phenomenon of Neutrino oscillations because this requires massive Neutrinos as described by Fermi and his Research Scholar Ettore Majorana.

Now if both the two equations (1) and (2) are applicable to the [(7)] photon having all the symbols remain unchanged with all the identical symbols, then it follows exactly that m_0 , i.e. the rest mass of the photon must be zero.

The assumption leading to the fact that for photons $m=0$, so that energies (E) in the formulae $E^2 = p^2 c^2 + m^2 c^4$ and $E=pc$ are identical. .

If these two energies are different then equation (1) is the total gravitational energy E_g of the photon so that $E_g^2 = P^2 C^2 + m_0^2 C^4$ and kinetic energy $E_k = Pc$. so we can write

$$E_g^2 = E_k^2 + m_0^2 C^4 \quad (3)$$

Based on this kind of thinking one question arise to verify about the mass of photons.

As photon considered as the fundamental particle to mediate electromagnetic radiation, [(8)],it consists of both the energy and momentum through space-time and propagates in vacuum at the constant velocity 'c', No speed should be greater than this.

Many experimental efforts are taken to improve the limits on the rest mass of the photon have arisen to challenge contemporary accepted theories, and the massive photon as a neutral massive particle is usually called vector boson.

3 WAVE-PARTICLE DUALITY

A wave is characterised by its frequency, wavelength, phase or group velocity, amplitude and intensity. Moreover, (8) a wave spreads out and occupies a relatively large region of space. A particle is characterised by its mass (m), velocity (v_p), momentum (p), energy (E). Moreover a particle occupies a definite position in space and hence is highly localised. Evidently the nature and properties of a wave and a particle are to a large extent conflicting. Because a wave is spread out in space and a particle is localised at a point in space.

Many types of question arises about the concerned matter. But these dual properties of light or radiation was experimentally theoretically confirmed by French theoretical physicist Louis de Broglie, who suggested that like radiation, matter also possesses dual (particle like and wave like) properties. His suggestion was partly based on his intuitive feeling that nature is symmetrical. So if radiation can show dual nature, then things like electrons which are considered particles should also act as waves at times. This is Dual nature of matter. The wave associated with matter is called matter wave or de Broglie wave. The relation between the wavelength ' λ ' associated with a material particle moving with momentum 'p' is obtained by

$$\lambda = h/ p = h/ mv$$

where, 'm' is mass and 'v' is the velocity of the particle.

4 De Broglie's wave equation

In his theory of relativity Einstein had proved the equivalence of mass and energy i.e. 'E = mc²', where 'm' is the mass and 'c' is the velocity of light in vacuum.

Similarly, in accordance with quantum theory of radiation proposed by Max Planck a radiation of frequency 'ν' consists of quanta or photon of energy E = hν, h= Planck constant. Combining these two, we get:

$$E = h\nu = mc^2$$

But in the case of a wave, c = λ . Thus, for a quantum of light or photon we get

$$E = hc / \lambda = mc^2$$

Therefore, λ =h/mc. So

$$\lambda = h/p \quad \text{where, } p=mc \text{ momentum of photon.}$$

Hence λ is the wavelength associated with quantum or particle having momentum 'p'.

5.1 De Broglie –Proca model

It was Luis De Broglie who noticed that photon (9) mass would lead to a larger speed of violet light than that of the red one. During eclipse in a double star system (a double star system is a pair of stars that appear close to each other in the sky as seen from the earth through an optical telescope. This is due to the fact the pairs from binary star, i.e binary system of stars in mutual orbit, gravitationally bound to each other. Important for direct calculation for stellar mass) the colour of the appearing star would change from violet to Red.

The equation which give the photon mass is written below [(10), (11)]

$$\nabla \cdot \mathbf{E} = \rho / \epsilon - M^2 \phi, \text{ is the charge density, } M = mc/h/4\pi; M=1/\lambda. \quad h/4\pi \text{ is the reduced Plank constant.}$$

This approach was invalidated on seeing the result of the dispersion of light in the atmospheres of stars. The effect was discovered by Belepolskii, Nordmann and Tikahoff interpreting as dispersion in the interstellar free space [(12), (13), (14)].

5.2 Proca Electrodynamics and Gauge Invariance

The phenomena of electro-magenic theory is one of the

best achievements in the history for the evolution of Physics with the base on the four equations. The fourth equation was modified by him, called displacement current term. The importance of this term is that: if it was not discovered, the production and transmission of electro-magnetic waves through free space were not possible as well. Maxwellian Electrodynamics is based on the hypothesis of a massless photon. The evidence for this, experienced yet to analyze desperately with a solid answers as regarding the quintessence of a zero-mass photon is the resulting gauge invariance of Maxwellian Electrodynamics. Gauge invariance was first introduced by Herman Weyl; it plays a commanding role in physics as a whole to illuminate about the photon for the evolution of OPTICKS to its present apparent massive state though yet to examine. However, one of the genius Romanian physicist Alexandru Proca (1897 – 1955) wanted to make some positive solution to this million dollars problem along with the strong lifted hands of his teacher L De Broglie. He construct an electrodynamics theory were the photon has a non-zero mass(7) via the Proca Lagrangian L, that is:

$$L = \frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \mu_0 J_\mu A^\mu \pm \frac{1}{4} \mu^2 A_\mu A^\mu$$

where, the first two terms are *Maxwellian terms* and the last is the *Proca term*.

where A_μ is the electrodynamics four vector potential, J_μ is the four electrodynamics current,

μ₀ = 4π × 10⁻⁷ kgmC⁻² is the permeability of free space, μ² > 0 is mass term of the photon and:

$$F_{\mu\nu} = \frac{\partial A_\nu}{\partial x^\mu} - \frac{\partial A_\mu}{\partial x^\nu}$$

is the electromagnetic field tensor. As usual, the Greek indices (μ, ν . . .) run from 0 to 3, i.e. (μ, ν = 0, 1, 2, 3). The potential that is obtained from the field equations are given by

$$\phi(r) = \frac{1}{4\pi\epsilon_0} \frac{qe^{-\mu r}}{r}$$

where ε₀ = 8.854187817 × 10⁻¹² C²s² m⁻³kg⁻¹ is the permittivity of free space. Yet, it might be possible for a non-zero photon mass exist since it has never been proven to be completely zero and to conduct an experiment to do so is quite impossible.

5.3 The Yukawa potential in static fields

The next effect we discuss regarding massive photons arises in static fields. For a static electric field, we must have that time derivative is zero and this concept was firstly introduced by Yukawa. So from his estimate we can say: $\frac{\partial}{\partial t} = 0$, so we consider the wave equation as:

$$(\nabla^2 - \mu^2) \phi = -\frac{\rho}{\epsilon_0}$$

Where the symbols have their usual meanings.

For a point charge $\rho(r) = Q \delta(r)$ which gives us

$$\phi(r) = \frac{1}{4\pi\epsilon_0} \frac{Q}{r} \exp(-\mu r)$$

and the electric field becomes

$$E(r) = \frac{Q}{4\pi\epsilon_0} \left(\frac{1}{r^2} + \frac{\mu}{r} \right) \exp(-\mu r)$$

In that situations if we investigate the basic facts of the afore mentioned two equations(11) then one can easily see that if $r \ll \mu^{-1}$, the inverse square law is indeed a good approximation, but if $r \gg \mu^{-1}$, then the law departs radically from the predictions of Maxwell's equations. So its most amazing fact that in plasma, the static scalar potential does have a Debye form analogously: i.e.

$$\phi(r) = \frac{1}{4\pi\epsilon_0} \frac{Q}{r} \exp(-\mu_D r)$$

where, $\mu_D = \sqrt{\frac{ne^2}{\epsilon_0 T}}$ is the inverse Debye shielding distance, n is the plasma density and T (in joules) is the plasma temperature. In a similar manner if we consider for the case of Superconductor, a static magnetic field obeys the equation written below:

$$(\nabla^2 - \mu_L^2) B = 0$$

where, $\mu_L = \frac{\omega_p}{c}$ is the London skin depth, with $\omega_p = \sqrt{\frac{ne^2}{\epsilon_0 m_e}}$ denoting the electron plasma frequency.

Thus, reviewing various analogies we can see that the conventional non-zero photon mass may be transformed to a finite massive value demonstrating the massive nature of the photon.

5.4 GRAVITATIONAL DEFLECTION OF MASSIVE PHOTONS; LOWENTHAL PROPOSAL

The year 1973 is one of the successful years in the history of massive photon as an eminent scientist Lowenthal proposed [(15)] a method for building limits on the photon mass on cultivating the gravitational deflection of electromagnetic radiation. From Einsteinian theory of general relativity it is predicted a deflection of starlight by the Sun of 1.75 arc sec (Hawking 1979). If then the photon(11) has a nonzero rest mass, this deflection angle would become

$$\theta = \theta_0 \left[1 + \frac{m_\gamma^2 c^4}{2h^2 v^2} \right]$$

where, $\theta_0 = 4MG/RC^2$ is the deflection angle for a massless photon, 'M' is the solar mass, 'G' the Newtonian gravitational constant, 'R' the photon impact the correction term.

$$\Delta = \theta_0 \frac{m_\gamma^2 c^4}{2h^2 v^2}$$

is equal to the difference between the measured deflection angle and the deflection angle calculated for photons with zero rest mass. By such doing, an expression set for an upper limit on the photon written as

$$m_\gamma^2 \leq \frac{hv}{c^2} \sqrt{\frac{2\Delta}{\theta_0}}$$

Using the above equation and the data available at the time on the deflection of electromagnetic radiation by the sun,

$$m_\gamma < 1 \times 10^{-33} \text{ g with } v = 5 \times 10^{15}, \Delta \approx 0.1 \text{ arcsec.}$$

5.5 CHERENKOV EFFECT

The Cherenkov radiation [(17)] is electromagnetic radiation emitted when charged particle like electron passes through a dielectric medium at a speed greater than the phase velocity of light in that medium. When a high energy (TeV) gamma photon or cosmic ray interacts with the Earth's atmosphere, it may produce an electron-positron pair with enormous velocities.

The velocity of the charged projectile which generates the massless Cherenkov radiation (18) can be considered during the process of radiation constant because the energy loss due to radiative process is small. So in the case of Massive Cherenkov effect the velocity can be considered constant only in case of very energetic and heavy charged.

As the emission of massive photons is distributed in all space directions irrespective of any conditions applied for, so it brings us to concern the fact that not

only in superconducting medium but also plasma medium in electron gas, ionosphere medium or photons in wave guides [(11)].

The bosons W_{\pm} and Z_0 are also massive and it means that the generalization of our approach to the situation in the standard model is evidently feasible.

5.6 SCHRÖDINGER'S EXTERNAL FIELD

In 1943, Schrödinger arranged a process to establish a new outlook for searching the photon rest mass for the case of electromagnetic fields of certain strength in empty space, and neglecting gravitation in his "Unitary Field Theory" [(19)].

He placed an upper limit [(20)] on the Photon rest mass by examining a modified version of Maxwell's equations, especially Ampere's law. The term added acts like vertical currents and by making a fit of the geological data he arrived at a finite photon rest mass.

5.7 MAGNETOHYDRODYNAMIC (MHD) PHENOMENA

MHD phenomena are characterized by a combination of ordinary hydrodynamics and Maxwell's electromagnetism (11), which is used for the description of the interactions between magnetic fields and a free fluid. (21). It was said that the photon possesses a finite rest mass, MHD phenomena within the interplanetary, magneto hydro dynamic turbulence as well Encompasses an a new way for non-zero value of Photon mass on the basis of ordinary Maxwell's description .many Researcher in that time influenced by MHD phenomena and trying to make a comparable results for the existence of the non zero valued photon mass.

One of them Ryutov used this model to investigate the fields due to the solar wind at various points within the earth's orbit and write in his concludal note that someone has to reduce the photon mass approximately an order of magnitude compared with Davis in 1975.

5.8 SOME EXTRA-TERRESTRIAL LIMITS ON PHOTON MASS

Besides the Previous proposal there is several of techniques proposed by theoretical physicist for finding non-zero value of Photon mass. So some extra terrestrial limits is constructed by them after long time discussion between large no of scientists across the world who are involved in the different laboratory. Though the investigations of invariance of 'c' over the

electromagnetic spectrum and black body radiations given by Planck provide the most immediate approaches to search an way to think about the chemistry to manage as well as philosophy for some trace of the massive photon., after a long time dedicated search an excellent review of them was written by Froome and Essen (1969) [(22)]. Considerably in 1937, Ross and Slow (23) made a determination after a hard work about the phase velocity of radio waves that was transmitted along the surface of the ground. If this deviation is suppose to impose to a nonzero photon mass effect on the fixed propagation path, it corresponds to $m_{\gamma} = 5.9 \times 10^{-42}$ g. Thus we can obtain another limiting case for the finiteness of photon mass.

6 CONCLUSION

Throughout the Article We have narrated about the past and present upper limits that have been found for the photon rest mass, at first the History of light and the idea how was the non zero value of photon mass came? And we have considered some possible areas which is considered as a most cited where future improvements might occur. It is great de Broglie who is the first person of the globe to talk about the non zero Value of photon mass. So it contradicts the scientist as if it is not violate the fundamental second postulate of Relativity? But in the mean time, Till now we are totally blind to know about the universe of astrophysics and cosmology (11) where many doubts and suspicious view wait for a mind-blowing resolution as well as for determination of a nonzero value for the mass of the photon, encouraged for work, the origin and the stability of large scale cosmic magnetic fields, the properties of the interstellar media and plasma, dark matter dark energy, Hidden dimension and so on. This intuition could be consistently helpful to conceive the phenomenon of the photon mass being normally zero and it can be also show that the photon mass has a non-conventionally finite and non-zero value.

Other than that, with the advent of *string theory* as an ultimate theory towards the understanding of our universe, it might be possible to determine hidden dimensions in which the photon's mass is trapped and remains undetected due to low-energy experiments. But currently various benchmarks have been established regarding high-energy experiments such as the detection of the *Higgs-boson*, almost 50 years after its prediction. Thus with the resource of high-

energy experiments it might be possible to determine more accurate values of the upper limit of photon mass and ultimately the true value of a non-zero photon mass.

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- Arka Dev Roy
 - Srifala Road, Rampurhat, Birbhum, West Bengal. India. PIN: 731224.
 - Email: arkadevroy99@gmail.com.

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