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A New Theory of the Essence and Mass of Photon

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Abstract

Many properties of a single photon, such as density, rest mass, and orbital angular momentum, are still unknown. In a previous study, the photon was presented as a superfluid prolate spheroid structure, with a long-axis radius, short-axis radius, and volume, embodied with two spins—transversal and longitudinal—which are responsible for the three-dimensional helical trajectory of the electromagnetic wave. In this study, the rest mass, density, and energy of photon are mathematically derived, and the relationship between the radius of photon and its frequency is demonstrated. In addition, the difference between the Compton and de Broglie wavelengths is clarified. The calculated density, volume, and rest mass of photon agree with previous experimental results. The photon's simultaneous longitudinal and transversal spins are moving forces of longitudinal and transversal trajectories, which are the origin of the three-dimensional helix shape of the electromagnetic field. A new mechanism for the photon movement is proposed, and the reason for the zero mass moving photon is revealed; a traveling photon in space exhibits zero mass because its boundaries demonstrate zero relative velocity with the surrounding vacuum. The orbital angular momentum of photon is described using similar macroscopic rotation concepts and applying hydrodynamics laws. A rotating photon is endowed with an angular velocity vector whose magnitude measures the speed with which the radius of the principal axis sweeps an angle, and whose direction indicates the principal axis of rotation and is given by the right-hand rule. The deviation angle is calculated using trigonometric functions, and the origin of the Lorenz factor is revealed.

Keywords

Photon Structure, Electromagnetic Wave, Photon Mass, Photon Energy

1. Introduction

The nature of light and photon remains mysterious and mostly unknown. In quantum electrodynamics (QED), a photon is an excitation unit associated with a quantized mode of the radiation field. As such, it is associated with a plane wave with precise momentum, energy, and polarization. Einstein, in his light quantum theory, demonstrated that the energy of a photon is related to its oscillation frequency, and the intensity of the light corresponds to the number of photons. In addition, he showed that photons demonstrate a particle nature that exhibits no mass, always move at the speed of $c = \lambda \nu$ in a vacuum, and exhibits constant energy and momentum, $h\nu$ and h/λ, respectively. However, the fact that a photon can be described as a particle says nothing about its nature. Further, he successfully described the photoelectric effect in 1905 by assuming that light comprises photons. However, no explanation exists for such a behavior [1]. In 1922, convincing evidence for light quanta appeared in the scattering of X-rays on electrons (Compton's experiment).

In the last three decades, research on single photons (SPs) has been a hotspot in the physics community. In particular, SPs are essential for the fundamental study of quantum mechanics [2] [3], quantum measurements [4] [5] [6] [7], quantum entanglement and information [8] [9] [10] [11], and the development of photonic quantum technologies, such as optical quantum computing [12] [13] [14] and quantum communication [15] [16] [17]. Photons, like other elementary particles, are best explained by quantum mechanics and exhibit wave-particle duality, displaying both wave and particle properties. Thus, an SP can be refracted by a lens or exhibit wave interference with itself and behaves like a particle that gives a definite result when its position is measured.

As bosons, any number of photons can occupy the same state, unlike electrons and other fermions; the Pauli Exclusion Principle is not applied to photons. Quantum mechanics describe electric and magnetic fields as being caused by the exchange of virtual photons. Thus, a strong connection exists between photons and electric and magnetic fields. Although photons are chargeless, they interact strongly with charged particles. The QED theory describes the interaction between electrons and photons; the photons serve as gage bosons, mediating the EM force between charged objects [18] [19].

According to modern physicists, energy in an electromagnetic (EM) field is made up of discrete packets. Although the structure of photons is still unknown, it is accepted that the energy of photons is stored as an oscillating electric field that cannot be divided. Therefore, each photon's energy is quantized or comes in discrete amounts, described as energy packets, meaning that the energy is organized such that the energy packets can be distinguished from the surrounding vacuum. Photons can interact with other particles, such as electrons, inducing the Compton Effect. Moreover, photons can be destroyed or created by many natural processes, e.g., when the radiation is absorbed or emitted and travel faster than the speed of light in an empty space.

At high energies, the fluctuation of a photon into a Fock state of particles of total invariant mass M can persist for a time of order $\tau = 2E\gamma/M^2$ until the virtual state is materialized by a collision or annihilation with another system [20].

There has been a century-long debate concerning photon mass. Exploring the discrete nature of light and SP experiments on temporal and spatial control, manipulation and structure of photons open a new era of quantum photonics. In 1915, Einstein explained how the mass of photon works, but not what it is. In particle physics, the Higgs field gives mass to other fundamental particles, but not photon. The special theory of relativity predicts that photons do not demonstrate mass simply because they travel at the speed of light. This is also backed up by the QED theory, which predicts that photons cannot demonstrate mass due to U(1) gage symmetry. However, a finite photon mass is quite compatible with the general principles of elementary particle physics, and an answer to the question of its size can only be found through experiments and observations. Although this concept of the massless photon has been questioned over the years [21] [22] [23] [24] [25], the Proca equations are the only and simplest relativistic generalizations of Maxwell's equations. These equations are the theoretical expressions for a possible nonzero rest mass of the photon.

Although it is certainly impossible to perform an experiment that would unambiguously prove that the rest mass of the photon is exactly zero, the considerable experimental effort has been made to determine, either directly or indirectly, whether the mass of the photon is nonzero.

Various experiments revealed that the photon rest mass varies depending on the methodology employed. It is 4×10^{-51} kg (2.244×10^{-21} MeV·c^{-2}) based on the satellite measurement of the earth's magnetic field [26], 10^{-52} kg (5.610×10^{-23} MeV·c^{-2}) according to low-frequency parallel resonance circuits [27], and 1.5×10^{-54} kg (8.414×10^{-25} MeV·c^{-2}) according to solar wind experiments [28]. Using the frequency-dependent time delays in the measurements of the dispersion measures of fast radio bursts (FRBs) on FRBs 150,418 and 121,102, the photon mass was, respectively, measured to be 3.2×10^{-50} kg (1.795×10^{-20} MeV·c^{-2}) [29] and 3.9×10^{-50} kg (2.188×10^{-20} MeV·c^{-2}) [30]. Therefore, experimental data show that photon exhibits nonzero real mass, which depends on the photon wavelength in free space [31] [32] [33] and is inversely proportional to the wavelength when the photon velocity does not depend on the wavelength, *i.e.*, at constant velocity [34]. Despite the scientific and technological progress and studies indicating that the photon physically exists, the deep nature of the photon is still a mysterious phenomenon, and there is still no satisfactory answer to the question of what a photon is [1].

Since de Broglie [35] [36] proposed a composite-photon hypothesis that a photon comprises a neutrino–antineutrino pair bound together, there has been a continuous interest in the possibility of a composite model of photon. His idea explains the significant difference in characteristics exhibited by a spin-1 photon and spin-1/2 neutrino. When a photon is emitted, a neutrino–antineutrino pair arises from the vacuum, whereas the neutrino and antineutrino annihilate when the photon is absorbed.

In this study, a new theory is proposed to answer the main questions that are still enigmatic for physicists, such as what is the real essence of SP, why photon exhibits no longitudinal mass but exhibits a rest mass, what determines the frequency and angular momentum of photon, and especially what is the structure of photon. This study is a continuation of a previous study, wherein a photon was presented as a fluid spheroidal shape, where the classical laws of hydrodynamics were applied and the geometry of photon, as well as the mechanism of photon movement, was described to calculate the radius, energy, and density of photon. An analytical formulation is presented to obtain the photon frequency and mass relative to its radius. The roots of Einstein's special relativity equation and Planck frequency–energy relation are presented.

2. Photon Speed in Space

Photon is presented as a prolate spheroid, elongated like a rugby ball as shown in Figure 1.

Different photons exist with different radii and volumes. The frequency, and thus, the energy of photon depends completely on the radius of photon, according to the following equation:

$$f = c/2\pi r ,$$

where r denotes the minor radius of the spheroid.

Photon is a fluid prolate spheroid shape endowed with two spins—longitudinal and transversal—which determine its movement in a helical trajectory to form the EM wave. The transversal spin determines its rotation about its center in cycles that determine the Compton wavelength, whereas the longitudinal movement in space is related to the de Broglie wavelength. The De Broglie wavelength is equal to the perimeter of the spheroid, while the Compton wavelength is equal to the short circumference ($2\pi r$, where r is the small radius). Thus, a photon traveling in space demonstrates longitudinal and transverse velocities.

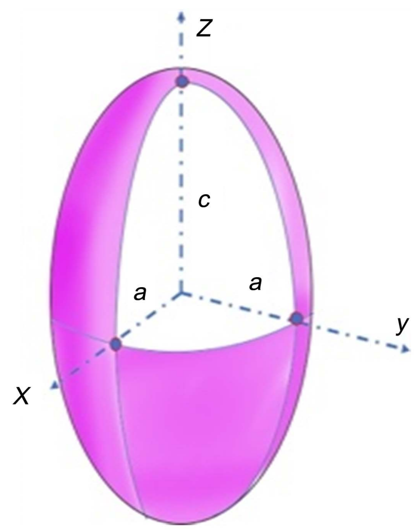


Figure 1. Photon is a prolate spheroid with a long semi-axis five times its short semi-axis, $c = 5a$.

The transversal velocity v_t is in a plane normal to the parallel longitudinal velocity v_l. The magnitude of the instantaneous velocity v_0, which is always equal to "c," the velocity of light in free space, is the resultant of its transversal and longitudinal velocities.

The transverse velocity v_t lies in a plane perpendicular to the parallel longitudinal velocity v_l. The magnitude of the instantaneous velocity v_0, which is always equal to the speed of light (c) in free space, is the resultant of the transverse and the longitudinal velocities. From **Figure 2**, owing to the Magnus effect, the vortex deviates an angle α and drifts on a three-dimensional helix trajectory.

The transversal rotation velocity v_t of the photon vortex is determined as follows **Figure 3**:

$$v_t = \left(v_0^2 - v_l^2\right)^{1/2}. \tag{33}$$

The angle α can be determined by the trigonometric function:

$$\sin\alpha = v_t / v_0 = \left(v_0^2 - v_l^2\right)^{1/2} / v_0 = \left(\left(v_0^2 - v_l^2\right) / v_0^2\right)^{1/2} = \left(1 - v_l^2 / v_0^2\right)^{1/2}.$$

Assuming $v_0 = c$ and $v_l = v$, we have

$$\sin\alpha = \left(1 - v^2 / c^2\right)^{1/2},$$

where $1 - v/c$ is the Lorentz factor, a factor by which time, length, and relativistic mass change for a moving object. The expression appears in several equations of special relativity and appears in the derivation of the Lorentz transformations.

The longitudinal and instantaneous velocities are v and c, respectively; if the longitudinal velocity achieves the speed of light, the instantaneous velocity will exceed the speed of light, and the photon will disintegrate.

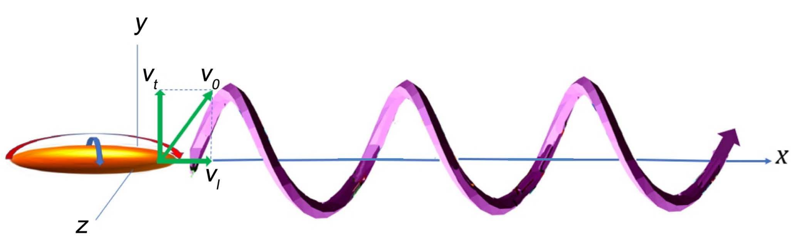


Figure 2. In three-dimensional space, the angular velocity is a vector whose magnitude measures the speed with which the radius of the major axis sweeps an angle, and whose direction indicates the principal axis of rotation and is given by the right-hand rule.

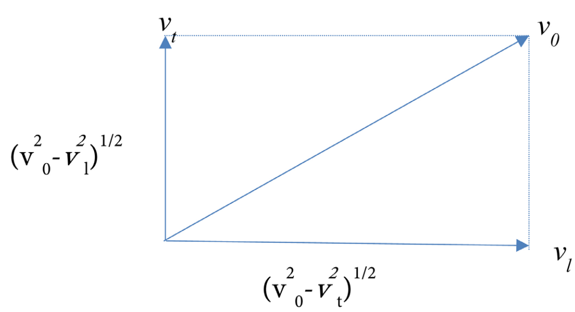


Figure 3. Transversal velocity v_t and the longitudinal velocity v_l give the resultant final instantaneous velocity v_0, which is at the speed of light c.

Although the resulting velocity of the photon with respect to an observer is given by c, its transverse and longitudinal velocities would differ depending on the observer, as an additional velocity v is found between the frames. The changes in transverse velocity due to the longitudinal motion of the photon are significant because the longitudinal velocity is very close to "c." The angular momentum of the photon depends on its instantaneous velocity v_0, which in turn depends on the longitudinal velocity reduced by the Lorentz factor, as follows:

$$v_0 = v_l / \sin\alpha = c / \sin\alpha = c \Big/ \left(1 - v^2/c^2\right)^{1/2},$$

where $v_l = \left(v_0^2 - v_t^2\right)^{1/2}$.

The velocity of photons varies in different media and is determined by the density of the medium; the relationship between the (longitudinal) wave propagation velocity v and the medium density ρ can be expressed as follows:

$$V = \left(\Gamma/\rho\right)^{1/2},$$

where Γ is a constant that depends on the specific properties of the medium.

The circulation of a photon vortex is expressed as follows:

$$\Gamma = 2\pi rc,$$

where Γ denotes the internal circulation of the photon, and r denotes the minor radius of the photon.

3. The Angular Momentum of Photon

The angular momentum (spin) of a photon indicates that an internal rotation is taking place, giving the photon its rest mass. The spin and associated orbital angular momentum are fundamental properties of a photon that can be described as macroscopic rotation with some rotational energy, and the laws of hydrodynamics can be applied. The velocity of a fluid element instantaneously passing through a given point in space in a vortex of radius r would indeed be constant in time; therefore, the circulation or vorticity is

$$\Gamma_e = 2\pi r_e c.$$

Γ_e is a fundamental constant for any vortex, provided it exists in time and space, and it disappears only when the vortex is destroyed.

For the photon as a vortex, its conserved angular momentum is related to the constancy of circulation or vorticity multiplied by its mass.

Therefore, the quantity $\Gamma_e m_e$ is angular momentum; thus, $2\pi r_e c m_e$ is a constant, which is equal to the Planck constant. The Planck constant expresses the angular momentum of 2π radians, which is equal to 360˚, because the minimal discrete value is equal to the Planck constant, reduced by 2π radians, denoted as $\hbar$ ("h-bar"). As the magnetic moment is quantized in units of μ_B, correspondingly, the angular momentum is quantized in units of $\hbar$. The final orbital angular momentum of the photon is a multiple of the spin value, which is 1 times the vortex angular momentum, and can be expressed as the Planck constant divided by 2π. The angular momentum of one radian is the minimal discrete Bohr magneton μ_B, expressed as the magnetic moment of one vortex radian in terms of the reduced Planck constant $\hbar = rcm$.

The quantity $\Gamma_e m_e$ is the angular momentum; thus, $2\pi r_e c m_e$ is a constant, which is equal to the Planck's constant. Planck's constant expresses the angular momentum of 2π radians, which corresponds to 360˚ because the minimum discrete value is equal to Planck's constant reduced by 2π radians, denoted by $\hbar$ ("h-bar"). As the magnetic moment is quantized in units of μ_B, the angular momentum is also quantized in units of $\hbar$. The final orbital angular momentum of the photon is a multiple of the spin value, which is 1 times the vortex angular momentum, and can be expressed as Planck's constant divided by 2π. The angular momentum of a radian is the minimum discrete Bohr magneton μ_B, expressed as the magnetic moment of a vortex radian in terms of the reduced Planck constant $\hbar = rcm$.

Because ω_0 is the transversal angular speed of the photon vortex, which is the expression of the characteristics of photon as a particle, it is equal to c/r, where ω_0 is measured in radians per second. Therefore, we have

$$E = h\omega_0 .$$

If $\omega_0 = c/r$, we have

$$E = hc/r = 2\pi rcmc/r = 2\pi rmc^2 .$$

Dividing by 2π, the minimal discrete energy of photon is obtained:

$$E = 2\pi rcmc/2\pi r = mc^2$$

4. The Rest Mass and Density of Photon

Maxwellian electromagnetism and QED are based on the hypothesis that the photon should be a particle with a rest mass of zero, and it is generally agreed that photons have no mass. However, a photon could carry energy and momentum from one place to another, and light rays would propagate in a vacuum with constant velocity c independent of inertial frames, which was the second postulate in Einstein's theory of special relativity. Consequently, the velocity of a particle of finite mass would never reach the constant c.

The assumption was plausible because light could not remain stationary, and finding counter examples of the theory was difficult.

Further, according to relativity, a photon demonstrates a minimum mass called the "rest mass" m_{rest}. However, the nature and origin of this mass are unclear.

According to the spheroid photon model, the wavelength of photon depends completely on the photon radius; consequently, the volume and mass of photon vary according to its radius, which explains why different experiments yielded different values of photon mass.

The photon rest mass is calculated as density times volume, as follows:

$$m_{\text{rest}} = \rho Q . \tag{7}$$

This indicates that the rest mass of the photon is the amount of liquid-like rotating vacuum, occupying a volume in space of a certain density, which passes in 1 s. As the volume Q is equal to the length ct times the area A, the following applies:

$$m_{\text{rest}} = \rho ctA$$

According to this equation, the photon rest mass is directly related to the rotation speed (spin), density, and area of the photon vortex. However, to calculate its mass, we need to know the photon density. If a photon as a vortex rotates around itself at the speed of light, this speed depends on its elasticity E and density ρ, as follows:

$$c = \left(E/\rho\right)^{1/2}$$

In a previous study [37], we demonstrated that the electric permittivity constant represents the elasticity of the vacuum, which exhibits the value of $8.87337441 \times 10^{-12}$ kgcm/s^2 cm^3 or $8.87337441 \times 10^{-10}$ kgm/s^2 m^2; thus, the photon density can be calculated as follows:

$$\rho = E/c^2 = 9.85930493 \times 10^{-27} \text{ kg/m}^3 ,$$

where $c^2 = 9 \times 10^{16}$ m^2/s^2, which is the same value of the vacuum density [38]. Both values of elasticity and speed of light in the vacuum are constants; therefore, they are independent of the photon volume. Knowing the photon volume and density allows us to calculate its rest mass. Because the photon is a rotating vacuum fluid, we must determine the mass in terms of the mass flow rate. The mass flow rate is the amount of mass passing a given point during some time interval t, m/t. The mass flow rate m/t is equal to the density times the velocity times the area A, through which the mass passes. Given that the photon is a rotating vacuum fluid, we must determine the mass in terms of mass flow rate. The mass flow rate is the amount of mass that passes a given point in a given time interval t, m/t. The mass flow rate m/t is equal to the density times the velocity times the area A through which the mass flows. The relationship between the mass flow rate and the density can be expressed mathematically as follows:

$$m/t = \rho cA .$$

Therefore, the photon spin is the origin of its mass, and if the spin stops, the photon vanishes and becomes a vacuum. This is the same as if a tornado stops rotating, and the tornado converts to air and disappears.

When a light wave is incident from a vacuum into a medium, the phase velocity of the photon (wave-like velocity) depends on the frequency [39]. Accordingly, the mass of the photon depends on the wavelength [28] [32].

Because $t = 1/f$, we have

$$m = \rho cA/f .$$

From this equation, it can be concluded that the mass of the photon is inversely proportional to its frequency; the greater the frequency, the lower the mass. If the volume of a green light photon is

$$V = 4/3\pi 5b^3 = 1.143221\times10^{-27}\ \text{m}^3,$$

where b denotes the minor radius and the photon density is 9.8 × 10^{-27} kg/m^3, then the photon rest mass can be calculated as follows:

$$m = \rho V$$

Therefore, the mass of the green photon is 1.143221 × 10^{-27} × 9.8 × 10^{-27} = 11.172 × 10^{-54} kg, which agrees with the de Broglie's assumption of 10^{-54} kg (5.610 × 10^{-25} MeV·c^{-2}) [40] and that of solar wind experiments 1.5 × 10^{-54} kg (8.414 × 10^{-25} MeV·c^{-2}) [28]. The variability of rest mass in different experiments is attributable to the different radii, volumes, and thus frequencies of different photons.

5. The Rest Energy of Photon

Considering a photon as a particle, its rest energy depends on both transversal and longitudinal spins, which rotate at the speed of light. Its kinetic energy is $1/2mv^2$, where

$$v = \left(2c^2\right)^{1/2}.$$

Thus, the total kinetic energy of both spins is

$$E_k = \frac{1}{2}m\left(\left(2c^2\right)^{1/2}\right)^2 = mc^2.$$

Considering a photon as a wave, the wave energy is $E = f\lambda$, where $f = ma$, and λ denotes the photon wavelength. Then, we have

$$E = maL = \lambda mc/t = \lambda mcf,$$

where $L = \lambda$ = length. Because $\lambda = 2\pi r$, which is the minor circumference of a photon, and $2\pi rmcf$ is equivalent to h, we have

$$E = hf.$$

Further, because frequency $f = c/\lambda$ and $h = \lambda mc$, we have

$$E = \lambda mcc/\lambda = mc^2,$$

which is the same as the rest energy of photon as a particle.

6. Why Is the Longitudinal Mass of Photon Zero?

How can a moving photon in space have a rest mass but the longitudinal mass is zero? According to relativity, massless particles travel at the speed of light, so they can never be stationary. However, such behavior has no explanation and does not imply that photon demonstrates no rest mass but demonstrates zero longitudinal mass. A photon exhibits longitudinal and transverse spins, which are orthogonal to the propagation direction (mean momentum) of light.

The transversal spin of photon moves it transversely, and this spin is related to the photon rest mass, whereas the longitudinal spin is responsible for translational speed and longitudinal mass. Although the photon vortex rotation is frictionless, it exerts some drag on the surrounding vacuum.

According to the superfluid theory of the vacuum, a photon is a nontrivial medium that is not empty but filled with quantum mechanical zero-point energy, is present everywhere, and behaves like a perfect fluid, in which a certain energy and density may be associated with extremely high thermal conductivity. Drag is a general term for any force opposing motion.

When a photon vortex moves in a liquid vacuum, it experiences two forms of drag force. One force perpendicular to the motion is called pressure drag, and the other is the shear force due to flow along surfaces "parallel" to the motion (edges), which is called viscous drag. The pressure drag is caused by the vacuum density hitting the surface of a photon and returning. This changes the linear momentum and results in a normal force corresponding to the force that causes the photon to rotate, *i.e.*,

$$F = \frac{1}{2}\rho c^2 A,$$

where ρ denotes the photon density, and A denotes the area of photon that interacts with the surrounding vacuum and exerts a drag force on it. Therefore, a photon exerts an equal pressure that opposes its rotation, which is given by

$$P = \frac{1}{2}\rho c^2,$$

where, in this case, ρ denotes the vacuum density, which is still equal to the photon density. The viscous drag results from the attraction between the vacuum and photon due to the relative velocity between the rotating photon and static vacuum fluid.

It is proportional to the density of the medium and the square of the relative flow velocity between the moving object and static medium, which in our case is a vacuum. The drag force is defined as the force component in the direction of the flow velocity, given by

$$F_d = \frac{1}{2}\rho v^2 A C_D, \quad (5)$$

where ρ represents the mass density of the vacuum, v represents the flow velocity relative to the photon, and C_D represents the drag coefficient.

The equation for the drag force is converted to a pressure equation by dividing both sides by the area A as follows:

$$P = F_d / A = \frac{1}{2}\rho_v v^2 C_D.$$

The shear stress diminishes the momentum by perimeter length unit, given by

$$P = \rho_v \overline{u} / \lambda,$$

where ρ_v denotes the vacuum density, $\overline{u}$ denotes the angular velocity, and λ denotes the vortex perimeter [38].

As such, photon faces two drag forces—viscous drag and pressure drag—which are greater than the photon force to drag the vacuum; hence, a photon is "lighter" than the opposed vacuum density. Thus, the surrounded vacuum drags the photon instead of the photon dragging the vacuum. Therefore, a photon rotates and slips on the vacuum as a tracked vehicle runs on snow. Although the tracked vehicle demonstrates a relative velocity with the snow, the velocity in the contact area between the continuous track and the snow is zero (**Figure 4**).

Similarly, longitudinal and transversal flows induce photon movement, which is supported by the vacuum's drag force, and the boundaries slip in a helical trajectory to form an EM wave shape (**Figure 5**).

In this case, the relative velocity between the photon and vacuum boundaries is 0 because photon slips into the vacuum. Thus, the mass is determined by the relative velocity of the photon that is in contact with the vacuum density, as follows:

$$m = \rho vtA.$$

Because the relative longitudinal velocity v is zero, the longitudinal mass will be zero.

In the frame of an observer of photon moving with a velocity v, the photon rest mass is reduced because its frequency was reduced to

$$f = f_0\left(1-v^2/c^2\right)^{1/2}.$$

If the rest mass energy of the moving photon is

$$m_0c^2 = hf_0\left(1-v^2/c^2\right)^{1/2},$$

and $f_0 = c/\lambda$ and

$$m_0c^2 = \left(hc/\lambda\right)\left(1-v^2/c^2\right)^{1/2}, \tag{28}$$

the moving photon mass will be reduced, as follows:

$$m = \left(hc/\lambda\right)\left(-v^2/c^2\right)^{1/2}.$$

Figure 4. The blue arrow indicates the vector velocity of the tracked vehicle, and the red arrows indicate the zero velocity between the track and ground.

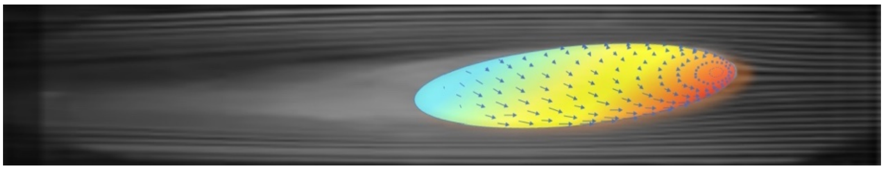
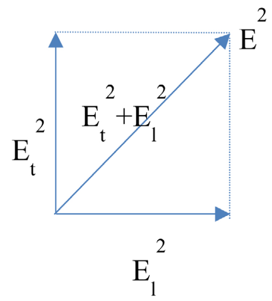


Figure 5. The rotating photon with pressure difference around the photon gives support that allows the photon to slip into the vacuum.

The relativistic energy of photon

The photon movement in space is mobilized by two right-angle spins—transversal and longitudinal spins—that yield the longitudinal and transverse momentum, respectively, and creates the helix trajectory.

Applying to Pythagoras' theorem, we can calculate the total energy of the moving photon as follows:



$$E^2 = E_t^2 + E_l^2 ,$$

where E_t and E_l denote the transversal and longitudinal energies of the moving photon, respectively. The transversal spin is responsible for the rest mass energy $E_t = mc^2$, whereas the longitudinal spin is responsible for translational energy and is

$$E_l = m_l c^2 + m_t c^2 = m_l c^2 + Pc$$

However, the longitudinal mass of the moving photon is zero; thus, its energy will be

$$E_l = 0^2 + Pc$$

Therefore, the relativistic energy gives us

$$E^2 = E_t^2 + E_l^2 = \left(m_t c^2\right)^2 + \left(pc\right)^2 = m^2c^4 + p^2c^2 .$$

7. The Kinetic Energy of the Longitudinal Mass of Photon

When De Broglie equated $\hbar\omega$ with mc^2, this was a mere assumption that turned out to be true, but the result of the equation explains not only the wave nature of particles but also the behavior of particles. The well-known equation is as follows:

$$\lambda = h/mv$$

This has been confirmed through experiments, such as the Davisson–Germer experiment for electrons [41].

The spheroid photon exhibits properties similar to those of visible particles, such as grains of sand. A photon interacts in collisions or absorption as a single entity rather than as an extended wave.

The energy added to an object to take it from an initial speed of zero to a certain final speed is its kinetic energy.

In a Compton scattering experiment, let an energy $\hbar\omega$ be absorbed by an electron that demonstrates rest mass m_0. Notably, this energy is not the entire energy of the incident photon but is only a part of the incident photon energy that is taken up by the electron in the process. This energy is related to the longitudinal mass energy. Consequently, the electrons would move with a kinetic energy of

$$E_K = E - E_0 = mc^2 \Big/ \left(1 - v^2/c^2\right)^{1/2} - m_0 c^2 \Big/ \left(1 - v^2/c^2\right)^{1/2},$$

where E denotes the total energy, and E_0 denotes the rest energy.

If the rest speed of the electron at rest is zero, then

$$E_K = mc^2 \Big/ \left(1 - v^2/c^2\right)^{1/2} - m_0 c^2 /1 = (\gamma - 1) mc^2,$$

where γ denotes the energy change of the moving photon in space, which corresponds to the Lorentz factor, given by

$$\gamma = 1 \Big/ \left(1 - v^2/c^2\right)^{1/2}.$$

This kinetic energy is entirely due to the energy $\hbar\omega$ absorbed by it. Thus, we have

$$\hbar\omega = (\gamma - 1) mc^2.$$

Then, the total energy is given by

$$E = \hbar\omega + mc^2 = \hbar(\omega + \omega_0) = \hbar\omega + h\omega_0,$$

Hence, we have

$$Mc^2 = \hbar\omega_0.$$

Therefore, the longitudinal mass energy of photon is equal to its rest energy, which is mc^2 or pc, where p denotes the momentum and is equal to mc.

Connecting quantum mechanics to Newton's laws

According to Planck's theory, photon energy is directly proportional to frequency:

$$E = hf.$$

The origin of this law can be explained using the classical hydrodynamic laws to describe photon as a particle. The rotation force of photon vortex according to Newton's law is $F = ma$

If the acceleration is c/t, then

$$F = mc/t,$$

where t denotes the time needed to complete one cycle.

Each cycle of transversal photon spin produces one Compton wavelength, which is equivalent to $2\pi r$, where r denotes the minor radius. Because Energy = $F \times$ distance and the distance is the minor circumference of photon $2\pi r$, we have

$$E = 2\pi rmc/t.$$

Further, because $1/t = f$, we have

$$E = 2\pi rmcf.$$

$2\pi rcm$ is a conserved momentum; therefore, it is a constant equal to Planck's constant, h.

In this case, the frequency indicates the number of times a wave EM passes within 1 s. Planck's constant is the energy contained in a wave [42].

Therefore, we have

$$E = 2\pi rmcf = hf$$

Next, the Planck constant is accurately determined by experiments and describes the ratio between the energy and frequency of photon.

8. Conclusions

In this study, a new theory is proposed about the properties of photon, such as radius, volume, mass, transversal spin, momentum, rest mass, Compton wavelength and energy, longitudinal spin, momentum, de Broglie wavelength, longitudinal mass, and energy, and it presented a mechanism of photon movement in space and medium. Photons are described as particles with real physical existence that exhibit a spheroid shape with transversal and longitudinal spins and move in space to create a three-dimensional helical EM wave with transversal and longitudinal trajectories.

The vacuum's inertial drag counteracts the drag force of a rotating photon, allowing it to slip into the vacuum with zero relative velocity between the vacuum and photon boundaries. The rest mass is related to the transversal spin, which is equal to mc^2, whereas the longitudinal movement exhibits zero relative velocity with the vacuum, and hence, the longitudinal mass is zero. The transversal mass of the moving photon is reduced by the Lorenz factor $1/(1 - v^2/c^2)^{1/2}$. However, interacting with a particle gives photon longitudinal kinetic energy to the particle and maintains its rest mass.

Once a photon is provided with a finite structure, radius, volume, density, and mass, the following consequences can be deduced:

1) Although all photons travel at the speed of light, different frequencies, volumes, and masses are related to the radius of the spheroid photon.

2) Virtual photons are those with volumes smaller than the Planck size, which is 10^{-33} cm.

3) Owing to the Magnus effect, a photon vortex deviates by an angle α and drifts on a three-dimensional helix trajectory of the EM wave.

4) The magnitude of the instantaneous velocity of the photon is the resultant of its transverse and longitudinal velocities, which is always equal to "c," the velocity of light in free space.

5) The magnitude of the deviation angle α can be calculated by the relationship between the transversal velocity v_t and instantaneous velocity v_0 as $\sin\alpha = v_t/v_0 = \left(1 - v_l^2/v_0^2\right)^{1/2}$, which is the origin of the Lorentz factor.

6) The Compton frequency of photon is related to the transversal spin and inversely proportional to the minor radius of photon, based on the following equation:

$$f = c/2\pi r \ .$$

7) The de Broglie wavelength is related to the longitudinal spin and is equal to the photon spheroid perimeter.

8) The photon density is independent of its volume, directly proportional to the photon elasticity, and inversely proportional to the square of the speed of light according to the following equation:

$$\rho = E/c^2 \ .$$

9) The photon rest mass is directly proportional to the photon density, area, and spin speed and inversely proportional to its Compton frequency f_c, according to the equation $m_{rest} = \rho cA/f_c$

10) The photon mass is directly proportional to the square of the minor radius of the photon, according to the equation $m = \rho vt\pi r^2$

11) The longitudinal mass of photon is zero because the relative velocity between the vacuum and photon boundaries is zero, according to the equation $m = \rho vtA$

12) The photon rest energy is induced by transversal and longitudinal spins.

13) The photon energy is directly proportional to the radius, rest mass, and Compton frequency of photon, according to the equation $E = 2\pi rcm_r f_c$.

14) Although the traveling photon demonstrates zero longitudinal mass, it still exhibits transversal mass with an energy equivalent to mc^2.

15) The photon speed varies and is inversely proportional to the density ρ and directly proportional to the circulation Γ, according to the equation $v = (\Gamma/\rho)^{1/2}$.

16) The angular momentum of the photon vortex is directly proportional to the radius, rest mass, and rotation speed; it is constant and equal to the Planck constant $h = 2\pi r_e c m_e$

17) The kinetic energy of photon is equal to the rest mass energy, according to the equation $mc^2 = \hbar\omega_0$.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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