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A New Theory for the Essence and Structure of the Photon

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Abstract

A photon is the smallest discrete amount or quantum of electromagnetic radiation, and it is the basic unit of light. It exhibits no shape, "point particle," according to the standard model of particle physics, meaning that a photon interacts as if it is entirely located at a single point in space and does not spread out to fill a three-dimensional volume. In this study, a new theory, in which the photon demonstrates a structure and shape, is proposed based on the perturbed quantum superfluid field (vacuum) in the photon epoch during the first seconds of the Big Bang. Photons are the nonlinear manifestation of Kelvin–Helmholtz instability that induces the formation of elliptical vortices, known as Kida vortices, which are converted to a three-dimensional spheroidal structure that remains unchanged in time and rotates with uniform angular velocity due to Coriolis force. Using hydrodynamics laws and applying them to a superfluid vacuum, the basic properties of the photon are described. Moreover, this study provides mathematical models to calculate the kinetic energy, radius, volume, charge, and particle-wave duality of photon. To confirm the proposed theory, the mathematical formulations are presented. We conclude that the photon shape is accessible to human imagination; knowing this shape helps determine photon properties and sheds light on how matter is made as well as explains the interactions of subatomic particles.

Keywords

Electromagnetic Radiation, Photon, Quantum Electrodynamics

1. Introduction

Despite their lack of mass and rest energy, photons are considered elementary particles because they demonstrate no electric charge and are spin-1 particles,

which make them bosons. They only exist as moving particles that carry energy and momentum that are proportional to the frequency. The Pauli exclusion principle does not apply to them; bosons like to crowd together, thereby occupying the same quantum state. In a vacuum, photons travel at a constant speed of 2.998×10^8 m/s, which are commonly referred to as the speed of light and are denoted by *c*.

In 1865, Maxwell unified the concepts of light, electricity, and magnetism, condensing experimental and theoretical knowledge about electricity and magnetism in 20 equations that describe light as an electromagnetic (EM) disturbance propagated through the field according to EM laws. The equations describe light as an alternating electric and magnetic field travelling at 2.998×10^8 m/s.

The concept of a photon originated in 1900 in the description of the black body radiation when Max Planck assumed that the emission and absorption of energy should appear in the form of energy quanta. In 1905, Einstein suggested that light should be considered as a collection of independent particles of energy and proved that light is a flow of photons. In addition, he explained how a stream of photons can act both as a wave and a particle. In 1926, Frithiof Wolfers—an optical physicist and G. N. Lewis—a chemist, described the notion of "photon".

In quantum electrodynamics (QED), a photon mediates the EM force between charged objects. As the gage bosons of QED, photons are considered massless and chargeless particles, exhibiting no internal structure [1]. It is assumed to be a massless and chargeless object with a point-like coupling to elementary, charged particles. As the scale of attainable energy grew, photons in collider experiments may materialize as pairs of electrons $\gamma \rightarrow e + e-$ through an interaction with a Coulomb field [2] [3].

In such interactions, a photon can be regarded as a structureless object, called the direct or bare photon.

Unlike in $e\gamma$ scattering, the photon structure is probed by partons from the proton in the so-called photoproduction events in *ep* collisions. By tagging high transverse energy (E_t) jets, high-pT charged particles [4], or heavy quarks [5] in photoproduction reactions, parton distribution functions of photon can be constrained. In some cases, a photon fluctuates into a charged fermion-antifermion pair, and a fermion interacts via a gage boson with another object; then, the parton content of the photon is resolved, and the photon reveals its structure. In such interactions, a photon can be regarded as an extended object comprising charged fermions and gluons—the so-called resolved photon [6]. If experimentally probed at very short distances, the intrinsic structure of a photon is recognized as a flux of quark and gluon components, quasi-free according to asymptotic freedom in quantum chromodynamics (QCD), and described by the photon structure function [7] [8] [9].

In the string theory, a photon is described by a tiny oscillating line, with the axis of the line being the polarization direction (*i.e.*, the inner photon direction

is the axis of the string of which the photon is made). Photon as a vibrating string in superstring theory is 10-dimensional, whereas it is 11-dimensional in M-theory [10]. In quantum field theory, the EM field couples to all particles carrying the EM current, and thus, a photon can fluctuate into virtual states of remarkable complexity, indicating that a physical photon exhibits an electron-positron pair constituent. Moreover, a photon (real or virtual) is regarded as structureless due to hadronic interactions. In reality, photons demonstrate an internal structure similar to that of hadrons, except that the structure only occurs with a probability of order $\alpha \sim 1/137$ [7]. In any quantum field theory, the existence of interactions implies that the quanta themselves can develop a structure. According to QCD, a photon is a superposition of a bare photon state, which interacts only with electric charges, and a hadronic photon state. Despite all these studies advance our understanding of the photon, the structure of photon remains unknown.

In this study, a new theory is proposed based on hydrodynamics laws to answer the main questions that are still enigmatic for physicists, such as "What is the real essence of a single photon?", "How is a photon formed?", and "What are the radius, volume, and internal dynamics of phonon?". The mechanism of the generation of photon and its structure and function are described. First, the superfluid nature of vacuum, vortex formation, and spheroid transformation are presented. Next, the classical hydrodynamics laws are applied, and to calculate the radius and volume, the geometry of photon is described; in addition, the particle-wave duality and origin of the EM wave shape are described. The roots of Einstein's special relativity equation and the Planck frequency-energy relationship are presented. This study allows us to describe and calculate the density, mass, and mechanism of photon movement. Moreover, a separate article presenting analytical formulations will be published to obtain the photon frequency, angular momentum, and mass relative to its radius. The root of the universe's speed limit, the speed of light, will also be discussed in a separate article.

2. Superfluid Quantum Field

In the early years of quantum mechanics, Paul Dirac theorized that a vacuum was actually filled with particles in negative energy states [11], giving rise to the concept of the "physical vacuum," which is not empty at all. In quantum mechanics, the idea of space is frequently used to justify mathematical procedures and indicate the amounts of detailed space properties, such as the speed of light in a vacuum governed by the vacuum permeability and permittivity. In QED, vacuum is a state with no matter particles and photons but with vacuum fluctuations and finite energy called the vacuum energy. A vacuum is defined as a state with the lowest possible energy and a superfluid behavior. The superfluidity of a vacuum is the basis for Maxwell's equations.

The special relativity is derived from Maxwell's equations. Einstein realized that both special and general relativities were based on fluid dynamical models [12].

According to the superfluid theory, a vacuum is assumed to be a nontrivial medium that is not empty but rather filled with quantum mechanical zero-point energy that extends everywhere, exhibits no size, shape, center, direction, time, or extent, is immovable, behaves like a perfect fluid in the sense that it is non-particulate, and demonstrates no structural memory, as well as like a frictionless fluid with extremely low viscosity with which one can associate certain energy and density with extremely high thermal conductivity. Therefore, a vacuum could comprise a fundamental substrate (on the quantum scale), such as an elastic solid-state medium, a fluid, or a Higgs condensate [13] [14] [15] [16]. Thus, vacuum energy results in real physically observable consequences, and its properties can be observed as exhibiting real physical effects [17] [18].

The superfluid vacuum theory proposes a mass generation mechanism that may replace or supplement the electroweak Higgs mechanism. Researchers showed that the masses of elementary particles could arise because of their interaction with a superfluid vacuum. This phenomenon is similar to the gap generation mechanism in superconductors [19]. Although the microscopic structure of vacuum is currently largely unknown, considering the vacuum as a fluid, the hydrodynamics laws could be applied to describe the mechanism of formation of photon and its structure.

Vacuum energy demonstrates a density generally viewed as a fundamental property of the universe; although no consensus exists as to its value, the most generally accepted estimate relies mainly on general relativity and is based on astronomical observations that determine the curvature of space–time and expansion of the universe.

In a previous study [20], the vacuum density was discussed in detail. The best estimate of the cosmological density was between $9.75839983 \times 10^{-27}$ and $(11.11 \pm 1.05) \times 10^{-27}$ kg/m^3. Considering the vacuum as a superfluid, we can apply hydrodynamic laws to describe the formation of elementary particles, such as electrons, positrons, quarks, and antiquarks, as vortices. This idea is not new because quantum vortices exhibit a long history in the physics of superfluid and superconductors. In the 40s, Onsager suggested the existence of quantized flows; this idea was further developed by Feynman by introducing the concept of quantum vortices [21]. In a previous study [22], the internal structure of electron was described as a whirlpool vortex. Quantum vortices can form via the Kibble–Zurek mechanism. Based on the formalism of spontaneous symmetry breaking, Tom Kibble developed the idea for the primordial fluctuations of a two-component scalar field, such as the Higgs field [23] [24].

If a two-component scalar field switches from the isotropic and homogeneous high-temperature phase to the symmetry-broken stage during the cooling and expansion of the very early universe (shortly after the Big Bang), the order parameter necessarily cannot be the same in regions that are not connected by causality. Depending on the symmetries of the system and order parameter, different types of topological defect, such as monopoles, vortices, or textures, can arise. In 2008, spontaneous quantum vortices were observed in atomic Bose-

Einstein condensates [25].

3. Photon Formation

Generally, physics does not handle how photons were created but how they can be emitted. As photons are electric fields propagating through space, the emission of photons requires the movement of charged particles. Different mechanisms, such as Blackbody radiation that causes light bulbs to glow, and the heat of an object to be felt from a great distance, spontaneous emission when electrons fall from an excited state to a lower energy state, or other mechanisms, such as fluorescence, stimulated emission, synchrotrons (electron bending), nuclear decay, or photoelectric effect, describe the photon emission but not its formation.

According to the Big Bang model, most photons were created in the first seconds of the Big Bang during the photon epoch [26]. Researchers believed that inflation followed the Big Bang and produced an extremely homogeneous universe, creating fluctuations in density from place to place, which is considered to be the seeds of all structures in the universe. Despite different models for the early universe that widely vary in their predictions of the size of these perturbations, they all predict the creation of black holes with masses ranging from Planck mass to hundreds of thousands of solar masses [27]. The photon epoch is the period in the evolution of the early universe in which photons dominated the universe energy. The photon epoch started after most leptons and antileptons were annihilated at the end of the lepton epoch, about 10 s after the Big Bang. These photons still interact frequently with charged protons, electrons, and (eventually) nuclei and may continue to do so for the next 380 decades.

The diversity of temperature and density after the Big Bang resulted in dynamic flow and the manifestation of physical effects, perturbations, and shearing forces between different vacuum field layers. If the shear profile is (quasi) piecewise linear, it yields propagating edge waves at the kinks. These are called vorticity waves. Next, the simple model proposed by Kida in the 80s gives an excellent leading-order description of this process [28]. The interaction between two such waves, propagating in opposite directions, is entirely responsible for producing Rayleigh instability/Kelvin–Helmholtz (KH) instability. The Rayleigh instability begins with the existence of tiny perturbations in the stream that leads to velocity shear in a single continuous fluid and KH instability. The direct consequence is the manifestation of elliptical vortices known as the Kirchoff ellipse and Kida vortex, which are the nonlinear manifestations of the KH instability that remain unchanged in time and rotate with uniform angular velocity [29]. Next, the core of an elliptical vortex comprises elliptical streamlines made off the superfluid vacuum. The ellipse rotates about its center at a rate proportional to the vorticity strength. The contour dynamics model is a model to calculate the time evolution of vortex patches through line integrations along contours [30]. The vortex patch exhibits no vorticity gradient inside or outside but demonstrates a vorticity jump crossing the surrounding contour line as shown in **Figure 1**.

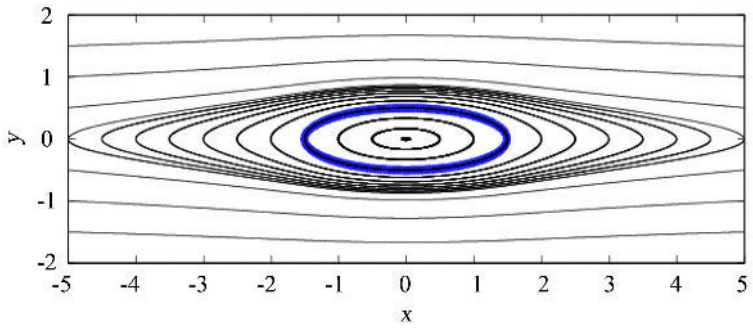

Figure 1. Elliptical vortex (Kirchoff ellipse), with elliptical streamlines, rotates with uniform angular velocity.

The vorticity in each region is constant over time due to Lagrangian conservation laws. However, like most anticyclonic vortices, it is unstable due to resonance between the turnover time and local epicyclic oscillation period, and a small linearly stable domain is found for vortex cores with an aspect ratio of approximately 5, where the vortex aspect ratio χ is defined to be $\chi = a/b$. a and b are, respectively, the vortex semi-major and semi-minor axes [29]. Because it is a two-dimensional model in the (x, y) plane, the Coriolis force is omitted, as it will only change the pressure distribution.

According to Kida, this vortex is defined by an elliptical patch of constant vorticity $\omega t = -S + \omega v$ (the "core"), where $-S$ is the background flow vorticity, and ωv is the vorticity of the vortex itself [28]. Such a vortex is steady if the semi-major axis is aligned with x and its vorticity satisfies

$$\omega v/S = -\chi(\chi+1)/(\chi-1),$$

Because this solution is steady, no streamline goes through the core boundaries, and the streamlines inside the core should be elliptical, with the same aspect ratio as the vortex core. Such a vortex rotates with a constant angular velocity γ, according to the equation [31],

$$\gamma = 2\pi\chi/(1+\chi)^2,$$

where χ denotes the aspect ratio, which is 5, and the initial vorticity is given to be a constant $q = 2\pi$ or 0, respectively, inside or outside the ellipse. In such a structure, the centripetal and centrifugal forces of the vortex are equalized. Thus, the vortex shape is guided by the equilibrium of forces in all directions. The elliptical core vortex not only rotates but also shows periodic oscillation of the aspect ratio known as nutation. Elliptical vortices are well observed in nature, such as the atmospheres of the gas giant planets, e.g., Jupiter's Great Red Spot, White Oval, and Neptune's Great Dark Spot.

When the fluid molecules move radially, the Coriolis force is induced transversely, and the angular momentum is conserved. Thus, the Kida vortex converts to a three-dimensional (3D) ellipsoidal structure. When the ellipse is rotated about its major axis, the result is a prolate (elongated) spheroid, shaped like an American football as shown in **Figure 2**.

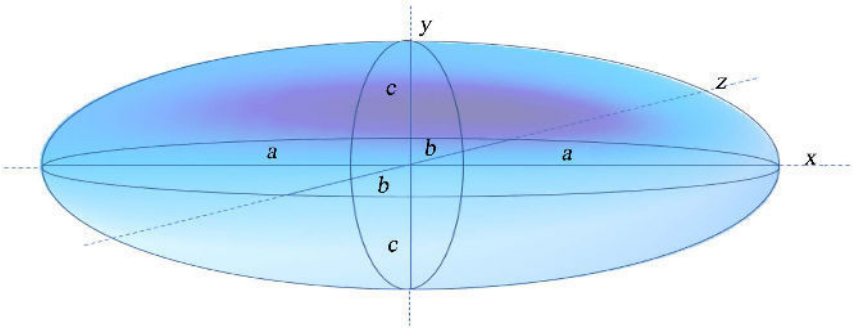

Figure 2. Prolate spheroid in the xyz coordinate system, with x as the symmetry axis, is a sphere-like surface for which the long axis cross-section is an ellipse, and the short axis cross-section is circular.

The equation of a spheroid in the xyz coordinate system with x as the symmetry axis is given by setting $c = b$, as follows:

$$\left(y^2 + z^2\right)/b^2 + x^2/a^2 = 1,$$

where a, b, and c denote the radius along the x-, z-, and y-axis, respectively.

The 3D spheroidal shape with an aspect ratio of approximately 5 gives stability to the vortex [28]. Thus, to exhibit a stable spheroid, it must satisfy an a/c aspect ratio of 5; therefore, $a = 5c$ and $b = c$.

The volume of a spheroid is given by

$$V = 4/3\,\pi abc = 4/3\,\pi 5b^3,$$

where b denotes the minor axis or radius.

The evolution from the Kida vortex to a 3D ellipsoidal model is described as a special class of oceanic eddies known as Mediterranean eddies. Although their shape is oblate ellipsoid, their mechanism of formation and stability give us a hydrodynamically good example to compare with the photon structure. The closed boundaries of eddies give stability to these water formations and are what allows their identification and tracking from satellite images; they effectively act as vehicles of water transportation over long distances.

4. The Radius and Volume of Photon

How to properly describe the EM fields of a single photon is still a fundamental and unresolved problem in physics. Normally, in physics, no question occurs about the photon radius because the belief is that a photon demonstrates no shape and hence no radius. However, experiments indicated that a single photon can locate in a very small space [32] [33] and very short time [34] [35], but how to know the size of a photon is still enigmatic.

The photon energy depends on the radiation frequency; photons of all energies from high-energy gamma- and X-rays exist, through visible light, to low-energy infrared and radio waves. If all photons travel at the speed of light, what determines the radiation frequency and energy differences?

According to our model, a photon exhibits a vortex spheroid shape, minor

axis, and major axis. The length of the major axis is five times that of the minor axis. The minor axis is the radius r of the circle in the center of the spheroid with a conference of $2\pi r$. The major axis represents the length of photon, which exhibits an elliptic shape circumference or perimeter. Unfortunately, unlike other shapes, no formula exists to calculate the exact or accurate value of the perimeter of an ellipse; several approximation formulas exist to calculate the approximate value of the perimeter, P, such as

$$P \approx \pi\sqrt{2\left(a^2+b^2\right)} \tag{1}$$

and

$$P \approx \pi\left[(3/2)(a+b)-\sqrt{ab}\right]. \tag{2}$$

However, Formulas (1) and (2), respectively, yield larger and smaller values than the actual value. So, we can obtain a relatively close answer by taking the average values obtained from Formulas (1) and (2).

If $a = 5b$, Formulas (1) and (2), respectively, become

$$P \approx \pi\sqrt{2\left(25b^2+b^2\right)} = \pi\sqrt{2\left(26b^2\right)} = \pi\sqrt{52b^2}\ .$$

$$P \approx \pi\left[(3/2)(a+b)-\sqrt{ab}\right] = \pi\left[(3/2)(5b+b)-\sqrt{5b\cdot b}\right] = \pi\left[9b-\sqrt{5}b\right].$$

The average of both formulas is

$$P \approx \frac{1}{2}\pi\left\{\left[9b-\sqrt{5}b\right]+\sqrt{52b^2}\right\} = 6.764b+7.211b = 13.97b\,,$$

where b denotes the minor radius.

The color wavelength is determined by the longitudinal photon movement; from the wavelength, we can determine the frequency by applying the formula

$$f = c/\lambda\ .$$

Therefore, knowing the photon frequency, we can calculate its minor radius r to be

$$r = c/13.97\,f$$

Thus, we can calculate the radii of different photons that give different colors. If the frequency of the green light is 566×10^{12} Hz, the radius of the green light photon is

$$r_{green} = 3\times10^8/13.97\times566\times10^{12} = 3.79409\times10^{-8}\ \text{m}\,.$$

Meanwhile, the radius of gamma-ray photons, which demonstrates a frequency of 2.42×10^{28} Hz, is 8.8737×10^{-22} m.

Applying Planck units for a single traveling EM wave, traveling at the speed of light, we can calculate the shortest wavelength of real photons to be

$$\lambda_p = \left(Gh/c^3\right)^{1/2} = 4.05096\times10^{-35}\ \text{m}\,.$$

Maximum universal cosmic radiation frequency limit = $c/\lambda_p = 7.4 \times 10^{42}$ Hz

Then, the radius of the smallest real photon according to the equation $f =$

$c/13.97r$ would be

$$\text{Planck radius} = 2.9019\times10^{-36}\ \text{m},$$

indicating that the maximum universal cosmic radiation frequency limit is determined by the limit smallest radius of a real photon. Once we determine the radius, the photon volume can be derived as follows:

$$V = 4/3\,\pi abc = 4/3\,\pi 5b^3.$$

If the radius of green light is $r_{green} = 3.79409 \times 10^{-8}$ m, its volume would be

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

The photon is treated as a superfluid spheroid vortex; thus, its local physical reality as a vortex determines the results of local measurements.

5. Transversal and Longitudinal Spins of Photon

Louis de Broglie was the first to propose a comprehensive theory on the possible internal structure of photons. According to his hypothesis, proposed in the 1930s, a permanently localized photon involves two particles or half-photons of spin 1/2, and the photon, comprising two elementary particles of spin h/4π, will obey the Bose–Einstein statistic, as required by the precision of Planck's law for a blackbody [36]. Then, the double-particle photon hypothesis would imply that photons are required to be stable localized moving EM structures whose energy quantum could only logically alternate between two components' electric state, with both components separating in space.

According to the spheroid model, the photon is endowed with longitudinal and transversal spins, both at the speed of light. In the transversal spin, photon rotates around the long axis, whereas the longitudinal spin is normal to the transversal spin and the photon rotates around the short axis as shown in **Figure 3**.

Vectors of the longitudinal (red arrow) and transversal (blue arrow) spins gives the resultant final spin of the surrounding contour flow vectors of a spheroidal photon (black arrows).

Both longitudinal and transversal spins determine the helical trajectory of photon in space, as opposed to the vacuum drag force. The spin angular momentum is associated with the polarization of light, so that right- and left-hand circular polarizations of a paraxial beam, respectively, correspond to the positive and negative helicities $\sigma = \pm 1$ of photons.

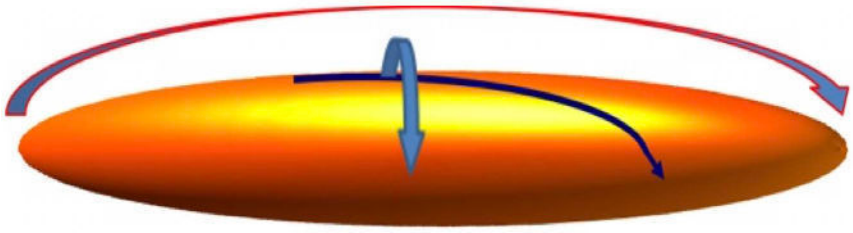

Figure 3. Rotation.

For right-handed (clockwise) spin photons, the photon axis of symmetry generally points to the right and a little bit upward with respect to the direction of the velocity vector. The longitudinal spin is responsible for the longitudinal orbital angular momentum in polarized vortex beams.

In electrodynamics, elliptical polarization is the polarization of EM radiation, such that the electric field vector's tip describes an ellipse in any fixed plane intersecting and normal to the direction of propagation as shown in Figure 4.

The spin drift, as it is properly used, refers to the tendency of a photon to move in a particular direction (along its flight path) because of the transversal spin. This is actually a function of the gyroscopic and Magnus effects. The Magnus force significantly affects stability because it tries to "twist" the photon along its flight path in which the transversal spins create gyroscopic rotation, which becomes stable. When it moves linearly, its center of gravity will follow the flight path, creating a small optical vortex around the main helix, which exhibits a trajectory in a fixed plane normal to the propagation direction, creating an optical vortex with five arms in the spiral as shown in Figure 5.

The number of arms in the spiral equals the topological charge. The higher the topological charge of a photon, the higher its energy. In an optical vortex, light is twisted like a corkscrew around its travel axis. The intersecting of the longitudinal and transversal spins give elliptic and pentagon polarization as shown in Figure 6.

When projected onto a flat surface, an optical vortex looks like rings of light, with a dark ring in the interference zone and a dark hole at the center as shown in Figure 7.

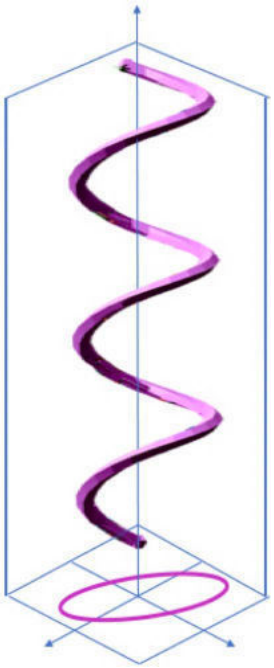

Figure 4. Helical shape of the elliptic trajectory of photon in a fixed plane normal to the propagation direction.

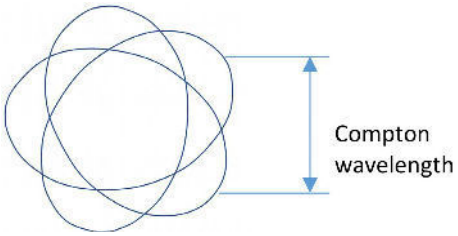

Figure 5. Gyroscopic rotation pathway of a photon creates a pentagon shape trajectory in a fixed plane normal to the propagation direction.

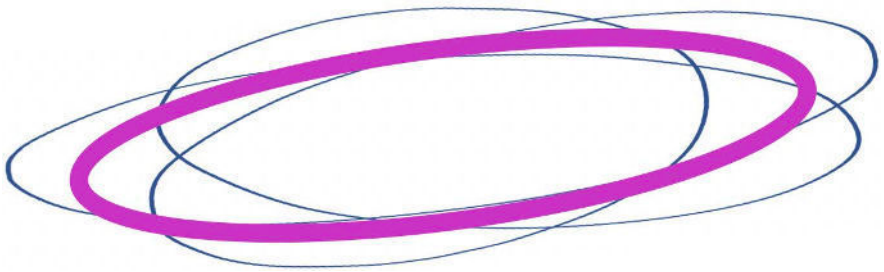

Figure 6. A combination of longitudinal and transversal trajectories in a fixed plane normal to the propagation direction.

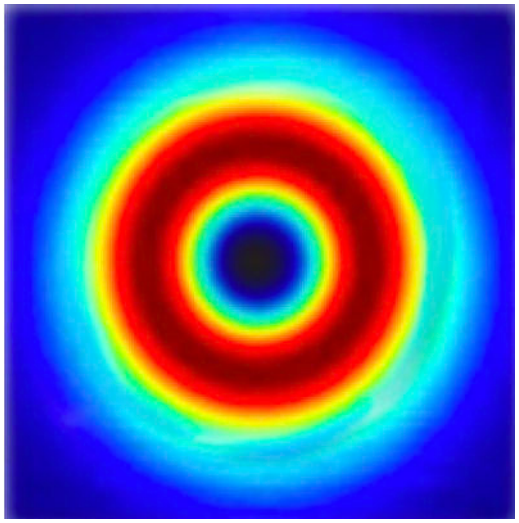

Figure 7. Artistic presentation of a ring shape circular polarization of optical vortex.

This spinning carries orbital angular momentum with the wave train and will induce torque on an electric dipole. The orbital angular momentum is distinct from the more commonly encountered spin angular momentum, which produces circular polarization [37].

6. Difference between the Compton and De Broglie Wavelengths

The transversal spin cycle gives the Compton wavelength, which is equal to $2\pi r$, where r denotes the minor radius of photon, whereas the longitudinal spin cycle gives the de Broglie wavelength, which is equal to $13.97r$ as shown in Figure 8.

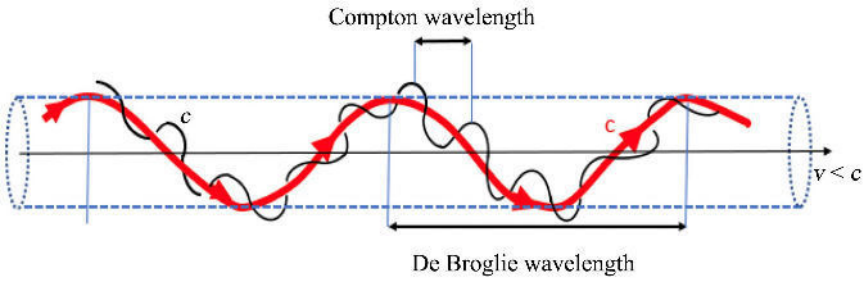

Figure 8. The Compton wavelength is generated by one cycle or rotation of one transversal spin, whereas the de Broglie wavelength is generated by one longitudinal spin.

A nonzero photon rest mass, as described by the Proca equations, would result in a third state of polarization in which the vector of the electric field points along the line of motion, and the particle is called a "longitudinal photon" [38]. If the longitudinal photon velocity differs from the longitudinal spin, it would be less than the speed of light, *i.e.*, $v < c$. De Broglie's hypothesis states that each portion of energy with a rest mass m_0 may be associated with a periodic phenomenon of frequency f_0, such that $hf_0 = m_0c^2$, where f_0 is the rest mass frequency [39]. He used the special theory of relativity to find that, in the frame of an observer of a photon energy packet moving with a velocity v, its frequency was reduced to

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

However, if

$$mc^2 = hf_0\left(1-v^2/c^2\right)^{1/2},\quad f_0 = c/\lambda,\ \text{and}\ \ mc^2 = \left(hc/\lambda\right)\left(1-v^2/c^2\right)^{1/2},$$

we have

$$\lambda = \left(h/mc\right)\left(1-v^2/c^2\right)^{1/2} = h/p,$$

also known as the "de Broglie wavelength" for a particle moving at velocity v to a fixed observer [40].

Notably, the Compton wavelength is independent of the photon velocity in space, provided the energy is the same as the rest mass energy of that photon.

The Compton frequency $f = c/\lambda$, where $\lambda = 2\pi r$ and r denotes the minor axis of the photon.

Next, because the de Broglie wavelength corresponds to the photon vortex perimeter, which is 13.9 times the minor radius, the de Broglie frequency is

$$f = c/13.97r$$

According to the above equation, the smaller the photon radius, the higher its frequency, the photon color frequency is an expression of the de Broglie frequency.

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

$$E = hv.$$

Therefore, the photon frequency and, hence, the photon energy depend completely on the photon radius. Thus, photons of different sizes exist; a photon is considered a real or virtual photon if the radius is, respectively, greater or less than the Planck length.

7. The Rest Mass Energy of Photon

The photon wave–particle properties can be accurately described using classical laws—Newtonian mechanics and Einstein's special relativity—that can exhibit particle and wave properties simultaneously.

Although photons never stop moving, the energy of a photon at "rest" and the energy of a moving photon should be distinguished.

For example, the energy of green light with a frequency of 5.71×10^{14} Hz is given by

$$E = hf = 6.62607004 \times 10^{-34} \times 5.71 \times 10^{14} = 3.78348599284 \times 10^{-19} \text{ J}.$$

The aforementioned frequency is the de Broglie frequency; therefore, this is the energy of a moving photon.

Although a photon is never stationary, considering a photon at rest when it is formed as an internal spin; the photon vortex energy is not related to the distance traveled, but the energy that it possesses is bounded by a single period of its cycle.

Maxwell's equations imply that a photon can be polarized in either of two directions—circular and vertical—both of which are orthogonal to the photon's direction of motion; more is not known.

A photon at rest demonstrates a longitudinal spin and a transverse spin, which is orthogonal to the longitudinal spin. The final spin is at 45˚ between both spins as shown in Figure 9.

Treated as a fluid spheroid, demonstrating two momenta and spins: longitudinal and transversal.

In general, the kinetic energy of a rotating particle is

$$E_k = 1/2\, mv^2$$

A photon's rest momentum is the resultant of longitudinal and transversal spin momenta, where both rotate at the speed of light.

Using the Pythagorean theorem, for a 90˚/45˚/45˚ triangle with sides equal to c, hence, the hypotenuse is equal to $(2c^2)^{1/2}$.

Figure 9. Photon.

If the actual photon velocity is $v = (2c^2)^{1/2}$, the total kinetic energy of the rotating photon vortex would be

$$E_k = 1/2\, m\left[\left(2c^2\right)^{1/2}\right]^2 = mc^2$$

Alternatively, considering that the kinetic energies of the transverse and longitudinal spins are both $1/2mc^2$, the total energy of the photon is $E = 2(1/2mc^2) = mc^2$.

8. Why Photon Is Chargeless?

The real nature and essence of charge are unknown. Considered among the subatomic particles, photons are bosons, exhibiting **no electric charge** or rest mass and one unit of spin; they are field particles that are thought to be the carriers of the EM field. In a previous study [41], a new theory for the essence and nature of electric charge was proposed based on the vortex model of an electron that demonstrates a finite size and an irrotational vortex structure. In such a structure, the vortex demonstrates suction power to the center of the vortex, which attracts virtual photons from the vacuum to the vortex core. In fact, according to the charge units, the electric charge is an expression of accelerated photon mass per area reduced by the stiffness of the vacuum, which exhibits the units ε_0 ML^3/T^2. According to the spheroid model, a photon is completely closed with definitive boundaries that do not attract anything to the photon vortex center. However, a photon reacts to charged particles according to their spin. Each photon carries two independent forms of angular momentum: spin and orbital angular momenta. The spin momentum is related to the transversal and longitudinal spins of photon, whereas the orbital angular momentum is related to the photon movement in space, which creates the helical trajectory of photon in space.

Thus, we can conclude that the charge itself comprises a virtual photon flow, thereby creating a helical movement in the charged particle vortex.

9. Conclusions

In physics, a photon, like other particles, exhibits no structure or shape, and physics studies photon behavior and effects but not its essence or shape. However, a photon, just like other observed particles, possesses a real physical identity. In this study, a new concept for the photon structure is presented. By postulating a photon fluid spheroid structure with internal rotation motion, we developed a simple "physical" theory elegantly combining the mechanics with mathematics, which might improve our understanding of the mysteries of the nature of the photon and resolve some enigmatic questions for physics, such as "Why photon has no mass and charge?" and "What determines the frequency and angular momentum of photon?".

A photon is described as a fluid spheroid condensation of the vacuum formed during the photon epoch. It is endowed with two spins: 1) the longitudinal spin

related to the Kirchoff ellipse and 2) the transversal spin due to the Coriolis effect. These two spins determine the photon movement in a helical trajectory to form the EM wave; thus, particle and wave are connected and explained simultaneously. Next, the frequency and, hence, the energy of photon depend completely on its radius, where the wavelength is related to the spheroid's perimeter. Thus, there are photons of different sizes and are considered real or virtual if the radius is, respectively, greater or less than the Planck length. The energy of each photon is quantized and stored as an oscillating electric field, which is the rotating vortex made originally of the vacuum that comes in discrete amounts and is described as energy packets. This means that the energy is structured such that the energy packets are distinguishable from the surrounding vacuum. This is a very fitting analogy because a photon contains energy that cannot be divided.

We conclude that a photon exhibits real physical existence, which demonstrates a spheroid shape with transversal and longitudinal spins, rotating against the vacuum that is dragged with transversal and longitudinal trajectories, creating a 3D helical EM wave. The transversal and longitudinal rotation cyclicities are responsible for the Compton and de Broglie wavelengths, respectively. The study of photon properties revealed the existence of an entirely new class of fundamental particles known as quantum particles. To confirm the spheroid structure of photon, future experimental studies are required. Moreover, what keeps the speed of light constant and why a photon cannot travel faster than the speed of light will be clarified in another study.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Ethical Approval

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