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THE FINE STRUCTURE CONSTANT, MODIFIED UNCERTAINTY PRINCIPLE, AMAZING PHOTONS AND FREE SPACE POLARIZATION

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ABSTRACT

A dynamic elementary dipole model, with a spinning twin elementary unit charge particles having opposite signs of the charges, is proposed to explain the internal structure and the mutually induced oscillating electric and magnetic fields of a propagating photon. The twin elementary unit charge particles under electric attraction force form a dynamic elementary dipole and achieve a relatively stable orbital motion with a constant drifting speed of its mass centre. From a combined mechanical and electromagnetic analysing, the widely accepted formula for the fine structure constant is derived. It is revealed that the fine structure constant is the ratio of the radius of the dynamic elementary dipole to the corresponding radius of its photon. The fine structure constant is also derived as the ratio of the spinning angular frequency inside the dynamic elementary dipole to the corresponding angular frequency of its photon. In the effect of the spin, the drift movement of the mass centre of the dynamic elementary dipole, accomplished in the joined action of the electric and the magnetic fields, is derived as the light speed in the free space. Base on the derivation of the least action of the spinning elementary unit charge particle, a modified uncertainty principle is proposed. The modified uncertainty principle permits dramatically increased levels of precision for scientific measurements and engineering design in comparison with the Heisenberg Uncertainty Principle. The spin energy of the elementary unit charge particle inside the dynamic elementary dipole is derived as just half of the energy of its photon. The quantum number of half for the spinning elementary unit charge particle is deduced. The free space is revealed as a dielectric medium full of dynamic elementary dipoles, having electric and magnetic polarizability naturally.

Keywords: Dynamic elementary dipole, fine structure constant, the least action, uncertainty principle, spin energy, quantum entanglement, vacuum polarization.

INTRODUCTION

The fine-structure constant was introduced by Arnold Sommerfield in 1916 to quantify the tiny gap between two lines in the spectrum of colours emitted by the Hydrogen atom (Sommerfeld, 1916, 1923; Schiff, 1968). The fine-structure constant has no dimensions or units, it is a pure number that shapes the universe to an astonishing degree. Richard Feynman proclaimed: "It's one of the greatest damn mysteries of physics: a magic number that comes to us with no understanding". Max Born declared, "... the explanation of this number must be the central problem of natural philosophy." Paul Dirac ranked the origin of the number "the most fundamental unsolved problem of physics." Wolfgang Pauli considered that quantum mechanics is inconclusive without understanding of the fine structure constant. This number and its place in the scale of the universe had particularly puzzled Wolfgang Pauli until he passed away in a hospital room numbered 137. The number 137 is the approximate denominator of the fine-structure constant known as $\alpha \approx 1/137.036$. What really makes the fine structure constant amazing, as Feynman and others realized, is if it was somehow even a tiny bit different, the universe wouldn't be the same; in particular, human life would not have evolved (Born, 1935; Bouchendira *et al*., 2011; Butto, 2020; Eichten *et al*., 1983; Feynman, 1965; Kragh, 2012; Pauli, 1940, 1946; Schiff, 1968; Uzan, 2003). The fine structure constant governs the interacting strength of the electromagnetic force between charged elementary particles and their surrounding electromagnetic fields. Hence, the fine-structure constant characterizes the whole range of physics from elementary particles to atomic, mesoscopic, and macroscopic systems. A better explanation of the origin of the fine structure constant remains one of the Holy Grails of modern physics.

While the author strived to understand the amazing photons and the free space polarization, suddenly realized that the fine structure constant is intimately linked with the particle-wave duality of photons. The cycloid motion of a harmonic oscillator for the propagating photon with particle-wave duality is first briefly reviewed from a mechanical perspective. Second, a model of twin spinning elementary unit charge particles as a dynamic elementary dipole has been proposed to explain the internal structure

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and the mutually induced oscillating electric and magnetic fields of a propagating photon. From a combined mechanical and electromagnetic analysing, the widely accepted formula for the fine structure constant is derived. Base on the derivation of the least action of the spinning elementary unit charge particle inside the dynamic elementary dipole, a modified uncertainty principle is proposed. The spin energy of the elementary unit charge particle is derived as just half of the energy of the corresponding photon. The free space is discussed as a dielectric medium full of dynamic elementary dipoles, having electric and magnetic polarizability naturally.

The progress on the understanding of the particle-wave duality of photons and the physical origin of the fine structure constant

The propagation of a single photon with particle-wave duality can be viewed as the cycloid motion of a harmonic oscillator from a mechanical perspective under the ideal approximation of frictionless free space (Zhang, 2021a, 2021b) which is shown schematically in Figure 1.

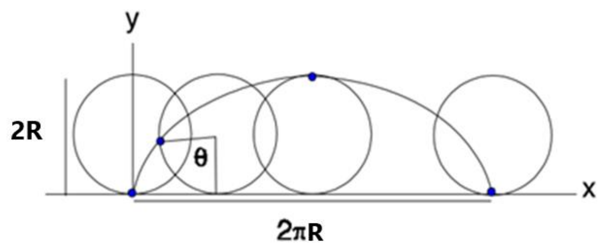

Fig. 1. The schematic diagram showing the cycloid motion model for a photon with particle-wave duality.

The period T (the time to complete one wavelength $\lambda = 2\pi R$), the frequency *f*, and the angular frequency ω of the photon propagating in the free space are defined as follows:

$$T = 1/f \tag{1}$$

$$\lambda = 2\pi R \tag{2}$$

$$\omega = 2\pi f = \frac{2\pi}{T} = \frac{c}{R} \tag{3}$$

where c is the speed of the propagating photons in the free space. It is widely accepted that all photons have an equal mechanical angular momentum ħ. ħ is the reduced Planck constant or Dirac's constant, $\hbar = h/2\pi$, where h is the Planck constant. Based on a simple harmonic oscillator model (Garret, 2017) for photons with particle-wave duality (Zhang, 2021a), the correlations between the mechanical angular momentum (ħ), the Planck constant (h), the equivalent mass (m), the angular frequency (ω), the quantized energy (ε), and the corresponding radius (R) of the harmonic oscillation of the photon with particle-wave duality are derived as follows:

$$\hbar = m\omega R^2 = mcR \tag{4}$$

$$h = mc\lambda = p\lambda \tag{5}$$

$$T = \frac{\lambda}{c} = \frac{h}{mc^2} \tag{6}$$

$$\varepsilon = hf = \hbar\omega = hc/\lambda = mc^2 \tag{7}$$

It is worth to point out that the mechanical angular momentum of photon particles from a mechanical perspective is slightly different to the optical angular momentum of the corresponding photon waves from an electromagnetic perspective (Bliokh and Nori, 2015), although they have interdependence. The conservation of mechanical angular momentum is fundamentally associated with the periodic motions of rotational symmetry and can be calculated using Noether's theorem (Bliokh and Nori, 2015). It is apparent that the cycloid motion of a harmonic oscillator model from a purely mechanical perspective is unable to explain the mutually induced oscillating electric and magnetic fields of the propagating photons with particle-wave duality.

Let us try to understand better the amazing photons from a combined perspective with both mechanic and electromagnetic insights. The movements (rotational, vibrational, and translational) of a pair of elementary unit charge particles with opposite signs of the charges inside a dynamic elementary dipole is able to create the mutually induced oscillating electric and magnetic fields of a propagating photon. Hence, it is reasonable to perceive a photon particle as a dynamic elementary dipole that is composed of a pair of elementary unit charge (e) particles with opposite signs of the charges. The absolute value of the elementary unit charge in the Universe is approximately $1.602176634 \times 10^{-19}\,C$ according to CODATA 2014 (Mohr *et al*., 2015), where C is Coulomb. A dynamic elementary dipole is the nucleus of the corresponding photon particle, so the radius (r) of the dynamic elementary dipole shall be much shorter than the corresponding photon radius (R). As a result, the following relation between them can be written:

$$r = \alpha R \tag{8}$$

where α is the fine structure constant, which will be verified in the following. The recommended value of the fine structure constant is 0.0072973525664 according to CODATA 2014 (Mohr *et al*., 2015), which is approximately equal to 1/137.035999139. Inside the dynamic elementary dipole, the relative motion of the particle having a negative elementary charge against the particle having a positive elementary charge, or vice versa, shall be a central force motion of two particles around their common centre of mass, which is mathematically reducible to an equivalent one-body particle problem with a reduced mass *m*. The speed of motions shall be the light speed *c* for analysing the motions of photons in the free space. To achieve a relatively stable obit of circulating motion demands that the electric attraction force between the twin particles shall be able to provide exactly the centripetal acceleration force (Jackson, 1975; Landau and Lifshitz, 1976; Slater, 1967), hence,

$$\frac{ke^2}{(\alpha R)^2} = \frac{mc^2}{\alpha R} \tag{9}$$

where k is the Coulomb's constant. The fine structure constant can be derived from equations (4) and (9) as follows:

$$\alpha = \frac{ke^2}{mc^2 R} = \frac{ke^2}{\hbar c} \tag{10}$$

In the derivation of equation (10), the reduced mass of the twin particles was taken as the equivalent mass of the corresponding photon, which will be verified theoretically later on. Equation (10) is the widely accepted formula for the fine structure constant that was first introduced by Arnold Sommerfield in 1916 (Butto, 2020; Kragh, 2012; Schiff, 1968; Sommerfeld, 1916; Uzan, 2003). The theoretically derived result of equation (10) puts the relation out of the best guess in equation (8) on a solid ground. Equation (9) implies that two elementary unit charge particles with opposite signs of the charges under electric attraction force will spiral towards each other to form a dynamic elementary dipole and achieve a relatively stable obit motion in the end, rather than annihilation. Towards this stage, a dynamic equilibrium between the dynamic elementary dipole and its surrounding space is achieved, the energy radiated by the elementary dipole and the energy absorbed by it from its surrounding space are balanced out dynamically (Zhang, 2021c).

Spontaneously induced electric and magnetic fields, magnetic flux, modified uncertainty principle, the quantization of spin energy, and spin quantum number

The circular motion of the equivalent one-body particle of the dynamic elementary dipole, induces a magnetic field directed orthogonally to the orbital plane (Jackson, 1975; Schiff, 1968; Slater, 1967). Inside the dynamic elementary dipole, the strength of the magnetic field B must fit the angular frequency of the elementary unit charge particle spinning motion. Hence, the spinning angular frequency ω_{se} of the elementary unit charge particle shall be

$$\omega_{se} = \frac{eB}{m} \tag{11}$$

The spinning speed is the light speed *c*, the spinning angular frequency ω_{se} of the elementary unit charge particle satisfies the following relation:

$$r\omega_{se} = 2\pi r f_{se} = \frac{eBr}{m} = c \tag{12}$$

where f_{se} is he spinning frequency of the elementary unit charge particle. Hence, from equations (11) and (12) we have

$$B = \frac{m\,c}{e\,r} \tag{13}$$

B is the magnetic field strength spontaneously induced by the relative circular motion of the elementary unit charge particles inside the dynamic elementary dipole. Meanwhile, the electric field strength *E* between the elementary unit charge particles shall be

$$E = \frac{k\,e}{r^2} \tag{14}$$

The direction of the electric field strength *E* is within the orbital plane. Divided the electric field strength *E* in equation (14) by the magnetic field strength *B* in equation (13), we have

$$\frac{E}{B} = \frac{k\,e^2}{mcr} = \frac{k\,e^2\,c}{\hbar\,c\,\alpha} = c \tag{15}$$

The magnetic field strength *B* is perpendicular to the electric field strength *E*. The drifting velocity v_d of the mass centre of the dynamic elementary dipole as a result of the joined action of the electric and the magnetic fields is

$$v_d = \frac{E \times B}{B^2} = c \tag{16}$$

Amazingly, the drift movement of the mass centre of the dynamic elementary dipole, accomplished in the joined action of the electric and the magnetic fields, is derived as the light speed *c*. From equations (8) and (12), it can be elicited as

$$\omega_{se} = 2\pi f_{se} = \frac{c}{r} = \frac{c}{\alpha R} = \frac{\omega}{\alpha} \tag{17}$$

For a photon, we have a variety of experimental technologies to determine its R, λ, ω, and f, which is related to the relative rotating motion of the photon. However, we have ω_{se}, f_{se}, and $\lambda_{se} (= 2\pi r)$, which are newly derived parameters to describe the spinning of the elementary unit charge particles inside the dynamic elementary dipole. We have not developed suitable technologies yet to measure them directly. The author believes that the current technologies should be able to be developed to measure them accurately without major technical barriers to overcome. Hopefully there will be people and funding available soon to develop these technologies. Two kinds of novel technologies can be developed for us to understand better the spinning of the elementary unit charge particle. One is to measure the ratio of the radius of the dynamic elementary dipole to the corresponding radius of the photon, another is to determine the ratio of the spinning angular frequency inside the dynamic elementary dipole to the corresponding photon angular frequency. The radius of the dynamic elementary dipole is the spinning radius of the elementary unit charge particle inside the dynamic elementary dipole. Based on these novel technologies, the fine structure constant can be determined accurately based on equation (17) as follows:

$$\alpha = \frac{r}{R} = \frac{\omega}{\omega_{se}} = \frac{f}{f_{se}} \tag{18}$$

The circle planar area of the spinning particle shall be

$$S = \pi r^2 \tag{19}$$

Hence, the quantum magnetic flux over the circle planar area is

$$\phi = SB = \frac{\pi\hbar\alpha}{e} = \frac{h\alpha}{2e} \tag{20}$$

The least action of the elementary unit charge particle rotating in the induced magnetic field (Jackson, 1975; Landau and Lifshitz, 1976; Schiff, 1968; Slater, 1967) shall be

$$\oint pdr = 2\pi rp = \pi rmc \tag{21}$$

Combining equations (4), (18), (20), and (21), the least action of the elementary unit charge particle rotating in the induced magnetic field can be derived as follows:

$$\oint pdr = e\phi = \frac{h\alpha}{2} \tag{22}$$

The Heisenberg Uncertainty Principle introduced by Werner Heisenberg (Heisenberg, 1927) is one of the cornerstones of quantum mechanics. It defines a limitation of simultaneous measuring a pair of canonically conjugate variables. Surprisingly, equation (22) implies a much lower limit of uncertainty than the Heisenberg Uncertainty Principle defined. Hence, the proposed modified uncertainty principle based on equation (22) shall be

$$\Delta x \Delta p \geq \frac{\hbar\alpha}{2} \tag{23}$$

$$\Delta E \Delta t \geq \frac{\hbar\alpha}{2} \tag{24}$$

Equations (23) and (24) may have profound implications for the advancement of the fundamental theory of physics, novel technologies and engineering with unprecedented levels of achievable precision. The Heisenberg Uncertainty Principal has become a matter of urgent practical topic of ever-growing interest and debating recently in the setting of quantum information, quantum cryptography, and quantum computing, where it is fundamental to the security of certain protocols. In particular, some schemes for quantum encryption derive much of their promised security from the Heisenberg Uncertainty Principle (Zhou *et al.*, 2016). Equations (23) and (24) may put their promised security in reconsideration. However, it is a great news for the dramatically increased levels of achievable precision for scientific measurements and engineering design.

In the study recently published by Delepinay *et al.* (2021), two vibrating drumheads, the size of a human hair, were prepared in a quantum entanglement state which evades the Heisenberg Uncertainty Principle. This means that the researchers were able to simultaneously measure the position and the momentum of the two drumheads precisely, which should not be possible according to the Heisenberg Uncertainty Principle. The researchers hope that their entangled drums will be sensitive enough to measure the tiny distortions in space created by gravitational waves. Another group has developed new methods to control and measure the motion of two tiny aluminium drums simultaneously (Kotler *et al.*, 2021) to a level of precision forbidden by the Heisenberg Uncertainty Principle. They aim to use their drum system to build long-lived nodes, or network end-points, in quantum networks for quantum teleportation, or to adapt their methods for designing quantum computers with calculative powers far beyond current Super-computers and for solving problems that need unprecedented levels of precision, for instance, the detection of gravitational waves.

The elementary unit charge particle spins 1/α cycles within the cycle of the rotating of the dynamic elementary dipole. The spin energy of the elementary unit charge particle within the dynamic elementary dipole is derived as

$$\varepsilon = \frac{\alpha h}{2} f_{se} = \frac{\alpha\hbar\omega_{se}}{2} = \frac{\hbar\omega}{2} \tag{25}$$

which is just half of the energy of the dynamic elementary dipole (the photon). Hence, the spin quantum number of the elementary unit charge particle within the cycle of the rotating of the dynamic elementary dipole based on equation (25) is ½. This means that the spin polarizing state of the twin elementary unit charge particles only returns to their original state after two complete cycles of the rotating of the dynamic elementary dipole. Equation

(25) implies that the energy of the dynamic elementary dipole (the photon) is equally distributed between its twin elementary unit charge particles.

When the energy ($\hbar\omega$) of a photon exceeds the energy threshold of 1.022 MeV (Bradt, 2008), the rotating dynamic elementary dipole (the photon) can be destabilized, a pair of a spinning electron and a spinning positron can be converted from the dynamic elementary dipole. Based on equation (25) and the conservation of energy, the spin energy (ε_{se}) and the spin quantum number (n_{se}) of the converted spinning electron (or the converted spinning positron) are

$$\varepsilon_{se} = \frac{\hbar\omega}{2} \approx 0.511\ MeV \tag{26}$$

$$n_{se} = 1/2 \tag{27}$$

For a separated spinning electron, there must be a spinning elementary positive charge particle somewhere in the Universe to form a pair with it, in order to fulfil the law of charge neutralization. We currently have not developed technology to measure directly the spin angular frequency ω_{se} of the separated spinning particle yet. However, we are able to determine the angular frequency ω of the rotating of the dynamic elementary dipole, even when the twin parts are separated far away. Equation (18) can be used to derive ω_{se} from the determined ω. From equations (17) and (26), the radius of the spinning electron can be derived as

$$r = \frac{\hbar\alpha c}{2\varepsilon_{se}} \approx 1.408968 \times 10^{-15}\ [\mathrm{m}] \tag{28}$$

Interestingly, exactly the same electron radius was reported by Mei and Mei (2019) based on two completely different ways of theoretical calculation.

From the above analysis, it can be seen that the quantization of elementary charge is more fundamental than the quantization of energy, the quantization of energy origins from the quantization of elementary charge. Amazingly, after the dynamic elementary dipole of the photon particle is converted to a pair of a spinning electron and a spinning positron, the spin energy and the spin quantum number of the spinning particles are kept the same as before the conversion, even after the two particles are moved far away from each other. This means that the pair of particles converted from the same photon are in the state of quantum entanglement.

The mass of a dynamic elementary dipole and the free space polarization

In the derivation of equation (10), the reduced mass of the dynamic elementary dipole has been taken as the equivalent mass of the corresponding photon particle, which can be verified theoretically as follows. Inside the dynamic elementary dipole, the relative circular motion of the particle having a negative elementary charge against the particle having a positive elementary charge, or vice versa, shall be a central force motion of two particles about their common centre of mass, which is mathematically reducible to an equivalent one-body particle with a reduced mass m_r. The radius of the circular motion is r. The moment of inertia of the circular motion of the equivalent one-body particle is

$$I = m_r r^2 \tag{29}$$

The rotational kinetic energy of the circular motion of the equivalent one-body particle is

$$E_{kr} = \frac{1}{2} m_r r^2 \omega_{se}^2 = \frac{1}{2} m_r c^2 \tag{30}$$

From equation (16), the mass centre of the equivalent one-body particle of the dynamic elementary dipole has a translational drift motion at the light speed. Therefore, the translational kinetic energy of the reduced mass of the equivalent one-body particle is

$$E_{kt} = \frac{1}{2} m_r c^2 \tag{31}$$

Hence, the total kinetic energy of the dynamic elementary dipole is

$$E_k = E_{kt} + E_{kr} = m_r c^2 \tag{32}$$

Equation (32) is the total kinetic energy of the dynamic elementary dipole, according to Einstein's Mass-Energy equation. The total kinetic energy of a photon particle shall be

$$E_k = m\ c^2 \tag{33}$$

The total kinetic energy of the dynamic elementary dipole equals to the total kinetic energy of its corresponding photon. Therefore, from equations (32) and (33), it is derived $m_r = m$.

There is a vast thermal bath of photons in the Universe, including the apparent photons in excited states ranging from radio waves to γ-rays, and the hidden ground state photons in quantum liquid state of super-fluidity (Zhang, 2021c, 2021d). Now it is revealed that all the photons are dynamic elementary dipoles. These discovering pave the way to explain the free space (vacuum) as a physical medium with electric and magnetic polarizability naturally. The free space polarization (Vacuum polarization) is an experimental verified fact (Gitman, 2016; Konstantinov, 2018). In the quantum theory, the vacuum polarization is explained from the assumption of some virtual processes of creation and annihilation of particle-antiparticle pairs within extremely brief time intervals by quantum fluctuations. Now, the free space is a dielectric medium full of dynamic elementary dipoles with defined dielectric and magnetic permeability, which are equal to the dielectric and magnetic constant (ε_0 and μ_0). The free space full of dynamic elementary dipoles is able not only to transmit interactions but also to participate in interactions.

The concept of "Vacuum" in the sense of empty space in the twentieth century was transformed into the concept of "Physical vacuum" filled with virtual particles that appeared for a brief moment as a result of vacuum fluctuations. However, the short-life existence of virtual particles within the quantum uncertainty includes the description of the virtual event by real quantities: time, Planck's constant, and energy. In this connection, the question arises as to how this real description becomes virtual (Konstantinov, 2018). Modern quantum field theory is not ready to describe nonlinear processes of production of real particles in a vacuum under the influence of external fields. For some of these fields, it is possible to construct the corresponding quantum theory of the Dirac field but there are insurmountable difficulties connected with the creation of electron-positron pairs from a vacuum leading to nonlinear many-particle problems (Gitman, 2016). Today, more than ever, the improvement of quantum theory in describing the phenomenon of the vacuum polarization becomes urgent in the advanced fields of physics, beginning with cosmology and astrophysics, and ending with accelerators and colliders (Konstantinov, 2018).

CONCLUSION

The cycloid motion of a harmonic oscillator model for the photon with particle-wave duality is briefly reviewed from a mechanical perspective. A dynamic elementary dipole model, with a spinning twin elementary unit charge particles having opposite signs of the charges, is proposed to explain the internal structure and the mutually induced oscillating electric and magnetic fields of a propagating photon. Inside the dynamic elementary dipole, the relative motion of the particle having a negative elementary charge against the particle having a positive elementary charge, or vice versa, is a central force motion of two particles around their common centre of mass, which is mathematically reducible to an equivalent one-body particle with a reduced mass. Two elementary unit charge particles with opposite signs of the charges under electric attraction force spiralling towards each other, form a dynamic elementary dipole and achieve a relatively stable orbital motion in the end, rather than annihilation. From a combined mechanical and electromagnetic analysing, the widely accepted formula for the fine structure constant is derived. It is revealed that the fine structure constant is the ratio of the radius of the dynamic elementary dipole to the corresponding radius of its photon. The fine structure constant is also derived as the ratio of the spinning angular frequency inside the dynamic elementary dipole to the corresponding angular frequency of its photon.

The magnetic field strength spontaneously induced by the relative circular motion of the twin elementary unit charge particles inside the dynamic elementary dipole, and the electric field strength between the twin elementary charge particles are calculated. The ratio between them is the light speed in the free space. In the effect of the spin, the drift movement of the mass centre of the dynamic elementary dipole, accomplished in the joined action of the electric and the magnetic fields, is derived as the light speed in the free space. Base on the calculation of the least action of the elementary unit charge particle in the spontaneously induced magnetic field, a modified uncertainty principle is proposed. The modified uncertainty principle permits dramatically increased levels of precision for scientific measurements and engineering design in comparison with the Heisenberg Uncertainty Principle. The elementary unit charge particle spins $1/\alpha$ cycles within one cycle of the rotating of the dynamic elementary dipole. The spin energy of the elementary unit charge particle is just half of the energy of the dynamic elementary dipole (the photon). A quantum number of half for the spin state of the negative or the positive elementary unit charge particle is deduced, which is related to the angular frequency of its corresponding photon. The process of the photon particle converted to a pair of a spinning electron and a spinning positron is discussed. Interestingly, the spin energy and the spin quantum number of the spinning electron (or the spinning positron) are kept the same as before the converting process, even after the two particles are moved far away from each other. This means that the pair of particles converted from the same photon are in the state of quantum entanglement.

There is a vast thermal bath of photons in the Universe, including the apparent photons in excited states ranging from radio waves to γ-rays and the hidden ground state photons in quantum liquid state of super-fluidity. It is revealed that all the photons are dynamic elementary dipoles. These discovering pave the way to explain the free space as a dielectric medium full of dynamic elementary dipoles with electric and magnetic polarizability naturally. It becomes unnecessary for the explanation of vacuum polarization from the assumption of some virtual processes, creation and annihilation of particle-antiparticle pairs by quantum fluctuations.

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