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Double Helix Structure of Photon

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Does photon have structure, what structure? A useful clue is: The EM theory predicts that the helical distribution of vector EH plus speed c makes the angular momentum of the circular polarized light. Photon possesses speed c and spin $\hbar$, weather its spin and other basic properties are also owing to the similar EH structure plus c? We are going to find out the answer. Starting from an ordinary symmetrical EM-wave beam, we do not presuppose it having any relation with the photon and quantization. We will prove the symmetrical wave beam is circular polarized; it is composed of an $h\nu$-energy packet and a conical (EM) wave with much smaller energy. The energy packet is a small and thin slice of circular polarized EH field wrapped by a cylindrical side membrane with helically distributed $\pm e$. Mechanical equilibrium between $\pm e$ and stresses Σ in the side membrane and the EH field inside construct a very steady structure to keep its integrity and energy. The energy-packet will be proved having almost all the basic properties we used to know for the photon(s). It floats on the front of the conical (EM) wave. They move with the same phase until meeting an obstacle. The energy packet and accompanying wave satisfy the same circular polarized wave function and play a role together in the processes of emission, absorption and interference. They show wave particle properties all the time. It seems such EM train can be reasonably treated as a photon and vice versa.

Keywords: Side membrane; $\in$ -(energy) packet; ψ -(EM)wave; elementary train; double helix structure.

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1. INTRODUCTION

Does photon have structure? Does the structure have a mechanism to make the basic properties of photon? A useful clue is: The EM theory predicts that the helical distribution of vector **E, H** plus speed c make the angular momentum of the circular polarized light [1,2]. As for the photon it possesses speed c and spin $\hbar$, weather its spin and other basic properties are also owing to the similar **E, H** structure plus c ?

Our object of study is an ordinary symmetrical EM wave beam. We do not presuppose it having any relation with the photon and quantization. What we do is trying to find out the beam's properties. We will prove the beam is circular polarized; it is composed of an $h\nu$ energy packet and a conical EM wave with much smaller energy. The energy packet is a small and thin slice of circular polarized **E, H** field with energy $h\nu$, it wrapped by a cylindrical side membrane. There is a pair of charges $\pm q$ and stresses σ_θ distributed double helically along the membrane. Mechanical equilibrium between $\pm q$, stresses σ_θ and the **E, H** field inside construct a very steady structure to keep its integrity and energy. The quantization law of charge requires $\pm q = \pm e$, (or $\pm ne$), so the EM beam is quantized. The energy packet will be proved having many basic properties they are almost as same as the photon's like $\in = h\nu$, spin= $\hbar$, etc. The energy packet and EM wave play a role together in the process of interference, emission and absorption. They show wave-particle property all the time.

2. THE SYMMETRICAL EM WAVE BEAM IS CIRCULAR POLARIZED AND HAS A CYLINDRICAL SIDE MEMBRANE

The field intensity of a vibrating electric dipole at point O is [3].

$$E(\rho,\vartheta,\nu,t)=\sqrt{\frac{\mu_0}{\varepsilon_0}}H=\frac{\pi \mathrm{M}_0\nu^2}{c^2\varepsilon_0\rho}\sin\vartheta\cos\omega(t-\frac{\rho}{c}) \tag{1}$$

It gives $E = H = 0$ when $\vartheta = 0$. For any symmetrical EM beam from point O, **s**ymmetry demands its wave surfaces circular, the beam conical and $d\vartheta$ small enough. The beam will have $E = H = 0$ at the tangent points if its lateral boundary is tangent to the line of $\vartheta = 0$. Owing to the symmetry, all these symmetrical beams from point O must have $E = H = 0$ on their whole lateral boundaries. Furthermore speaking, any other symmetrical beam from O must have the same property if its boundary is tangent to the former and so on. Then, the first important property of the symmetrical EM beams from point O is that its lateral boundary always satisfies $E = H = 0$.

Let x, y be the rectangular coordinates on the wave surfaces, $z = \rho$ be the radius vector of the beam from point O and R be the radius of wave surface. Then the wave function of a symmetrical EM wave beam from point O is

$$E(r,z,\nu,t)=E_0(r,z)\cos 2\pi(\frac{t}{T}-\frac{z}{\lambda})$$

$$(E_0 = A(\frac{r}{R})\frac{\nu^2}{z} \succ 0 \text{ , } r=\sqrt{x^2+y^2}\prec R\text{ , } 0\prec\nu\prec\infty) \tag{2}$$

We do not presuppose this wave beam has any relation with photon and quantization.

For brevity, let us call the geometrical plane that is perpendicular to the EM beam the "observation plane (O-plane)". Of course, if the beam is conical, the "O-plane" implies the concentric spherical surfaces.

Eq. (2) will excite a standing wave on the O-plane at point z . Let $t = t' - \frac{z}{c}$, the standing wave function is

$$E(r,z,\nu,t)=A(\frac{r}{R})\frac{\nu^2}{z}\cos 2\pi\frac{t}{T} \quad (0\prec r\prec R\prec\infty)$$

$$A(\frac{r}{R})_{r=R}=0 \tag{3}$$

The amplitude $A(\frac{r}{R})\succ 0$ is always even and equal to zero on the side boundary $r = \pm R$. Its Fourier series is

$$A(\frac{r}{R})=\sum_{j=1}^{\infty}b_{2j-1}\cos 2\pi(2j-1)\frac{r}{4R}\overset{let}{=}\sum_{j=1}^{\infty}b_{2j-1}\cos 2\pi(2j-1)\frac{r}{\Lambda}$$

$$(\Lambda = 4R \text{ , } |r| \le R) \tag{4}$$

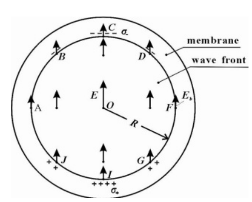

Fig. 1. Axial symmetry of $\vec{E}(E_x, E_y)$ on the $\in$ - packet and circular polarized light wave surfaces. It forms double helix EH distribution along z. (Vector $\vec{H}$ not drawn here)

Substitute Eq. (4) into (3), we have

$$E=\frac{\nu^2}{2z}\sum_{\kappa=2j-1,\,j=1}^{j\to\infty}[b_\kappa\cos 2\pi(\frac{r}{\Lambda_\kappa}-\frac{t}{T})+b_\kappa\cos(\frac{r}{\Lambda_\kappa}+\frac{t}{T})]$$

$$\overset{let}{=}E_+(r-\nabla t)+E_-(r+\nabla t)$$

$$(\Lambda_\kappa=\Lambda_{2j-1}=\frac{\Lambda}{2j-1},\Lambda=4R,\nabla=\frac{\Lambda}{T},|r|\le R) \qquad (5)$$

Here functions $E_+(r-\nabla t)$ and $E_-(r+\nabla t)$ are two compound travelling waves along opposite radial directions on the O-plane. It leads to the following three results: (A), (B) and (C):

(A). Symmetry requires all b_{2j-1} and eq. (4), (5) unrelated to the r direction. Since the radiation of vibrating $\vec{E}$ is anisotropic [3], it will make the coefficients b_{2j-1} different in the different r-directions. So the EM-wave beam must be circular polarized (important property II). It makes the time average of any coefficient b_{2j-1} and $A(\frac{r}{R})$ to be rotational symmetry on the O-planes

The wave function of such right circular polarized and conical EM- wave beam can be written as [4]

$$E(r,z,\nu,t)=E_0(r,z)e^{2\pi i(\frac{z}{\lambda}-\nu t)}$$

$$(\, r\prec R\ ,\ E_0(r,z)=A(\frac{r}{R})\frac{\nu^2}{z}\succ 0\ ,\ \nu\lambda=c\,)$$

$$E(R,z,\nu,t)=0 \qquad (\, r=R\,) \qquad (6)$$

(B). Since the compound travelling waves $E_+(r-\nabla t)$ and $E_-(r-\nabla t)$ is tangent to the O-plane and all radial, so the energy flows that pass through any cross section in a same sector are equal. That is

$$S_+(r_i,z,t)r_i\delta\theta\delta z=S_+(r_\kappa,z,t)r_\kappa\delta\theta\delta z\ \ (\,-R\prec r_i\prec r_\kappa\prec R\,) \qquad (7)$$

Poynting Vectors tangent to the O-plan is

$$S_-=S_+=\sqrt{\frac{\varepsilon_0}{\mu_0}}E_+^2=\sqrt{\frac{\varepsilon_0}{\mu_0}}\frac{A^2(\frac{r}{R})}{z^2}\nu^4\sin^2\theta\succ 0\ .$$

Let $r_i=r$, $r_\kappa\to R$ in eq. (7) and let $\lim_{r\to R}A(\frac{r}{R})=+const.\overset{let}{=}A_R$ be the limit at the side boundary; the important property III is

$$A(\frac{r}{R})=A_R\sqrt{\frac{R}{r}} \qquad (\ 0\prec r\prec R\ ,\ A_R=\lim_{r\to R}A(\frac{r}{R})\,)$$

$$A(\frac{r}{R})_{r=R}=0 \qquad (8)$$

(C). for any θ , the limits of Poynting Vectors $\lim_{r\to\pm R}E_\pm(\frac{r}{R})=A_R\frac{\nu^2}{z}\sin\theta$ at two boundaries are equal and not zero in general. Since all $\left|\cos 2\pi(2j-1)(\pm\frac{r}{4R})\right|_{r=\pm R}=0\quad(j=1,2,...)$, so eq. (5) gives us

$$\left|E_+(r-\nabla t)+E_-(r+\nabla t)\right|_{r=\pm R}\equiv 0 \qquad (9)$$

The compound travelling wave $E_+(r-\nabla t)$ and $E_-(r-\nabla t)$ tangent to the O-plane will reflect at the side boundary with 180^0 phase loss and becomes $E_-(r-\nabla t)$ and $E_+(r-\nabla t)$. It means that the train's whole side boundary surface is a surface of perfect reflection for the compound travelling wave $E_+(r-\nabla t)$ and $E_-(r-\nabla t)$. As well known, the reflection of EM wave cannot happen between the vacuum or field itself; Reflection can only happen at the interface between two different media, [3,5]. For this circumstance, the only possibility is there must be a mass less media differed from vacuum, named membrane always around the side boundary to make the perfect reflection and keeps all EM beam's energy inside the boundary surface, not to diverge (important property IV).

We may be very shocked by the "EM -beam wrapped by a side membrane" It seems to be unbelievable. But in fact, when we used to say "photon is an $h\nu$ energy packet", we really need an understood that the energy $h\nu$ must be in a very small "carrier" or "box" differed from vacuum, otherwise nothing can prevent any kind of energy to diverge.

The existence of the side membrane leads to the following four results (C_1), (C_2), (C_3) and (C_4):

3. DOUBLE HELIX DISTRIBUTION OF $\pm$ CHARGES e AND STRESSES IN THE SIDE MEMBRANE. THE SYMMETRICAL EM BEAM IS CERTAINLY QUANTIZED

(C_1) The EM momentum rate of change perpendicular to the arc ds on the boundary is

$\frac{2S(R,z,\theta)}{c}ds$. It will make a pair of circular tension $T(R,z,\theta)$ at two ends of the arc ds. According to the mechanical equilibrium condition, we have $2T\,d\varphi = 2T\frac{ds}{2R} = \frac{2S}{c}ds$. Where $d\varphi$ is the angle between the tangent and T. R Is the radius of the wave surface. So

$$T(R,z,\theta) = \frac{2R}{c}S(R,z,\theta) = \frac{2R}{cz^2}\sqrt{\frac{\varepsilon_0}{\mu_0}}A_R^2\nu^4\sin^2\theta \quad (10)$$

The tension $T(R,z,\theta)$ on the boundary cross sections distributes double helically along z-axis. Maximum stress $\Sigma_{\max}$ happens at the points A and F ($\theta = \pm 90^0$) of all the wave surfaces.

$$\Sigma_A = \Sigma_F = \Sigma_{\max} \propto \frac{R}{z^2}A_R^2\nu^4 \quad (11)$$

Maximum $\Sigma_{\max}$ forms double helix through the points A and F and along z-axis (important property V).

(C_2) Surface charge density σ_θ on the inner side of the membrane is $\sigma_\theta = D_n = \varepsilon_0 E_n$. Since $E_n = \frac{A_R}{z}\nu^2\cos\theta$, Fig. 1, so for the upper helical half the absolute value of σ_θ is

$$\sigma_\theta = \left|\varepsilon_0\frac{A_R}{z}\nu^2\cos\theta\right| \qquad (0 \le \theta \prec \pi) \quad (12)$$

The points of the same σ_θ (+ and -) on the inner side of the membrane form equal σ_θ-double helix along z-axis. It means the charges also distribute helically like the distribution of Σ and $\Sigma_{\max}$ (important property VI).

Total negative charge in the upper helical half of the membrane is

$$q = \int_z^{z+\delta}dz\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sigma_\theta R\,d\theta = 2\varepsilon_0\Phi A_R\nu^2\delta \qquad (\Phi = \frac{R}{z}) \quad (13)$$

The lower half has the same amount of $+q$. Where δ is the length of the charged membrane.

According to the quantization principle of charge, the train with $q = \pm e$ is the lowest energy train that can exist isolated in reality. The others are $\pm ke\ (k = 2,3,...)$. Let us name the one ($q = \pm e$) as elementary train. It has $\pm$ charge e, lowest energy $\in$ and shortest length δ (important property VII).

4. ELEMENTARY TRAIN IS COMPOSED OF AN $\in$-(ENERGY) PACKET AND A CONICAL ψ-(EM) WAVE

(C_3) The wave surfaces will become bigger and bigger when the conical train moves forward. Maximum radius $R_{\max}$ must exist, otherwise the train will be broken at last and no finite ($\succ \varepsilon \succ 0$) energy can go far. It contradicts the observation facts.

When the train just emitted from a point source, its energy distributes all over the conical train. After the radius grows up to the $R_{\max}$, all or at least absolute majority energy will be restricted in a cylindrical side membrane of radius $R_{\max}$. We name it as $\in$-(energy) packet. The rest of it is a closely connected conical wave, named ψ - (EM) wave. The elementary train is composed of an $\in$-(energy) packet and a conical ψ -(EM) wave. They satisfy the same circular polarized wave function, eq. (6). They move synchronically with the same phase in free space until meeting an obstacle (important property VIII).

$\in$ -packet is a circular polarized E, H field wrapped by a cylindrical side membrane with helical distributed $\pm e$. Mechanical equilibrium among the helical distributed $\pm e$ and the stresses Σ_θ in the cylindrical side membrane and the circular polarized EM field inside construct a very steady structure to keep its integrity, shape and size. The membrane is also an EM shield to prevent the external EM influences during the propagation.

We will prove that the $\in$-packet and ψ - wave structure makes the elementary train(s) to act as both a wave and a particle all the time, not "exhibit different characters for different phenomenon".

5. DERIVATION AND PROOF OF THE $\in$-PACKET'S OTHER BASIC PROPERTIES

(C_4) Since the EM-beam is very narrow, we can let $d\sigma_r = 2\pi z^2\sin\varphi\,d\varphi \approx 2\pi r\,dr$ be the area of the ring on the wave surface. According to the Maxwell theory, average energy $\in$ of the conical $\in$-packet is

$$\in=\frac{1}{2}\int_{z-\delta}^{z}dz\int_{0}^{R}\varepsilon_0\frac{A^2(\frac{r}{R})}{z^2}\nu^4 2\pi r\,dr \quad (z\prec z_0-L) \tag{14}$$

Here we suppose the energy of the membrane can be neglected in comparison. L Is the length of the elementary train or ψ - wave, L is to be decided; δ is the length of the $\in$-packet and membrane (we do not know if it is equal to L or not here); z_0 is the distance between the point source O and the end of the elementary train when its energy packet just becomes totally cylindrical. Eq. (14) and (8) give us

$$\in=\frac{1}{2}\int_{z-\delta}^{z}dz\int_{0}^{\Phi}2\pi\varepsilon_0 A_R^2\Phi\nu^4 d\varphi=\pi\varepsilon_0 A_R^2\Phi^2\nu^4\delta$$

$$(\Phi=\frac{R}{z}=\frac{R_{\max}}{z_0}) \tag{15}$$

After the $\in$ -packet becomes cylindrical, its amplitude is $A_R\sqrt{\frac{R_{\max}}{r}}\nu^2$. So, for $z\succ z_0$, $\in$-packet energy is

$$\in=\frac{1}{2}\int_{z_0}^{z_0+\delta}dz\int_{0}^{R_{\max}}2\pi\varepsilon_0 A_R^2 R_{\max}\nu^4 dr=\pi\varepsilon_0 A_R^2 R_{\max}^2\nu^4\delta \tag{16}$$

According to the law of energy conservation, Eq. (15) and (16) must equal, it leads to $z_0=1m$ for any ν . Any elementary trains of different frequencies spend the same time t_0 to become cylindrical:

$$t_0=\frac{z_0}{c}=\frac{1}{c}\sec \qquad (z_0=1m) \tag{17}$$

It is the Important property IX. Eliminate L from Eq. (13), (16) and let $q=e$, we have

$$\in=h\nu \tag{18}$$

$$h=\frac{\sqrt{3}}{4}ceA_R \tag{19}$$

h Here is an undecided coefficient independent of frequency ν . The energy that the $\in$-packet carries is proportional to the frequency ν (important property X).

Quantization of EM energy is a consequent inference of the Maxwell EM theory itself as Einstein expected when he was alive. In fact, in 1905, Einstein first proposed that energy quantization was a property of EM radiation itself.

The pivotal question was then: how to unify Maxwell's wave theory of light with experimentally observed particle nature? The answer to this question occupied the rest of Einstein's life, [6,7] although it was solved by the quantization way: Quantum electrodynamics and its successor. It is a pity that these theories paid little attention to the photon structure and the mechanism of spin. The work of this paper shows that the direction Einstein insisted is very instructive.

According to the special relativity $\in=mc^2$, [6] the definition of inertia moment and eq. (16), the $\in$-packet's moment of inertia about z-axis on the O-plane is

$$I=\frac{\delta}{2}\int_{0}^{R_{\max}}r^2\frac{\varepsilon_0}{c^2}A_R^2R_{\max}\nu^4 2\pi\,dr=\pi\varepsilon_0A_R^2R_{\max}^4\nu^4\frac{\delta}{3c^2}=\frac{\in R_{\max}^2}{3c^2} \tag{20}$$

During a beam of circular polarized light is incident on an absorbing surface, classical EM theory predicts that the surface must experience a torque. The calculation gives the torque T per unit area as [2,5]

$$\mathrm{T}=\frac{\mathrm{I}}{2\pi\nu} \tag{21}$$

Irradiance I of the beam is the power per unit area that the unit surface absorbs every second.

Since EM energy is quantized as proved in (C), let N be the number of $\in$-packets that hit the unit surface every second. So, N is the number of $\in$-packets in the cube $1(m^2)\times c(m)$ of the train that hits the unit surface with c in a second. Total spin and total energy of the $\in$-packets that the unit surface absorbs in a second is $\mathrm{T}=N\Sigma$ and $\mathrm{I}=N\in$ respectively. Where Σ and $\in$ are the $\in$-packet's spin and energy. So

$$\Sigma=\frac{\in}{2\pi\nu} \tag{22}$$

According to the definition of particle's angular momentum, $\Sigma=2\pi\nu I$ and eq. (20), (22), we have

$$R_{\max}=\frac{\sqrt{3}\,c}{2\pi\nu} \tag{23}$$

For visible light, if we take $\lambda=6\times10^{-7}m$, then $R_{\max}$ is $1.7\times10^{-7}m$. [8,9] The area $\pi R_{\max}^2$ of $\in$-packet's cross section is really very small. It is a measure of the $\in$-packet's area of collision.

On the other hand, Eq. (18) and (22) give us the spin of the $\in$-packet with right helical structure: [2,10]

$$\Sigma = \frac{h}{2\pi} \overset{let}{=} \hbar \tag{24}$$

$\hbar$ Is a constant disregard of frequency ν. It is the translation motion of the helical structure of E, H plus intrinsic speed c make the $\in$ -packet's constant spin $\hbar$ and $\in = h\nu$ (Speed condition is understood, because the condition $\nu\lambda = c$ in eq. (6) must be satisfied)

If the elementary train is left circular polarized, its spin $-\hbar$ is in the opposite direction of helix on the O-planes independent of its travel direction +z or -z. $\in$-Packet's spin $\pm$, right or left is decided by the direction of its **E,H** structure, not other factors. $\in$ -Packet can take only one fixed spin $\hbar$ or $-\hbar$ (important property XI).

So for the entanglement of two photons, it must be like a pair of gloves.

On the other hand, since $z_0 = 1m$ and $\Phi = \frac{R_{\max}}{z_0} = R_{\max}$; let $q = e$, then Eq. (13) and (19) give:

$$\delta = \frac{\pi e^2}{4\varepsilon_0 h\nu} \tag{25}$$

$$\frac{\delta}{R_{\max}} = \frac{\sqrt{3}\pi^2 e^2}{6c\varepsilon_0 h} \approx 0.04 \tag{26}$$

The $\in$-packet is a thin slice of circular polarized **E-H** field floating on the front of the ψ -wave.

Since the $\in$ -packet possesses energy $\in = h\nu$, definite shape and volume, it is really a particle. So we can use Einstein relativistic formula $\in^2 = p^2c^2 + m_0^2c^4$ to it and let $m_0 = 0$, it gives [11,6]

$$p = \frac{h}{\lambda} \qquad (\vec{p} = h\vec{\kappa}\,,\ \kappa = \frac{1}{\lambda}) \tag{27}$$

The $\in$ -packet possesses a momentum $p = h/\lambda$ (important property XIII).

$\in$-Packet as a mass less particle of speed c, it of course can play the role of force carrier for EM force.

Owing to the helical distributed $\pm e$ and extremely small size, the external electric and magnetic fields of the $\in$-packet's $\pm e$ will offset each other, so the $\in$- packet is "charge free" and "magnetic free". The $\in$-packets with different spin directions are no way to distinguish. They are rigorously identical. This must be the reason why the $\in$-packets obey B-E statistics (important property XIV) [11,12].

On the other hand, if an $\in$ -packet has big enough energy $\succ 2mc^2$ and assaulted by a heavy nucleus in the pair production [13,14], strong compression will make the field intensity **E** and energy density $E^2\,(\propto A_R^2)$ in the $\in$-packet greatly increased. It will cause the $\in$-packet split equally along the double helix of maximum stress $\Sigma_{\max}$ $\propto A_R^2$, eq. (11), and become two equal parts with different sign of charge $+e$ and $-e$. So the unformed $\pm$ charged particles produced are certainly symmetrical and possess intrinsic spin $\hbar/2$ but with different sign $\pm$ of charges e [15]. Besides, Just after the $\in$- packet split, owing to the repulsion between the same sign of charges, the continuously distributed half-circular charged element $-dq$ (and $+dq$) will split into two $-2\times\frac{dq}{2}$ (and $+2\times\frac{dq}{2}$) and locate at two ends of the membrane diameter on every cross section. The semi-circular charge $-e$ (like electron) and $+e$ (like positron) has now become the charged double helixes along the side membrane. Translation of $+e$ and $-e$ double helixes will produce different z-direction of magnetic **B** on the O-planes, It will cause the unformed $\pm$ particles move along opposite z-direction to depart and become two formed $\pm$ charged elementary particles at last.

Differed from the photon, $-$ and $+$ charged elementary particles, all fall into two categories. Each category carries the same sign of charge $-e$ or $+e$ but different directions of helical structure of charge. They will produce different directions of magnetic **B** on the O-planes for the same translational motion. Two categories of these particles are distinguishable by their **B** directions. This is why such particles they differed from the photons that satisfy B-E statistics, these particles satisfy F-D statistics [11,12].

If two electrons of different categories reside in the same orbital inside the atom or molecule, owing to the repulsion of opposite directions of B, the repulsive forces will adjust two electrons to be stable equilibrium; if these two electrons are of the same category, attractions from two sides of the electron will make their equilibrium unstable and break the equilibrium. So, if two electrons are in stable equilibrium at a quantum state, they must be of different categories. Similar reasons are also available to the fermions. It seems this is the reason for the Pauli Exclusion Principle.

The classical formula of total power P emitted by a vibrating electric dipole $\mathrm{M}=\mathrm{M}_0\cos 2\pi\nu t$ is [3]

$$\mathrm{P}=\frac{16\pi^3\mathrm{M}_0^2\nu^4}{3\varepsilon_0 c^3}\overset{(19)}{=}(\frac{64\sqrt{3}\pi^3\mathrm{M}_0^2}{9\varepsilon_0 c^4 e A_R}\nu^3)h\nu\overset{let}{=}N h\nu \quad (28)$$

Here N is the number of the elementary trains radiated every second. The source radiates $N\propto\nu^3$ photons every second and every photon has energy $\in=h\nu$, so its radiative power is $\mathrm{P}\propto\nu^4$. The classical difficulty in the explanation of $\in=h\nu$ and $\mathrm{P}\propto\nu^4$ is no longer existed.

Eq. (16) gives us

$$\frac{\in}{\delta}=\pi\varepsilon_0\nu^4 A_R^2 R_{\max}^2=\varsigma(\nu) \quad (29)$$

For definite ν, $\in/\delta$ is constant. It means if a ν-train possesses higher energy $n\in=nh\nu$, it must have a longer membrane length $n\delta$ of the $\in$-packets series (property XV).

Elementary train(s) and photon(s) possess almost all the same basic properties. It seems we can say such elementary EM-train is really a photon and vice versa. At least they are equivalent.

6. EXPERIMENTAL EVIDENCE FOR THE EXISTENCE OF ψ-WAVE. $\in$-PACKET AND ψ-WAVE PLAYS A ROLE TOGETHER IN THE PROCESS OF EMISSION AND ABSORPTION

For Einstein spontaneous emission decrease of atom population in energy level 2 is

$$dN_2=-AN_2dt \quad (30)$$

A Represents transition probability per second. Then we have $N_2=N_{20}e^{-At}$ and the radiative lifetime. $\tau_{spon}=\frac{1}{N_{20}}\int_0^{N_{20}}t\,dN_2=\frac{1}{A}$ [1,10]. In the viewpoint of that the photon is an elementary train, to radiate a train needs a lasted time τ_0. Quantization of charge makes any spontaneous photon (elementary train) of the same ν having the same τ_0 and train length $L=c\tau_0$. We suppose we can take $\tau_0\approx\tau_{spon}=\frac{1}{A}$.

The elementary train radiated from level 2 is $E=E_0 e^{-2\pi i(\nu t-\frac{z}{\lambda})}$ ($E_0^2=h\nu$, $0\le t\le\tau_0$). But in the natural spectral line there is a frequency width $\Delta\nu$. It is owing to the finite length $L=c\tau_0$ of the train. Fourier analysis gives $\tau_{spon}\Delta\nu\ge 1$, so we have $\Delta\nu\approx\frac{1}{\tau_{spon}}\approx\frac{1}{\tau_0}\approx A$. Like A, $\Delta\nu$ is also a measure of the time τ_0.

Usually radiative lifetime is of order $10^{-8}\to 10^{-9}\,\mathrm{sec}$. So (a) elementary train length $L=c\tau_0$ is about 0.1 $\leftrightarrow$ 1 meter ($\succ\succ\delta$); and (b) since the visible light frequency ν is $(8\to 4)\times 10^{14}\,1/\mathrm{sec}$. It gives $\frac{\Delta\nu}{\nu}\approx 10^{-7}\to 10^{-6}$ [16].

The width $\Delta\nu$ of natural spectral line means the electron radiates a continuous spectrum between $\nu-\frac{1}{2}\Delta\nu$ and $\nu+\frac{1}{2}\Delta\nu$. If we divide $\Delta\nu=(2n+1)\delta\nu$ into $2n+1\ (\succ\succ 1)$ parts of $\delta\nu$, the spectrum can be interpreted as that the electron radiates $2n+1$ spectral lines of energy $\delta\in_\kappa=\frac{h}{2n+1}(\nu_\kappa+\kappa\delta\nu)$, $(\nu_\kappa=\nu,\ \kappa=0,\ldots\pm n)$ simultaneously. The total energy radiated is

$$\in=\frac{h}{2n+1}\sum_{\kappa=0}^{\pm n}(\nu_\kappa+\kappa\,\delta\nu)=h\nu\pm\frac{h}{2n+1}\sum_{\kappa=1}^{n}\kappa\,\delta\nu=$$

$$=h\nu\pm\frac{n(n+1)}{2(2n+1)}h\,\delta\nu\cong h(\nu\pm\frac{n}{4}\delta\nu)\cong h(\nu\pm\frac{\Delta\nu}{8})\cong h\nu \quad (31)$$

It implies the continuous spectrum is equivalent to three EM-train $E=E_0 e^{-2\pi i(\nu t-\frac{z}{\lambda})}$, $\Delta E_+=\Delta E_0 e^{-2\pi i(\nu t+\frac{\Delta\nu}{8}t-\frac{z}{\lambda})}$ and $\Delta E_-=\Delta E_0 e^{-2\pi i(\nu t-\frac{\Delta\nu}{8}t-\frac{z}{\lambda})}$. They possess energy $(E_0)^2=h\nu$ and $(\Delta E_9)^2\cong\frac{h\Delta\nu}{8}$ respectively. Since $e^{2\pi i\frac{\Delta\nu}{8}t}+e^{-2\pi i\frac{\Delta\nu}{8}t}=2\cos(\frac{\pi\Delta\nu}{4}t)$, so we have

$$\Delta E = \Delta E_0 e^{-2\pi i(\nu t+\frac{\Delta\nu}{8}t-\frac{z}{\lambda})} + \Delta E_0 e^{-2\pi i(\nu t-\frac{\Delta\nu}{8}t-\frac{z}{\lambda})}$$

$$= 2\Delta E_0 \cos(\frac{\pi t}{4}\Delta\nu)\ e^{-2\pi i(\nu t-\frac{z}{\lambda})} \quad (32)$$

The time t to radiate a spontaneous photon train from level 2 is τ_0, since $\tau_0\,\Delta\nu \geq 1$ and $\cos\pi/4 = \sqrt{2}/2$ so

$$\Delta E \cong \sqrt{2}\ \Delta E_0 e^{-2\pi i(\frac{t}{T}-\frac{z}{\lambda})} \quad (33)$$

Since a spontaneous photon is composed of an $\in$-packet and a ψ-wave, and $h\nu$ is solved by the Schrodinger equation, it must be carried by the $\in$-packet, so ΔE, eq. (33) must be the wave function of ψ-wave. ψ-Wave possesses a real energy $(\sqrt{2}\Delta E_0)^1 \cong \frac{h\Delta\nu}{4}$. It is decided by the existence of $\Delta\nu$; On the contrary, it is the finite length $L = c\tau_{spon} = c\tau_0$ of the elementary wave train to make the width $\Delta\nu$. So, the line width $\Delta\nu$ and the existence of ψ-wave are interdependent. Existence of $\Delta\nu$ is really an important experimental evidence for the existence of ψ-wave. It is also an experimental evidence for the photon's $\in$-packet and ψ-wave structure. Eq. (32) can be rewritten into a more accurate form:

$$\in = \frac{h}{2n+1}\sum_{\kappa=0}^{\pm n}(\nu_\kappa + \kappa\delta\nu) = h\nu \pm \frac{h}{2n+1}\sum_{\kappa=1}^{n}\kappa\delta\nu =$$

$$= h\nu \pm \frac{n(n+1)}{2(2n+1)}h\delta\nu \cong h(\nu \pm \frac{n}{4}\delta\nu) \cong h(\nu \pm \frac{\Delta\nu}{8}) = h\nu + \frac{h\Delta\nu}{4} \quad (34)$$

Since the photons from the universe all possess the $\Delta\nu$ so $\frac{h\Delta\nu}{4}$ is a loss-free energy for the ψ-wave to interfere and propagate; therefore the factor $\frac{1}{z}$ in the amplitude of ψ-wave, eq.(6) will never be zero, It implies we will have $\frac{1}{z} \to \frac{1}{z_{00}}$ and the ψ-Wave will also become cylindrical at last.

On the other hand, after the electron in ground state absorbs a $h\nu$-photon, it has the ability to jump up and make the spectral line width $\Delta\nu$ in the level 2. It means the electron in level 1 also possessing the energy of ψ-wave. It must be absorbed before jump. So, both $\in$-packet and ψ-wave are emitted together and absorbed together in the atom and molecular [8].

7. PACKET AND ψ-WAVE PLAY A ROLE TOGETHER IN THE DOUBLE SLIT EXPERIMENTS

For the single slit Fraunhofer diffraction, the irradiance distribution in the focal plane is $I_1 = I_0(\sin\beta/\beta)^2$ [2]. Since the space behind the slit is uniform, the $\in$-packet as a particle has straight trajectory here. For simplify, let us restrict our discussion in small β region, so we can ignore the influence of diffraction. Then, above formula also represents the angular distribution of the number of $\in$-packet(s) behind the slit Δx it passes. This symmetrical deflection is owing to the symmetrical momentum $\pm\Delta p_x$ of the Heisenberg uncertainty principle at Δx [17].

For the double slit experiment, $\in$-packet as a particle, it cannot split into two parts to pass two slits. Only the $\in$-packet with its ψ-wave and the ψ-wave from another slit can form the interference pattern in the focal plane. The irradiance distribution function of double-slit is $I_2 = I_0(\frac{\sin\beta}{\beta})^2\cos^2\gamma$ [2]. Here the factor $(\sin\beta/\beta)^2$ constitutes the envelop of the interference fringes given by the term $\cos^2\gamma$. If $\cos^2\gamma \equiv 1$, that is if no second ψ-wave (and its $\in$-packet) arrives at the focal plane or without the second slit, then $I_2 = I_1$, two irradiance distribution functions become the same. So the envelop really represents the angular distribution of the $\in$-packet(s) behind a slit Δx it passes, if we ignore the $\in$-packet(s) from the second slit. It also represents the number distribution of the $\in$-packet(s) from the first slit that arrives at the focal plane. It is the phase difference γ between the $\in$-packets and the ψ-wave from another slit at the focal point decided the relative degree of brightness of the fringes: brightest if $\cos^2\gamma \equiv 1$; darkest if $\cos^2\gamma \equiv 0$; the other is median bright. So the brightness of the fringe is not totally decided by the number of $\in$-packets (photons) that arrived at the point; it is also and even mainly decided by the phase difference between the $\in$-packets and the coherent ψ-wave from another slit at the point they meet. This phase difference restricts the ability or activity of the photon(s) (The probability of photon(s) to interact with matter).

So if we ignore the $\in$-packet(s) from the second slit, a half of the envelop I_2 : $\frac{I_0}{2}(\frac{\sin\beta}{\beta})^2$ really represents the angular distribution of the $\in$-

packet(s) behind the first slit Δx it passes. It also represents the number distribution of the $\in$ -packet(s) from the first slit that arrives at the focal plane. It is the phase difference γ between the $\in$ -packets and the ψ -wave from another slit at the focal point decided the relative degree of brightness of the fringes: brightest if $\cos^2\gamma \equiv 1$; darkest if $\cos^2\gamma \equiv 0$; the other is median bright. So the brightness of the fringe is not totally decided by the number of $\in$ -packets (photons) that arrived at the point; it is also and even mainly decided by the phase difference between the $\in$ -packets and the coherent ψ -wave from another slit at the point they meet. This phase difference restricts the ability or activity of the photon(s) (The probability of photon(s) to interact with matter).

The analysis gives us an interesting property of the $\in$ -packet: Phase difference between the $\in$ -packet and another coherent ψ -wave at the point they meet can restrict, even eliminate the $\in$ -packet ability or activity, the probability to interact with matter: Perfect restriction when $\gamma = 180^0$; no restriction when $\gamma = 0^0$; partial restriction when $0 \prec \gamma \prec 180^0$. We wonder if we can use this property in the experiences and applications.

Since $\in$ - packet and ψ -wave satisfy the same wave function eq. (6) (only difference is in the amplitude $E_0(r,z) = A(\frac{r}{R})\frac{v^2}{z}$ that contains different factor $\frac{1}{z_0}$ or $\frac{1}{z_{00}}$). Their partial derivatives are

$$\frac{h^2}{4\pi^2}\frac{\partial^2 E(x,y,z,t)}{c^2\partial t^2} = -\frac{(h\nu)^2}{c^2}E_0(x,y,z)e^{-2\pi i(\nu t - \frac{z}{\lambda})} \quad (\in \overset{(18)}{=} h\nu) \qquad (35)$$

$$\frac{h^2}{8m\pi^2}\frac{\partial^2 E(x,y,z,t)}{\partial z^2} = -\frac{1}{2m}(\frac{h}{\lambda})^2 E_0(x,y,z)e^{-2\pi i(\nu t - \frac{z}{\lambda})} \quad (p \overset{(28)}{=} \frac{h}{\lambda}) \qquad (36)$$

For the relativistic particles, we can find the solution of $\in, p$ from the eq. (35), (36) and substitute into Einstein's $\in^2 - p^2c^2 = m_0^2c^4$, it leads to the Klein-Gordon equation

$$\frac{\partial^2 E}{c^2\partial t^2} = \frac{\partial^2 E}{\partial z^2} - \frac{m_0^2c^2}{\hbar^2}E \quad (E = E(x,y,z,t)) \qquad (37)$$

Let $m_0 = 0$, The Klein-Gordon equation here becomes the Schrodinger equation for the photon:

$$\frac{\partial^2 E}{c^2\partial t^2} = \frac{\partial^2 E}{\partial z^2} \quad (E = E(x,y,z,t)) \qquad (38)$$

Therefore, Maxwell wave equation is really the Schrodinger equation for the photon. ψ -Wave is the probability wave for the $\in$ - packet(s).

8. EXISTENCE OF LONGER TRAIN $nh\nu$ IN THE EINSTEIN STIMULATED EMISSION [1,11]

For stimulated emission, the number of downward transitions from energy level 2 to level 1 in dt is

$$dN_2 = -Bu_\nu N_2 dt\ . \qquad (39)$$

There is no reason to prevent us to introduce the idea of average stimulated radiative lifetime:

$$\bar{\tau}_{stim} = \frac{1}{N_{20}}\int_0^{N_{20}} t\, dN_2 = \frac{1}{Bu_\nu} \qquad (40)$$

Average EM train length for the stimulated emission is $\bar{L}_{stim} = c\bar{\tau}_{stim} = \frac{c}{Bu_\nu}$.

Since photon's $\in$ -packet and ψ - wave are all circular polarized E, H field of speed c and satisfy the same wave function; their possible differences are the magnitude of amplitude A_R and length L , so, similar to the eq. (15) the energy of the ψ - wave is $\in = \pi\varepsilon_0 A_R^2\Phi^2\nu^4 L$. Then similar relation $\in / L = \varsigma(\nu)$ like eq. (29) still holds. For definite ν , $\in / L$ is constant. Plus eq. (40) and $\tau_{spon} = \frac{1}{A}$, it gives us $\frac{\bar{\in}_{stim}}{\in_{spon}} = \frac{\bar{L}_{stim}}{L_{spon}} = \frac{\bar{\tau}_{stim}}{\tau_{spon}} = \frac{A}{Bu_\nu}$. Since $\in_{spon} = h\nu$, we have the average energy of the stimulated trains $\bar{\in}_{stim} = \frac{A}{Bu_\nu}h\nu$. For natural light source and visible ray $\frac{A}{Bu_\nu} = (e^{\frac{h\nu}{\kappa t}} - 1) \succ\succ 1$, so we have

$$\bar{\in}_{stim} = \kappa h\nu \quad (k = \frac{A}{Bu_\nu} \succ\succ 1). \qquad (41)$$

Average energy $kh\nu \succ\succ h\nu$ implies that the stimulated atoms may emit the trains of energy:

$h\nu$ … $kh\nu$ … $n(\succ k)h\nu$. Stimulated atom spends more time to radiate a longer train with bigger energy.

Where do these extra energies storage in the atoms before emission? Fourier analysis gives us $\tau_{spon}\Delta\nu_{spon} \geq 1$ and $\bar{\tau}_{stim}\Delta_{stim} \geq 1$. Since $\tau_{spon} = \frac{1}{A}$, $\bar{\tau}_{stim} = \frac{1}{Bu_\nu}$ and eq. (40), the width of energy level 2 for the spontaneous emission $\Delta\in_{spon}$ and stimulated emission $\Delta\in_{stim}$ are

$$\Delta\in_{spon} = h\Delta\nu_{spon} \geq hA \; . \tag{42}$$

$$\Delta\in_{stim} = h\Delta\nu_{stim} \geq hBu_\nu \tag{43}$$

Because $\frac{A}{Bu_\nu} \succ\succ 1$, so $\Delta\in_{stim} \prec\prec \Delta\in_{spon}$. It means that the energy is stored by the compression of the width of atom's energy level. Narrower width stores more energy, it spends more time to radiate a longer train with bigger energy just like a "spring" being compressed.

Eq. (39), (40) are also available for the level 1 by replaced subscript 2 to 1. Level 1 and 2 have the same average stimulated radiative lifetime. It infers that the electron at level 1 can accept a train of $h\nu$ or $2h\nu$, or…, and its ψ -wave directly (then even can accumulate them or vice versa) from the radiation field to compress energy level 1 and then jump to level 2 with energy $nh\nu$ $(n = 2,3,...)$ and corresponding ψ -wave. This result further approves above assertion that the $\in$ -packet and the ψ -wave play a role together in the processes of emission and absorption.

It infers that the EM field in thermal equilibrium is composed of steady distributed $2\pi n\nu$ $(n = 1,2,3,...)$ standing ψ -waves (Fourier modes) and $nh\nu$ $(n = 1,2,3,...)$ energy packets (the state of n photons) [18]. This result indicates the correctness and facticity of the Max Plank postulate. It led to the Plank's law in 1900 and opened the quantum epoch [17,19].

Laser and maser seem to be really the EM-trains with energy $nh\nu$ $(n \succ\succ 1)$. Its coherent length is nL .

Since an electron can only possess one of the spin $\pm\frac{\hbar}{2}$, so the electron at ground state in the atom can only absorbs a photon with opposite sign of spin $\mp\hbar$, then jumps to level 2 and becomes an electron with spin $\mp\frac{\hbar}{2}$. If this electron continues to absorb a photon $h\nu$ to compress energy level 2 and recover to its original spin $\pm\frac{\hbar}{2}$, the total spins of the two absorbed photons must be zero. Then we can easy arrive at a conclusion that the spin of the long stimulated photons train emitted with energy $nh\nu$ is $+\hbar$, $-\hbar$ or zero. On the contrary, if the laser is composed of n identical photons of same phase, its spin will be $+n\hbar$ or $-n\hbar$. This difference of assertions can be checked in the experiments we suppose.

9. CONCLUSION

The main purpose of the paper is trying to find out the possible structure of photon and its mechanism to make photon quantized and its basic properties. It seems the purpose has been successfully achieved.

According to above study, we can conclude that photon is composed of an $\in = h\nu$ (energy) packet accompany with a conical ψ - (EM) wave. The energy packet is a small and thin slice of circular polarized E-H field (light) wrapped by a cylindrical side membrane with helically distributed $\pm e$. Mechanical equilibrium between $\pm e$ and stresses Σ in the side membrane and the E-H field inside construct a very steady structure to keep its integrity and energy. $\in$ -Packet is proved to possess almost all the basic properties we used to know for the photon, like $\in = h\nu$, spin $+\hbar$ or $-\hbar$ etc. It can be a force carrier for the EM force. Since spin $\pm$ is decided by the direction of the photon helical structure, entanglement between two photons with different spin $+\hbar$ and $-\hbar$ is like a pair of gloves. Helical distributions of $-e$ (or $+e$) and $\pm e$ decide the charged elementary particles and photon to be distinguishable (by vector B) or not and to obey different statistics, B-E statistics or F-D statistics. The different distributions of charge $-e$ (or $+e$) and $\pm e$ also decide the particle to obey the Pauli Exclusion Principle or not [11].

The $\in$ -packet is a small and thin slice of circular polarized E-H field floating on the front surface of the ψ -wave. They move synchronically with the same phase until meeting the obstacle or interface. $\in$ - -Packet and ψ - wave play a role together in the processes of emission, absorption and interference. Such structure makes the photon to act as both a wave and a particle all the time, not "exhibit different characters for different phenomenon".

We hope this research will be useful in the investigating optoelectronic devices.

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Author has declared that no competing interests exist.

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