"$h\nu$-Energy Packet floating in Front of the Wave Beam" Hybrid Structure of Photon and its Self-Interference in the Single Photon Double-Slits Experiment

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Author's contribution

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

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ABSTRACT

In the single photon double slits experiment, what mechanism makes the interference? Whether it is owing to the external factor or the photon has a special structure it can interfere photon itself to make the interference pattern? Because the photon is a quantum of EM radiation as Einstein proposed, so we start the study from an EM wave beam (an EM radiation). Under the demand of the symmetry and quantization, we found the wave beam is certainly circular polarized and covered by a side membrane. There is a pair of $\pm$ charges $\pm q$ and the circular tension $T(R,z,\theta)$ distributes double helically along the side membrane. Quantization of charges requires $\pm q = \pm e$ or $\pm q = \pm ke$ ($k = 2,3,\cdots$). Mechanical equilibrium among the helical distributed $\pm e$ or $\pm q = \pm ke$, tension T and the circular polarized EM field inside construct a steady structure to keep the quantized EM beam integrity, shape and size. Its energy $h\nu$ concentrates in a cylindrical packet of radius $R_{\max}$ and length δ, named $\in$-(energy) packet. With the aid of Einstein theory of spontaneous emission, we proved that the photon is consisted of the $\in = h\nu$ (or $\in = nh\nu$) energy packet and accompany with a conical ψ-(EM) wave beam; $\in$-packet floats in front of the ψ-wave. It is such hybrid structure that makes photon self interference in the double slits experiment.

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1. INTRODUCTION

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 [1-2].

When a single photon passes through a slit Δx, owing to the $\pm \Delta p_x$ of the Heisenberg uncertainty principal $\Delta x \Delta p_x \geq 1$, it will be deflected in general. When we use single photon one after another to shot a slit for a long time, the angular distribution of total single photons behind the slit Δx must be symmetrical and continuous; because behind the slit is free space, photon moves straight here, so, these single photons must also distribute symmetrically and continuously on the screen at last. But in the real single photon double slit experiments, it is not continuous, but an interference pattern. For the dark fringe where did the photon go? The only possible explanation is that it must be "interfered".

For the single photon, where does interference come from? Whether it is owing to the external factor or the photon has a special structure it can interfere photon itself to make the interference pattern? Because the photon is a quantum of EM radiation as Einstein proposed, so we start the study from an EM wave beam (an EM radiation) to see, under the demand of symmetry and quantization, what structure the EM wave beam should be, what properties it will possess, what mechanism makes it quantized and how to explain the experimental phenomena include the single photon double-slits interference

We have tried to find the answer for over ten years, progress was gradually. We first found the symmetrical EM wave beam in the field of a vibrating electric dipole at point O is certainly circular polarized and has a side membrane. There is a pair of $\pm$ charges distrbute helically on the side membrane. Quantization principle of charge makes the symmetrical wave beam quantized. Further derivation and calculation prove such quantized EM wave train has almost all the basic properties as same as the photon, we think we can try to treat it as a photon and vice versa.

For the purpose to explain self interference in the single photon double slids experiment, we need the contents published before to be reference and basis [3-9]. It is added here just for the convenience of editors, reviewers and reader.

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

The field intensity of a vibrating electric dipole at point O is [10]

$$E(\rho, \vartheta, \nu, t) = \sqrt{\frac{\mu_0}{\varepsilon_0}} H = \frac{\pi M_0 \nu^2}{c^2 \varepsilon_0 \rho} \sin \vartheta \cos \omega (t - \frac{\rho}{c}) \tag{1}$$

Where ρ is the radius vector; ϑ is the angle between ρ and z-axis. $\varpi = 2\pi\nu$ is the angular frequency. M_0 is the electric moment of the dipole.

For any symmetrical wave beam from point O, symmetry requires the beam conical, its wave surfaces circular and $d\vartheta$ small enough. Eq. (1) gives $E = H = 0$, when $\vartheta = 0$. All the beams from point O will have $E = H = 0$ at the tangent points if its side boundary is tangent to the line of $\vartheta = 0$. Because of the symmetry, all such symmetrical beams must have $E = H = 0$ on their whole side boundaries. Furthermore speaking, other symmetrical beams from O must have the same property if its boundary is tangent to the former and so on. So, whole side boundary of any symmetrical EM wave beams from point O always has $E = H = 0$ (The first important property).

Let us call the geometrical plane perpendicular to the EM beam as "observation plane (O-plane)". Of course, if the beam is conical, the "O-plane" means the concentric spherical surfaces.

Let x, y and $r (\leq R)$ be the rectangular coordinates and radius on the wave surfaces; and $z = \rho$ be the radius vector of the beam from source O. The symmetrical plane wave

$$E(r, z, \nu, t) = E_0(r, z) \cos 2\pi (\frac{t}{T} - \frac{z}{\lambda}) \quad (\quad E_0 = A(\frac{r}{R})\frac{\nu^2}{z} \succ 0 \quad ,$$

$$r = \sqrt{x^2 + y^2} \leq R, \quad 0 \prec \nu \prec \infty) \tag{2}$$

will excite a standing wave on the O-plane at point $z = z_0$. If we let $t = t' - \frac{z}{c}$, the standing wave function can be written as

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

$$A(\frac{r}{R})_{r=R} = 0 \ \text{(According to the property I) (3)}$$

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

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

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

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

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

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

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). Since the radiation of vibrating $\vec{E}$ is anisotropic, [10] it will make the coefficients b_{2j-1} different in the different **r**-directions, so for the symmetrical wave beam it must be circular polarized (The second important property). It makes the time average of any coefficient b_{2j-1} to be rotational symmetry on the O-planes

The wave function of a (right) circular polarized conical wave beam can be written as:

$$E(r,z,v,t) = E_0(r,z_0)e^{2\pi i(\frac{z}{\lambda}-vt)}$$

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

$$E(R,z,v,t) = 0 \quad (\ r = R) \tag{6}$$

(B). Because the compound traveling 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 sector are all equal. That is

$$S_+(r_i,z,t)r_i\,\delta\theta\delta z = S_+(r_k,z,t)r_k\,\delta\theta\delta z$$

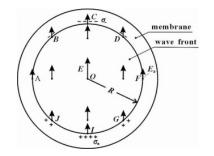$$(-R \prec r_i \prec r_k \prec R) \tag{7}$$

The Poynting Vectors tangent to the O-plan is

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

and $r_k \to R$ 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; then we have the third important property as follow:

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

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

The symmetrical vectors $E_0(r,z) = A(\frac{r}{R})\frac{v^2}{z} \succ 0$ on the $z = z_0$ wave surface are drawn in Fig.1[10]

Fig. 1. Central symmetry of $\vec{E}(E_x, E_y)$ on the wave surface of the $\in$ -packet and circular polarized light. It forms double helix distribution along z- axis

(C). For any θ, the limits of Poynting Vectors $\lim_{r \to \pm R} E_\pm(\frac{r}{R}) = A_R\frac{v^2}{z}\sin\theta$ at two boundaries are equal and not zero in general. But owing to 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:

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

The compound traveling wave $E_+(r - \nabla t)$ and $E_-(r - \nabla t)$ along radial directions on the O-plane will reflect back at the side boundary with 180^0 phase loss to become $E_-(r - \nabla t)$ and $E_+(r - \nabla t)$. It implies that the train's whole side boundary must be a surface of perfect reflection for the traveling waves $E_+(r - \nabla t)$ and $E_-(r - \nabla t)$. Because the reflection of EM wave can not happen between the vacuum or field itself; Reflection can only

happen on the interface between two different media, Under the circumstance here, the only possibility is there must be a mass less media differed from vacuum, we call it as membrane, always around the side boundary of the EM beam to make the perfect reflection and keeps the beam's energy inside the boundary, not to diverge to zero (The fourth important property).

We may be very shocked by the "EM beam being wrapped by a side membrane" It seems unbelievable. But, as a matter of fact, when we said "photon has energy $h\nu$", we really need an understood that the energy $h\nu$ must be in a very small "carrier" differed from vacuum, otherwise nothing can prevent any kind of energy diverge to zero.

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

3. DOUBLE HELICES DISTRIBUTION OF STRESSES Σ AND $\pm$ CHARGES q IN THE SIDE MEMBRANE. THE SYMMETRICAL EM BEAM IS DEFINITELY 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 cause 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 T and the tangent. R Is the radius of the beam's wave surface. Then we have

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

Maximum stress Σ_{max} happens at the points A and F ($\theta = \pm 90^0$) of all wave surfaces Fig. 1. It distributes double helically along the z-axis (The fifth important property).

If a photon's energy is $\in \succ 2mc^2$ and have assaulted by a heavy nucleus, 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 along the double helix of the maximum stress $\Sigma_{max} \infty A_R^2$, eq.(10), into two equal parts with different sign of charge $+e$ and $-e$, then a pair of $\pm$ charged elementary particles or $\pm$ charged fermions will be produced. Such structure of photon can explain the mechanism of pair production and where the $\pm$ charge $+e$ and $-e$ come from in the universe, not produced from vacuum.

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

$$\sigma_\theta = \left|\varepsilon_0\frac{A_R}{z}\nu^2\cos\theta\right| \quad (\ 0 \leq \theta \prec \pi\ ) \qquad (11)$$

The points of the same σ_θ (+ and -) on the inner side of the membrane form equal σ_θ -double helix along the z-axis. The charges also distribute helically like the distribution of Σ_{max} (The sixth important property).

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

$$q = \int_z^{z+\delta}dz\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sigma_\theta R\,d\theta = 2\varepsilon_0\Phi A_R\nu^2\delta \quad (\ \Phi = \frac{R}{z}\ ) \qquad (12)$$

The lower half has the same amount of positive charges.

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 call the train ($q = \pm e$) as elementary train; the one ($q = \pm ke$) as quantized train. Elementary train carries $\pm$ charge e , lowest energy $\in$ and shortest length δ of the membrane (the seventh important property).

(C_3) The wave surfaces of the conical elementary train will become bigger and bigger when the train moves forward. Maximum radius R_{max} of the elementary train must exist, otherwise it will diverge unceasingly; no finite ($\succ \varepsilon \succ 0$) energy can go far. It contradicts the observed facts.

When the elementary train just emitted from a point source, its energy distributes all over the conical train. After the radius grows up to R_{max}, all EM energy of the elementary train will be restricted in a cylindrical side membrane of radius R_{max} and length δ . We call it as $\in$ -(energy) packet of the elementary train. Include the above

properties; this is the eighth important property of the elementary train.

Actually, we have noticed that there may be a possible opposing opinion about the existence of R_{max}: "The conical wave beam and its energy can go far, because the energy of a conical wave beam can collapse to a point when it is measured". Indeed, this opinion may be right for the phenomena on earth; but it can not explain the phenomena from the universe. For the light beam from a star in deep universe, if it is a conical wave, it will cover any big celestial body, such as the sun; how to calculate the deflection angle through the sun? So this opposing opinion is not available in general.

Therefore $\in$-packet is a circular polarized E, H field wrapped by a cylindrical side membrane with radius R_{max}, length δ and helical distributed $\pm e$. Mechanical equilibrium among the helical distributed $\pm e$ and tension $T(R, z, \theta)$ in the cylindrical side membrane and the circular polarized EM field inside construct a steady structure to keep its integrity, shape, size and energy. The membrane is also an EM shield to prevent external EM influences during it moves in the space.

So far, we have no reliable enough evidence to judge that the length δ of the $\in$-(energy) packet is equal to or shorter than the length L of the elementary train. If they have the same length, the $\in$-packet is just like a "bullet"; if it is shorter, then the $\in$-packet is floating in front of the conical remaining wave of the elementary train; for the second situation, the $\in$-packet and conical remaining wave have the same wave function except amplitude. In other words, if $\delta \prec L$, the elementary train has a hybrid structure: $\in$-(energy) packet floating on the front of the conical remaining wave beam" structure. Is it equal or shorter? Please refer to chapter V.

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

(C_4) Since $d\vartheta \approx 0$ as mentioned above, the elementary train 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 its wave surface. According to Maxwell theory, average energy $\in$ of the conical elementary train can be written as

$$\in = \frac{1}{2}\int_{z-\delta}^{z}dz\int_{0}^{R}\varepsilon_0\frac{A^2(\frac{r}{R})}{z^2}v^4 2\pi r\, dr \quad (R \prec R_{max}, z \prec z_0) \quad (13)$$

Here we suppose the energy of the membrane can be neglected in comparison. δ Is the length of the $\in$-packet and charged membrane; z_0 is the distance between the point source O and the end of the elementary train when the $\in$-packet just becomes totally cylindrical. Substitute eq. (8) into eq. (13), it gives

$$\in = \frac{1}{2}\int_{z-\delta}^{z}dz\int_{0}^{\Phi}2\pi\varepsilon_0 A_R^2\Phi v^4 d\varphi = \pi\varepsilon_0 A_R^2\Phi^2 v^4\delta \quad (\Phi = \frac{R}{z} = \frac{R_{max}}{z_0}) \quad (14)$$

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

$$\in = \frac{1}{2}\int_{z_0}^{z_0+\delta}dz\int_{0}^{R_{max}}2\pi\varepsilon_0 A_R^2 R_{max}v^4 dr = \pi\varepsilon_0 A_R^2 R_{max}^2 v^4\delta \quad (15)$$

Law of energy conservation requires that Eq. (15) and (16) must be equal, it leads to $z_0 = 1m$ for any v. All elementary trains of different v spend the same time t_0 to become cylindrical:

$$t_0 = \frac{z_0}{c} = \frac{1}{c}\sec \quad (z_0 = 1m) \quad (16)$$

This is the ninth important property of the $\in$-packet.

Take the square of eq. (12), let $q = e$ and eliminate δ from the Eq. (12), (15), we have

$$\in = hv \quad (17)$$

$$h = \frac{\sqrt{3}}{4}ceA_R \quad (18)$$

h Is a constant unrelated to the frequency v. Eq. (17) and (18) mean that the energy of the $\in$-packet is proportional to the frequency v; Obviously, constant h is just the famous Planck Constant (The tenth important property). [11-12].

Therefore, quantization of EM energy is a consequent inference of the Maxwell EM theory itself as Einstein expected. The work in this paper shows the direction Einstein insisted is very instructive.

According to the definition of inertia moment, $\in = mc^2$ and eq. (15), the $\in$-packet's moment of inertia about z-axis is

$$I = \frac{\delta}{2}\int_0^{R_{max}} r^2 \frac{\varepsilon_0}{c^2} A_R^2 R_{max} v^4 2\pi\, dr = \pi\varepsilon_0 A_R^2 R_{max}^4 v^4 \frac{\delta}{3c^2} \overset{(15)}{=} \frac{\in R_{max}^2}{3c^2} \quad (19)$$

On the other hand, 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 τ per unit area as [10,13].

$$\tau = \frac{I}{2\pi v} \quad (20)$$

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

Because the EM energy is quantized as proved in (C), let N be the number of the $\in$-packets that hit the unit surface every second. In fact, 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 velocity c per second. Total spin and total energy of the $\in$-packets the unit surface absorbs in a second is $\tau = N\Sigma$ and $I = N\in$; Substitute them into eq. (20), we have the relation between the spin Σ and energy $\in$ of the $\in$-packet:

$$\Sigma = \frac{\in}{2\pi v} \quad (21)$$

According to the definition of particle's angular momentum, $\Sigma = 2\pi v I$ and eq. (19) and (21), we have the radius of the $\in$-packet:

$$R_{max} = \frac{\sqrt{3}c}{2\pi v} \quad (22)$$

On the other hand, since $\Phi = \frac{R_{max}}{z_0} = R_{max}$, if we let $q = e$ in the square of eq. (12) and take eq. (15) and (17) into account, at last we have

$$\delta = \frac{\pi e^2}{4\varepsilon_0 h v} \quad (23)$$

$$\frac{\delta}{R_{max}} = \frac{\sqrt{3}\pi^2 e^2}{6c\varepsilon_0 h} \approx 0.04 \quad (24)$$

Eq. (24) shows that the $\in$-packet is a very thin slice of the circular polarized E-H field.

For visible light, if we take $\lambda = 6\times10^{-7}m$, then R_{max} is $1.7\times10^{-7}m$ and $\delta \approx 0.04 R_{max} \overset{(25)}{\approx} 7\times10^{-9}m$. For visible light, the $\in$-packet is a very thin and small piece of EM field. The area πR_{max}^2 of the $\in$-packet cross section is about $10^{-14}\,m^2$. It is a measure of the $\in$-packet's area of collision. It might be useful in the problems of photon collision with elementary particles.

On the other hand, Eq. (18) and (22) give us the spin of the $\in$-packet with right helical structure: [1,8]

$$\Sigma = \frac{h}{2\pi} \overset{let}{=} \hbar \quad (25)$$

$\hbar$ Is a constant unrelated to frequency v. It is the translation motion of the E, H helical structure plus intrinsic speed c makes $\in = hv$ and constant spin $\hbar$ of the $\in$-packet. (Speed condition is understood, because the condition $v\lambda = c$ in eq. (6) must be satisfied)

It is evident, if the $\in$-packet has left helical structure, its spin is $-\frac{h}{2\pi} = -\hbar$. So $\in$-Packet's spin $\pm$, right or left is decided by the direction of its E, H structure, not other factors. An $\in$-packet can take only one fixed spin $\hbar$ or $-\hbar$ (The eleventh important property). So for the entanglement of two $\in$-packets, it is just like a pair of gloves. Right (structure) is still right and left is still left no matter how far the distance they apart.

Since the $\in$-packet possesses energy $\in = hv$, definite shape and volume, it is really a particle. Einstein relativistic formula $\in^2 = p^2 c^2 + m_0^2 c^4$ and let $m_0 = 0$, it gives [8-9].

$$p = \frac{h}{\lambda} \quad (\vec{p} = h\vec{k}, \quad k = 1/\lambda) \quad (26)$$

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

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

Due to the helical distributed $\pm e$ and extremely small size, the external electric and magnetic far 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 directions of spin are no way to distinguish. They are rigorously identical and obey B-E statistics (The fourteenth important property) [8-9].

Eq. (16) gives us

$$\frac{\in}{\delta} = \pi \varepsilon_0 v^4 A_R^2 R_{max}^2 = \varsigma(v) \tag{27}$$

For definite v, $\in/\delta$ is constant. It means that for the quantized train like laser and maser, because it possesses higher energy $n\in = nhv$, so it must have a longer coherence length $n\delta$, not bigger cross section (The fifteenth property) [2,10].

The elementary train ($\in$-packet) has so many basic properties as same as the photon, we think we can try to treat it as a photon and vice versa.

5. EXPERIMENTAL EVIDENCES FOR THE EXISTENCE OF ψ-WAVE AND " hv (ENERGY) PACKET FLOATING IN FRONT OF THE ψ-WAVE" HYBRID STRUCTURE OF PHOTON

For the Einstein spontaneous emission, let A be the transition probability per second, then the decrease of atom populations in energy level 2 is $dN_2 = -AN_2 dt$. It gives $N_2 = N_{20} e^{-At}$ and the radiative lifetime: [13,3,6].

$$\tau_{spon} = \frac{1}{N_{20}} \int_0^{N_{20}} t\, dN_2 = \frac{1}{A} . \tag{28}$$

Under the viewpoint of that the photon is an elementary train; to radiate an EM-train need a lasted time τ_0. Quantization of charge will cause all the spontaneous photons (elementary trains) of the same v have the same τ_0 and the same train length $L = c\tau_0$.

On the other hand, as well known, there are two bright yellow spectrum lines from the sodium lamp in the experiment. Their wavelengths are 5895.92x10^{-10}m ($v \approx 5.088 \times 10^{14}$ 1/sec) and 5889.95 x10^{-10}m ($v \approx 5.093 \times 10^{14}$ 1/sec) respectively. Frequency difference between two yellow spectrum lines is about $\Delta v_{Na} \approx 5 \times 10^{11}$ 1/sec .

To radiate a photon is a result of quasi-periodic vibration (Δt finite). According to the Fourier analysis, the intrinsic line width Δv of the spectral line is due to the finite length $c\Delta t = c\tau_0$ of

the elementary train (photon). They satisfy $\Delta v \Delta t \geq 1$. Therefore, if the elementary train length equals to the length of the $\in$-packet $\delta \overset{(24)}{\approx} 7 \times 10^{-9} m$, then $\Delta v \geq \frac{c}{c\Delta t} = \frac{c}{\delta} \approx 4.3 \times 10^{16} \ggg \Delta v_{Na}$; the intrinsic line width Δv of a sodium yellow spectrum line will be far greater than $\Delta v_{Na} \approx 5 \times 10^{11}$ 1/sec ; it will cover another sodium yellow spectrum line. In other words, if the elementary train length is equal to the length of $\in$-packet, only one very broad yellow spectrum line can appear in the experiment, not two! This is a strong experimental evidence to prove that the length L of elementary train is far longer than the length δ of the $\in$-packet. Let us name the remainder wave beam of the elementary train as ψ-wave (beam). The elementary train is consisted of a hv (energy)-packet and a conical ψ-wave. It forms "a very small and slim hv energy packet floating in front of the ψ-wave" hybrid structure (The sixteenth important property).

6. SELF-INTERFERENCE OF A PHOTON IN THE SINGLE PHOTON DOUBLE SLIT EXPERIMENT [7,14].

For the single photon double slit experiment, we often supposed that a bright spot on the screen means a photon passes the slit and arrives at the point; dark spot means no photon arrives. But in fact, the actual situation seems not like this. Because (1) It is the $\pm \Delta p_x$ of the Heisenberg uncertainly principal $\Delta x \Delta p_x \geq 1$ gives the single $\in$-packets (photons) a symmetrical and continuous deflection through the slit, so the angular distribution of the single $\in$-packets behind the slit Δx must be also symmetrical and continuous; and (2) behind the slit is free space, photon moves straight here, so the single $\in$-packets (photons) must also distribute symmetrically and continuously on the screen that is parallel to the plane the slits locate; but (3) what appears on the screen is bright and dark interference fringes, not continuous bright pattern. It means the degree of brightness and darkness on the screen is not purely proportional to the number of $\in$-packets that arrived at the point; (4) when the single photon faces the double slits, the width $R_{max} \approx 1.7 \times 10^{-7} m$ of the $\in$-packet is far smaller than the width of a slit, as a particle it is impossible to split into two to pass two slits respectively. Only the $\in$-packet with its ψ-wave beam and the

second ψ-wave beam through another slit can form interference pattern on the screen. So, the bright and dark fringes are the result of self-interference, the interference between the $\in$-packet (with its ψ-wave) and the ψ-wave from another slit; as to the single $\in$-packet (single photon) itself, it just locates randomly at a point on the pattern. So, it is the phase difference between the $\in$-packet and the coherent ψ-wave from another slit and the number of $\in$-packet decides together the degree of brightness and darkness.

Let us emphasize that the interference do not happen between two single photons, ("two pure particles"), because (1) due to quantization, there are only two possible results of the interference for the two photons, double brightness or zero (dark), no intermediate state; (2) Time difference between two photons makes them no possibility to meet at the same point.

Due to the quantization of $\in$-packet and the energy of ψ-wave is far smaller than $h\nu$, ψ-wave has no ability to influence $\in$-packet's energy. How can the ψ-wave interfere the brightness of the $\in$-packets (photons)? The only possibility for the ψ-wave to influence the photon is to restrict the activity of the $\in$-packet (photon) that is to restrict a photon's probability to interact with matter

As a matter of fact, two beams of ψ-wave will form a distribution diagram of phase differences at all points of the space behind the double slits. The screen is just a tool to exhibit this distribution.

Besides, if we connect a slit and a point on the screen with an extended silver line, this is the path of a photon; we will found a periodic distribution of bright points and dark points along the line. The photons will display the periodic variation of its activity here.

In order to see clearly the differences between self-interference of a photon and the ordinary interference of light, we discuss the Fraunhofer diffraction.

7. SELF INTERFERENCE OF SINGLE PHOTON IN THE FRAUNHOFER DIFFRACTION

For single slit Fraunhofer diffraction, the irradiance distribution in the focal plane is

$I_1 = I_0 (\sin\beta / \beta)^2$, where $\beta = \frac{\pi b}{\lambda}\sin\theta$ [13-15]. In order to ignore the influence of diffraction, let us restrict our discussion within the small angle $\pm\theta \approx 0$ in the following. Within this angle $\sin\beta / \beta \approx 1$, $I_1 \approx I_0$ the brightness in the focal plane is uniform in this region. Because the influence factor $\sin\beta / \beta \approx 1$ of the diffraction can be ignored, so uniform brightness means the number distribution of $\in$-packets (photons) in the focal plane is also uniform here. On the other hand, since all $\in$-packets in the same θ direction behind the slit will arrive at the same point in the focal plane, so the uniform distribution of $\in$-packets in the focal plane infers that the angle distribution of the number of $\in$-packet behind the slit it passes is also uniform and symmetrical within the small angle $\pm\theta \approx 0$. This symmetrical deflection of $\in$-packets (photons) behind the slit is owing to the symmetrical momentum $\pm\Delta p_x$ of Heisenberg uncertainty principle at Δx.

For the double slit Fraunhofer diffraction, $\in$-packet (photon) as a particle, it can not split into two parts to pass two slits. Only the $\in$-packet together with its own ψ-wave beam and another ψ-wave beam through the second slit (that is split from the same original ψ-wave) can form the probability distribution pattern in the focal plane. The irradiance distribution function of the double-slit is $I_2 = I_0 (\frac{\sin\beta}{\beta})^2 \cos^2\gamma$. [13] Factor $(\frac{\sin\beta}{\beta})^2$ constitutes the envelop for the interference fringes given by the interference factor $\cos^2\gamma$. If $\cos^2\gamma \equiv 1$, it is equivalent to no second slit. Compare to the above analysis, this envelop really represents the angular distribution of the number of $\in$-packet(s) behind the slit Δx it passes. It also represents the number distribution of the $\in$-packet(s) that arrives at the focal plain.

It is the phase difference γ between the $\in$-packets and the ψ-wave beam from another slit at the focal point they meet decided the relative brightness of the fringes; the $\in$-packets and ψ-wave of the same photon occur self-interference here: brightest if $\cos^2\gamma \equiv 1$; darkest if $\cos^2\gamma \equiv 0$; the other is median bright. Differ from the ordinary interference, self-interference of single photon is not the superposition of amplitude between two wave beams; it is just a restriction. It restricts the irradiance with a factor $0 \leq \cos^2\gamma \leq 1$. The brightness of the fringe is not totally decided by

the number of $\in$-packets (photons); but 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.

Phase difference between the $\in$-packet and coherent ψ-wave beam can restrict the ability or activity (the probability of photon to interact with matter) of the photon itself. (The eighteenth important property).

8. CONCLUSION

In order to see whether the photon has a special structure to make self interference in the single photon double-slits experiment, we study an ordinary EM wave beam. Under the demand of symmetry and quantization, we found the symmetrical wave beam is definitely circular polarized and covered by a side membrane. There is a pair of $\pm$ charges $\pm q$ and the circular tension $T(R, z, \theta)$ distribute helically along the side membrane. Quantization of charges makes $\pm q = \pm e$ or $\pm q = \pm ke$. Mechanical equilibrium among the helical distributed $\pm e$ (or $\pm q = \pm ke$), tension T and the circular polarized EM field inside construct a steady structure to keep its integrity, shape and size; The EM beam's energy concentrates in a cylindrical packet, the $\in$-(energy) packet. We have derived, calculated and proved that the $\in$-packet(s) possesses very many properties that are almost as same as the basic properties of the photon(s). So, we think we can try to treat the $\in$-packet(s) as a photon. With the aid of Einstein theory of spontaneous emission we proved that the photon is consisted of an $\in = h\nu$ (or $\in = nh\nu$) -energy packet accompany with a conical ψ- (EM) wave; $\in$-packet floating on the front of the ψ-wave. It is such hybrid structure makes photon self interference in the single photon double slits experiment.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Sennian Chen. Double Helix Structure of Photon. Phys Sci Int J. 2020;24 (2):31-41.
2. Sennian Chen. Double Helix Wave-Particle Structures of Photon and Charged Elementary Particles. The Equation of Motion of the Particle with Both Intrinsic Spin and Double Helix Structure has the Same form as the Schrodinger Equation. Phys Sci Int J. 2020;24(3):43-60.
3. Sen Nian Chen. Electron's helical structure and mass radius relation. IEEE Conference Publication. IEEE Xplore; 2018.
4. Steven Weinberg, fourth Patrusky Lecture at Science Writers. Why am I dissatisfied with quantum mechanics《Global Science》(Scientific American); 2013;11.
5. Grant R. Fowles, Introduction to Modern Optics; Dover Publication, Inc., New York. 1989;219.
6. Rossi B, Optics. Reading, Mass.; Addison-Wesley; 1957.
7. Darling, David. Wave–Particle Duality". The Internet Encyclopedia of Science. The Worlds of David Darling; 2007.
   Retrieved 18 October 2008.
8. Sir Geoffrey, Ingram Taylor. Interference Fringes with FeebleLight". Prof. Cam. Phil. Soc. 1909;15:114.
9. Feynman, Richard P, Robert B, Leighton; Matthew Sands. The Feynman Lectures on Physics, Vol. 3. Addison-Wesley. 1965;1:1–1.8.
   ISBN 978-020 1021189.
10. Chen SN, What mechanism makes EM radiation quantized. Photon structure and size. PIERS in St. Petersburg; 2017.
11. Müller-Kirsten HJW. Introduction to Quantum Mechanics: Schrödinger Equation and Path Integral. US: World Scientific. 2006;14.
    ISBN 978-981-2566911.
12. Rae, Alastair IM. Quantum Physics: Illusion Or Reality?. UK: Cambridge University Press. 2004;9–10.
    ISBN 978--1139455275.
13. Chen SN.Electron's helical structure and mass radius relation. PIERS in St. Petersburg; 2017.
14. Sen Nian Chen. What mechanism makes EM radiation quantized. Photon structure and size. IEEE Conference Publication. IEEE Xplore; 2018.

15. Young's double-slit experiment with single photons and W. Rueckner, Joseph Peidle; Published 2013; Physics; American Journal of Physics. An apparatus for a double-slit interference experiment in the; 2013.