SunQM-6s1: Using Bohr atom, {N,n} QM field theory, and non-Born probability to describe a photon's emission and propagation

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Abstract

In this paper, we developed several new methods to describe a photon's emission and propagation process: 1) To explain a photon that emitted from a Bohr atom from the n=3 to n=2 electron orbit transition, we added a virtual electron that doing RF rotation in a virtual 2D orbit with n=2.43, and it can intuitively explain the frequency and the transverse wave of the photon; 2) Using the newly designed {N,n} QM field theory and the non-Born probability (NBP), we described the photon's emission and propagation process as a series excitation of a {N,n} QM field's nLL QM state from low n to high n (e.g., from the {N,n} QM field's ground state n=1, or |1,0,0> to the first excited state n=2, or |2,1,1>, then to the second excited n=3, or |3,2,2>, and then to the third excited state n=4, or |4,3,3>, …). To describe a photon (that propagated to high n in the {N,n} QM field) with a limited size, in the NBP density formula (of the nLL QM state in the {N,n} QM field), we used the multiplier n' for the exponential index so that we can describe a photon with any appropriate size that we want; 3) We hypothesized that a photon has an onion-like multi-shells physical structure (a superposition of many QM states), and has a "standard" size of about 100x of its wavelength. We explained a photon's wave-particle duality as that its out-shells have the wave character, while its inner core has the particle character. We explained a photon's double-slit experiment as that its out-shell wave's interference guided its inner core's particle motion; 4) We explored the possibility that whether the redshift (with Hubble's constant ~ 70 (km/s)/Mpc) is the natural attribute of the photon propagation; 5) Alternatively, we used only two QM states to describe a photon's emission and propagation: the ground state of {N,n} QM field |1,0,0> and the excited state of {N,n} QM field |2,1,1>, with $r_1 = c * t$, so that the speed of the light c is incorporated into the description. 6) We believe that the {N,n} QM field theory can be used for other particles' description as well. Finally, we explained the physical meaning of the matter wave's wave function as the NBP 3D distribution of a particle/celestial body's movement trajectory (that is described by the Schrodinger equation).

Key Words: Quantum mechanics, photon emission and propagation, quantum field, non-Born probability

Introduction

The SunQM study [1] ~ [16] have demonstrated that the formation of Solar system was governed by its {N,n} QM, and the non-Born probability (NBP) can be used to describe many macro-world's phenomena [17] ~ [19]. The success of the SunQM study makes us to believe that "all mass entities (from the whole universe to a single quark) can be described by Schrodinger equation and solution" (see SunQM-11 section IX). Then we extend this idea to the force field, re-classified the four fundamental forces into three pairs: G/RFg-force, E/RFe-force and S/RFs-force, and proposed a new {N,n} QM field theory (i.e., all force fields can also be described by Schrodinger equation and solution [20]). In the current paper, we try to use the new {N,n} QM field theory and NBP to describe a photon's emission and propagation process. Note: for {N,n} QM nomenclature as well as the general notes for {N,n} QM model, please see SunQM-1 section VII. Note: Microsoft Excel's number format is often used in this paper, for example: x^2 = x^2, 3.4E+12 = $3.4*10^{12}$, 5.6E-9 = $5.6*10^{-9}$. Note: The reading sequence for SunQM series papers is: SunQM-1, 1s1, 1s2, 1s3, 2, 3, 3s1, 3s2, 3s6, 3s7, 3s8, 3s3, 3s9, 3s4, 3s10, 3s11, 4, 4s1, 4s2, 6 and 6s1. Note: for all SunQM series papers, reader should check "SunQM-9s1: Updates and Q/A for SunQM series papers" for the most recent updates and corrections.

I. Using Bohr atom to explain a photon's emission process

I-a. To explain an emitted photon's frequency based on Bohr's hydrogen atom model

Figure 1a showed a standard Bohr hydrogen atom with n=3 orbit (with three periods of de Broglie wave), and with n=2 orbit (with two periods of wave). QM text books told us that an electron transition from n=3 to n=2 orbit will emit a photon with wavelength 656.1 nm (also see Table 1 column 12). Table 1 showed the detailed calculation that how an emitted photon gets its frequency (Δf) based on Bohr atom. The conception and method of the calculation has been explained before (although separately) in SunQM-4 and in SunQM-2's Table 2/Table 3. Here we combine all previous (separated) explanations into one explanation. The baseline of the explanation is:

a) The wave-particle duality told us that a QM process can be described in either a particle version or a wave version;

b) The wave mechanics told us that a wave has group velocity and phase velocity;

c) QM text books [21, 22] told us that the relationship between the particle's classical velocity and the (de Broglie) matter wave's group velocity (v_{gr}), and the phase velocity (v_{ph}) is:

$$v_{classical} = v_{gr} = 2v_{ph} \qquad \text{eq-1}$$

d) Using above information, it was concluded that the particle description can be (solely) based on $v_{classical} = v_{gr}$, and (in {N,n} QM) the (de Broglie) wave description can be (solely) based on v_{ph}.

Below is the detailed explanation:

1) Bohr atom's particle description version:

From text books, we know that in Bohr atom model (shown in Figure 1a), the electric force F_e balanced out the centrifugal force F_c, and makes the electron to rotate around a proton with speed v_n (as shown in Table 1 column 5).

$$F_e = \frac{1}{4\pi\epsilon_0}\frac{q^2}{r_n{}^2},\ F_c = m\frac{v_n{}^2}{r_n},\ F_e = F_c,\ \frac{1}{4\pi\epsilon_0}\frac{q^2}{r_n{}^2} = m\frac{v_n{}^2}{r_n},\ \text{or } v_n = \sqrt{\frac{1}{4\pi\epsilon_0}\frac{q^2}{r_n m}}, \qquad \text{eq-2}$$

The total energy (E_n) of this orbital rotating electron is calculated as

$$E_n = K_n + V_n = \frac{1}{2}mv_n{}^2 - \frac{1}{4\pi\epsilon_0}\frac{q^2}{r_n} = \frac{1}{2}mv_n{}^2 - mv_n{}^2 = \frac{-1}{2}mv_n{}^2, \qquad \text{eq-3}$$

as shown in column 6 (it is used as a control, and named as the "particle E" because it is calculated as an electron particle). Notice that this v_n is the electron's true orbital velocity (or particle's classical velocity $v_{classical} = v_{gr}$). Here are some formulas that related to the electron's group velocity:

$v_{n,gr} = \frac{v_{1,gr}}{n}$, known from traditional QM, eq-4

$\lambda_n = n\lambda_1$, defined from Bohr Model's and de Broglie wave, eq-5

$v_{n,gr} \neq \lambda_n f_{n,gr}$, assumed, but it is **WRONG!** (The correct one is eq-6)

$f_{n,ph} = \frac{v_{n,ph}}{\lambda_n} = \frac{v_{n,gr}}{2\lambda_n} = f_{n,gr}\frac{n}{2}$, $v_{n,gr} = 2v_{n,ph} = 2\lambda_n f_{n,ph} = 2\lambda_n f_{n,gr}\frac{n}{2} = n\lambda_n f_{n,gr}$, $v_{n,gr} = n\lambda_n f_{n,gr}$, deduced, eq-6

$f_{n,gr} \neq f_{1,gr}/n^2$, assumed, but it is **WRONG!** (The correct one is eq-7)

$v_{n,gr} = n\lambda_n f_{n,gr}$, $v_{1,gr} = \lambda_1 f_{1,gr}$, $v_{n,gr} = \frac{v_{1,gr}}{n}$, $n\lambda_n f_{n,gr} = \frac{\lambda_1 f_{1,gr}}{n}$, $nn\lambda_1 f_{n,gr} = \frac{\lambda_1 f_{1,gr}}{n}$, $f_{n,gr} = \frac{f_{1,gr}}{n^3}$, deduced, eq-7

Combining eq-3 and eq-4, we obtained the n to n' transition energy (i.e., the emitted photon's energy)

$$\mathrm{E_n - E_{n'}} = \frac{-1}{2}\mathrm{m v_n}^2 - \frac{-1}{2}\mathrm{m v_{n'}}^2 = \frac{-1}{2}\mathrm{m v_1}^2\left(\frac{1}{n^2} - \frac{1}{n'^2}\right), \qquad \text{eq-8}$$

2) Bohr atom's (de Broglie) matter wave description version:

Now if we treat this orbital moving electron as (de Broglie) wave, then it has wavelength (as shown in column 7)

$$\lambda_n = \frac{2\pi r_n}{n} \qquad \text{eq-9}$$

Note: here we define the group wave and the phase wave have the same wavelength.

$$\lambda_n = \lambda_{n,gr} = \lambda_{n,ph}, \qquad \text{eq-10}$$

According to the general wave mechanics, its orbital (phase) velocity

$$v_{n,ph} = \lambda_n f_{n,ph}. \qquad \text{eq-11}$$

Therefore, based on eq-1, its orbital (phase) frequency (as shown in column 8) is

$$f_{n,ph} = \frac{v_{n,ph}}{\lambda_n} = \frac{v_{n,gr}}{2\lambda_n} \qquad \text{eq-12}$$

In SunQM-2 section 1-c, we had discovered the wave version of orbital energy E_n formula

$$E_n = -Hmf_{n,ph}, \qquad \text{eq-13}$$

Where *m* is the mass (kg) of the object doing orbital movement (not the quantum number m), H= h/*m'* is the "quasi-Planck constant", and h is the Planck constant and *m'* is a mass scaling factor with unit of kg. For an orbital moving electron, its H = h/m_e = 7.274E-4 (J.s/kg) (see the original from SunQM-2 Table 2, and now is copied here in Table 1 column 9, where m_e is the mass of electron). The calculated eq-13 is shown in column 10 of Table 1. Notice that the wave version of the orbital energy E (in column 10) equals to the particle version of the orbital energy E (in column 6). Here are some more formulas that related to the electron matter wave's phase velocity:

$$v_{n,ph} = \lambda_n f_{n,ph} = n\lambda_1 \frac{f_{1,ph}}{n^2} = \frac{\lambda_1 f_{1,ph}}{n} = \frac{v_{1,ph}}{n},\ v_{n,ph} = \frac{v_{1,ph}}{n}, \text{ deduced,} \qquad \text{eq-14}$$

$$f_{n,ph} = \frac{v_{n,ph}}{\lambda_n} = \frac{v_{1,ph}}{n}\frac{1}{n\lambda_1} = \frac{v_{1,ph}}{\lambda_1}\frac{1}{n^2} = f_{1,ph}/n^2,\ f_{n,ph} = f_{1,ph}/n^2, \text{ deduced,} \qquad \text{eq-15}$$

$$2\pi f_{n,ph} = \omega_{n,ph}, \text{ (defined in SunQM-4's eq-27)} \qquad \text{eq-16}$$

Combining eq-13 and eq-15, we obtained the n to n' transition energy (i.e., the emitted photon's energy) is

$$E_n - E_{n'} = -Hmf_{n,ph} - Hmf_{n',ph} = -Hmf_{1,ph}\left(\frac{1}{n^2} - \frac{1}{n'^2}\right), \qquad \text{eq-17}$$

$$\Delta f_{n\to n',ph} = f_{n',ph} - f_{n,ph} = f_{1,ph}\left(\frac{1}{n'^2} - \frac{1}{n^2}\right), \text{ deduced,} \qquad \text{eq-18}$$

and the n to n' transition emitted photon's wavelength is

$$\lambda_{n\to n'} = \frac{c}{f_{n,ph} - f_{n',ph}} = \frac{c}{f_{1,ph}\left(\frac{1}{n^2} - \frac{1}{n'^2}\right)} \qquad \text{eq-19}$$

Here are some formulas that interchange between phase velocity and group velocity of the electron matter wave:

$$f_{n,ph} = \frac{v_{n,ph}}{\lambda_n} = \frac{v_{n,gr}}{2\lambda_n} = \frac{n\lambda_n f_{n,gr}}{2\lambda_n} = \frac{n}{2}f_{n,gr} \qquad \text{eq-20}$$

$$f_{3,ph} - f_{2,ph} = f_{1,ph}\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = \frac{-5}{36}f_{1,ph} \qquad \text{eq-21}$$

$$f_{3,ph} - f_{2,ph} = f_{1,ph}\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = f_{1,gr}\left(\frac{n}{2}\right)\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = f_{1,gr}\left(\frac{1}{2}\right)\left(\frac{1}{3^2} - \frac{1}{2^2}\right) \qquad \text{eq-22}$$

In Table 1, columns 7 through 10 showed the Bohr atom's wave description by using eq-9, eq-20, and eq-13. Columns 11 through 13 showed the transition (or emitted photon's) wavelength (by using eq-19), column 14 using column 8 to calculate $\Delta f_{n\to n\prime,ph} = f_{n\prime,ph} - f_{n,ph}$, column 15 using column 7 to calculate $\Delta f_{n\to n\prime,ph}$, column 16 using column 4 and column 3 to calculate electron's classical orbit frequency $f_{n,gr}$, column 17 using column 16 to calculate electron orbit's (phase) frequency $f_{n,ph}$, and column 18 using column 17 to calculate $\Delta f_{n,ph}$. All these calculations confirmed that eq-1 through eq-22 are correct.

This calculation gives the physical meaning of ***the emitted photon's frequency*** (based on a Bohr atom): it ***equals to the difference of orbital phase frequencies*** $\boldsymbol{\Delta f_{n\to n\prime,ph}}$ (as shown in eq-18), not the electron's classical orbit frequencies' difference $\Delta f_{n\to n\prime,gr}$. Eq-22 showed the $f_{n,ph}$ to $f_{n,gr}$ relationship for the transition of n=3 to n=2. We can see that for n=3 orbit (in Figure 1a), the phase wave's wavelength $\lambda_{n=3} = \frac{2\pi r_{n=3}}{3}$, so the electron needs to move 3 (phase) waves to finish one orbital circle (while the group wave only needs to finish one wave per orbital circle). So the higher the n, the relative shorter the $\lambda_n = \frac{2\pi r_n}{n}$ will be, and electron needs to move more (=n) phase waves to finish one orbital circle. This explains where the "n" comes from in eq-20. The "1/2" in eq-20 comes from eq-1. This n/2 factor had also been seen in SunQM-4's eq-40 (where we had made a huge effort to prove that it was not wrong).

Next, we try to see whether we can find a more intuitive physical explanation for the photon frequency $\Delta f_{n=3\to n=2,ph}$. In eq-23, eq-24, or eq-25, $\Delta f_{3\to 2,ph}$ was represented as the electron movement frequency in terms of $f_{3,gr}$, or $f_{2,gr}$, or $f_{1,gr}$, and we see the absolute value of $\Delta f_{3\to 2,ph}$ higher than that of $f_{3,gr}$ but lower than that of $f_{2,gr}$. What we want is to find a "n" orbit so that the electron in this "n" orbit rotates in the same frequency as $\Delta f_{3\to 2,ph}$, or the photon's wave frequency. Inspired by the Raman scattering explanation (where a virtual electron exciting energy state is created to help the explanation, see wiki "Raman scattering"), here we create a virtual electron orbit with a virtual quantum number "n_x", and this "n_x" satisfy all formulas (eq-1 through eq-22), except it is not an integer. Solving eq-26, we obtained n_x = 2.43. So now we have found the most intuitive explanation: for the n=3 to n=2 transition, the emitted photon has the same frequency as a electron's true orbital rotation frequency at a virtual orbit n=2.43 (notice that the value of n=2.43 is between the start n=3 and end n=2)! Thus, we can use Bohr model (or a semi-classical and semi-QM theory) to (self-consistently) explain the photon emission.

$$f_{3,ph} - f_{2,ph} = f_{3,gr}\left(\frac{n=3}{2}\right) - f_{2,gr}\left(\frac{n=2}{2}\right) = \frac{f_{1,gr}}{3^3}\left(\frac{3}{2}\right) - \frac{f_{1,gr}}{2^3}\left(\frac{2}{2}\right) = f_{1,gr}\left(\frac{1}{2}\right)\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = -\frac{5}{72} f_{1,gr} \quad \text{eq-23}$$

$$f_{2,gr} = \frac{f_{1,gr}}{2^3}$$

$$f_{3,gr} = \frac{f_{1,gr}}{3^3} = \frac{2^3}{3^3} f_{2,gr}$$

$$f_{3,ph} - f_{2,ph} = f_{3,gr}\left(\frac{n=3}{2}\right) - f_{2,gr}\left(\frac{n=2}{2}\right) = \frac{2^3}{3^3} f_{2,gr}\left(\frac{3}{2}\right) - f_{2,gr} = -\frac{5}{9} f_{2,gr} \quad \text{eq-24}$$

$$f_{3,ph} - f_{2,ph} = f_{3,gr}\left(\frac{n=3}{2}\right) - f_{2,gr}\left(\frac{n=2}{2}\right) = f_{3,gr}\left(\frac{3}{2}\right) - f_{3,gr}\frac{3^3}{2^3} = -\frac{15}{8} f_{3,gr} \quad \text{eq-25}$$

Define $f_{3,ph} - f_{2,ph} = -f_{n,gr}$, use eq-7, we have $f_{n,gr} = \frac{f_{1,gr}}{n^3}$,

$$f_{3,ph} - f_{2,ph} = f_{1,ph}\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = f_{1,gr}\left(\frac{n=1}{2}\right)\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = f_{1,gr}\left(\frac{1}{2}\right)\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = -f_{n,gr} = -\frac{f_{1,gr}}{n^3} ,$$

$$\frac{1}{n^3} = \left(\frac{1}{2}\right)\left(\frac{1}{2^2} - \frac{1}{3^2}\right), n \approx 2.43 , \quad \text{eq-26}$$

The most important part of this work is, the SunQM series studies have demonstrated that all these equations (eq-1 through eq-22, used for the electron orbit calculation) can be directly used to calculate the planet orbital movement in Solar system (see SunQM-2's Table 1, Table 2, and Table 3), and probably even the graviton emission!

(Note: In SunQM-2 section 1-c, eq-3 was written as $E_n = -Hmf_n$, because the f_n is the orbit phase frequency, so it should to be written as $E_n = -Hmf_{n,ph}$. Also in SunQM-2's Table 1, Table 2, and Table 3, all f_n should be written as $f_{n,ph}$. Also in SunQM-4 section I-c, all f_n should be $f_{n,ph}$, and all f_j should be $f_{j,ph}$).

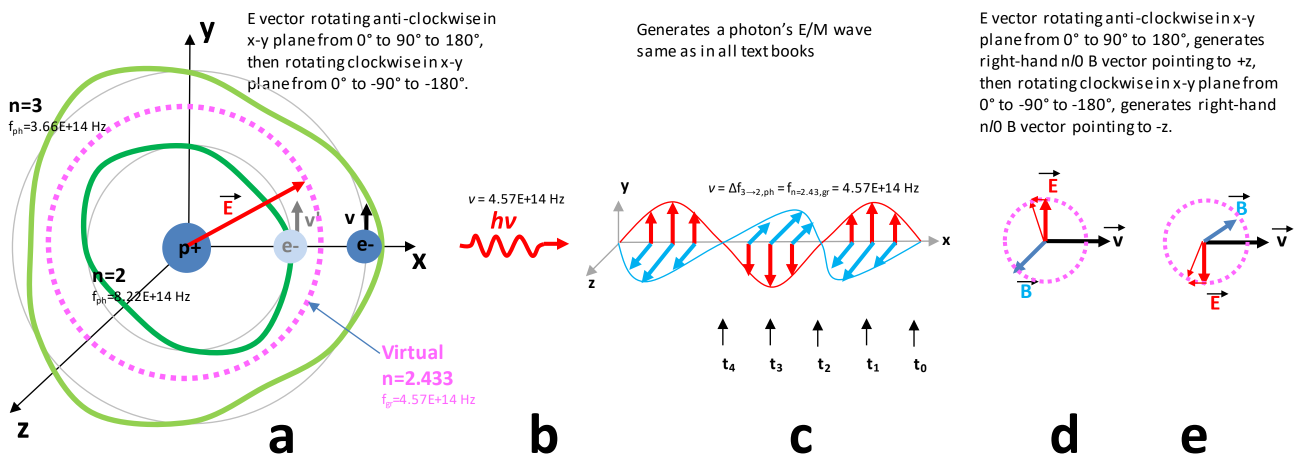


Figure 1a. A Bohr atom model's n=3 orbit (with three periods of de Broglie wave), and n=2 orbit (with two periods of wave). A virtual orbit at n = 2.43 is shown in pink color.
Figure 1b. The transition of electron from n=3 to n=2 orbit emits a photon.
Figure 1c. A propagating photon's transvers electromagnetic wave.
Figure 1d. During the 1st half-wave, $\vec{\mathbf{E}}$ vector (of a virtual electron at the virtual n=2.43 orbit) rotating anti-clockwise in x-y plane from 0° to 90° to 180°, generates right-hand n*l*0 $\vec{\mathbf{B}}$ vector pointing to +z (based on {N,n} QM field theory).
Figure 1e. During the 2nd half-wave, $\vec{\mathbf{E}}$ vector (of a virtual electron at the virtual n=2.43 orbit) rotating clockwise in x-y plane from 0° to -90° to -180°, generates right-hand n*l*0 $\vec{\mathbf{B}}$ vector pointing to -z (based on {N,n} QM field theory).

Table 1. To show how an emitted photon gets its frequency (Δf) based on Bohr atom.

	Z	orbit n =	$r_n = n^2 * r_1/Z$	$v_{n,gr}$=sqrt[e^2*Z/(4π $\varepsilon_0 m r_n$)]	**particle E** **E_n= -1/2* (1/4πε_0)* Ze^2/r_n**	$\lambda_n = 2\pi r_n/n$	$f_{n,ph} = v_{n,gr}/2/\lambda_n$	H=h/m'	**wave E** **E_n = -Hm $f_{n,ph}$**	transition	$\lambda_{n\to n'}$= c/f =hc / (E_n-$E_{n'}$)	observed or Ritz $\lambda_{n\to n'}$	Δf_{ph} $f_{n',ph}$ -$f_{n,ph}$=	photon's Δf Δf=c/λ	use f_{gr} $f_{n,gr}$= $v_{n,gr}$/ 2πr_n	$f_{n,ph}$= $f_{n,gr}$ *n/2 =	photon's Δf $\Delta f_{n,ph}$ = $f_{n',gr}$ *(n')/2 - $f_{n,gr}$ *(n)/2 =
unit			m	m/s	**J**	m	1/s	J.s/kg	**J**		nm	nm	1/s	1/s	1/s	1/s	1/s
e^- in H atom	1	1	5.29E-11	2.19E+06	**-2.18E-18**	3.32E-10	3.29E+15	7.274E-04	**-2.18E-18**						6.58E+15	3.29E+15	
e^- in H atom	1	2	2.12E-10	1.09E+06	**-5.45E-19**	6.65E-10	8.22E+14	7.274E-04	**-5.45E-19**	$\lambda_{2\to 1}$ =	121.50	121.57	2.47E+15	2.47E+15	8.22E+14	8.22E+14	2.47E+15
e^- in H atom	1	3	4.76E-10	7.29E+05	**-2.42E-19**	9.97E-10	3.66E+14	7.274E-04	**-2.42E-19**	$\lambda_{3\to 1}$ =	102.52	102.57	2.92E+15	2.92E+15	2.44E+14	3.66E+14	2.92E+15
										$\lambda_{3\to 2}$ =	656.12	656.28	4.57E+14	4.57E+14			4.57E+14
virtual e-	1	2.433	3.13E-10	8.99E+05											4.57E+14		

Note: E represents energy (not electric field vector).

I-b. Using a Bohr-RF model to explain an emitted photon's transverse electromagnetic wave

From the electrodynamics text books, we see that a photon can be described as a transvers electromagnetic wave (which can be deduced out from the Maxwell's equations). Here we want to know, can we use the newly designed {N,n} QM field theory to explain the emitted photon's transvers electromagnetic wave (shown in Figure 1c) based on Bohr atom (shown in Figure 1a)? The answer is "yes", if we use the Bohr-RF model, but not the original Bohr model.

In our original Bohr model (Figure 1a), we have (practically) assumed that during photon emission (in +x direction) all n orbits are in x-y plane and rotate anti-clockwise. Looking along x-axis in opposite direction of photon's propagation, we see the proton-electron electric field $\vec{\mathbf{E}}$ vector oscillates up and down along y-axis with the oscillation frequency equals to an virtual electron doing orbital rotation at a virtual n=2.43 orbit (see Figure 1a and 1c), so the $\vec{\mathbf{E}}$ part (both vector direction and oscillation frequency of this virtual electron) fits photon's transverse wave well. However, according to {N,n} QM field theory (in SunQM-6), the uni-directional anti-clockwise spinning $\vec{\mathbf{E}}$ vector (in Figure 1a) will generates nl0 $\vec{\mathbf{B}}$ vector pointing only to +z, and will never points to -z (see Figure 1c). So we have to modify the original Bohr model to accommodate this.

The electron movement in a hydrogen atom is in complete RF (at any n orbit), so when we degenerate an electron's xyz-3D RF movement into a xy-2D RF movement, we should see the electron's orbit movement has 50% probability in anti-clockwise and 50% probability in clockwise at any time. In the emitted photon wave explanation, it can be (and it should be) explained as the first half of the photon wave correlates to the anti-clockwise (n=2.43) virtual orbit moving (virtual) electron generated $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$, and second half of the photon wave correlates to the clockwise (n=2.43) virtual orbit moving (virtual) electron generated $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$. Therefore, we name the Bohr model in Figure 1a (with the first half circular orbit in anti-clockwise, and the second half circular orbit in clockwise) as the **Bohr-RF** model, because it incorporated the 2D RF character. In the old days (before SunQM was discovered, and when QM was only for the micro world), the Bohr model was said incorrect due to its orbital angular momentum $\overrightarrow{\mathbf{L}_{\mathrm{n=1}}} = \hbar$, while Schrodinger QM has $\overrightarrow{\mathbf{L}_{\mathrm{n=1}}} = 0$ (see SunQM-1 Table 1 and SunQM-2 Table 6). Now we know that this is because in the micro world, all n QM states (of a hydrogen atom's n orbital electron) are in complete RF (with ~ 100% mass occupancy in the n orbit space shell), so if we need to use a 2D orbit to describe, then we have to use the Bohr-RF model because its $\overrightarrow{\mathbf{L}_{\mathrm{n=1}}} = 0$ (and not to use the Bohr model, because Bohr model correlates to <1% mass occupancy)! On the other hand, for a self-spinning macro world QM with < 1% mass occupancy (the 3D orbit movement is degenerated in to 2D), the Bohr model is still valid. For example, Mars planet in the current Solar system can be described by {2,1//6} QM orbit with n=1, and the orbital angular momentum > 0. However, for a self-spinning macro world QM with ~100% mass occupancy (e.g., a pre-Sun ball at size of {2,1//6}), things become more complicated if we want to use a 2D orbit description at r = {2,1}. We probably need to use Bohr-RF model to describe the RF part of the pre-Sun ball at r = {2,1}, and use Bohr model to describe the self-spin of pre-Sun ball at r = {2,1}. The bring home message is: Bohr model is for <1% mass occupancy, so it does not contain the RF information, and Bohr-RF model is for ~100% mass occupancy, so it does contain the RF information.

In this way, we have the final version of the most intuitive explanation based on Bohr-RF model (as shown in Figure 1): **the n=3 to n=2 transition emitted photon's transvers electromagnetic wave (in +x direction) directly correlates to a virtual electron doing a RF rotation in a (xy-2D) virtual orbit with n=2.43, with its $\vec{\mathbf{E}}$ vector spinning anti-clockwise from 0° to 90° to 180° that generates right-hand n*l*0 $\vec{\mathbf{B}}$ vector pointing to +z, and followed by its $\vec{\mathbf{E}}$ spinning clockwise in x-y plane from 0° to -90° to -180° and generating right-hand n*l*0 $\vec{\mathbf{B}}$ vector pointing to -z**. By looking Figure 1c from t_0 to t_1 to t_2, we see that the $\vec{\mathbf{E}}$ vector looks like spinning anti-clockwise from 0° to 90° to 180°, and from t_2 to t_3 to t_4, the $\vec{\mathbf{E}}$ vector looks like spinning clockwise from 0° to -90° to -180°. This view become more obvious when we look at the animated photon wave propagation as shown in wiki "Electromagnetic radiation".

Alternatively, we can explain the $\vec{\mathbf{E}}$ vector clockwise spinning from 0° to -90° to -180° (in Figure 1a) as the induced $\vec{\mathbf{E}}$ vector caused by an original $\vec{\mathbf{E}}$ vector spinning from 180° to 270° to 360° (for induced $\vec{\mathbf{E}}$ or $\vec{\mathbf{B}}$, see Lenz's Law in Giancoli's text book "Physics for Scientists & Engineers with Modern Physics", 4th ed. 2009, p759, Figure 29-2a).

Notice that in the Bohr-RF model, when the virtual electron moved in a virtual orbit for 360°, its $\vec{\mathbf{E}}$ vector spun only for a half circle, and after the virtual electron moved 720°, its $\vec{\mathbf{E}}$ vector finished a complete circle. So the RF effect caused kind of "Mobius strip" effect. Also recall that eq-41-SunQM-3s11 $\omega_{\mathrm{n,ph}} = \left(\frac{\mathrm{n}}{2}\right)\omega_{\mathrm{n}}$ correlates to the spin quantum number s = n/2 (see SunQM-4 section I-c). Then, does RF (and/or $\omega_{\mathrm{n,ph}}$) have something to do with Einstein's hidden variable?

II. Using {N,n} QM field theory and non-Born probability (NBP) to describe a photon's emission and propagation process

II-a. A general time-dependent probability density formula for Schrodinger equation's solution

From the general quantum mechanics text book, we learned that a hydrogen atom's proton-electron system can be described by Schrodinger equation

$$i\hbar \frac{\partial}{\partial t}\Psi\,(r,\theta,\varphi,t) = \left[\frac{-\hbar^2}{2m}\nabla^2 + V\,(r,\theta,\varphi,t)\right]\Psi\,(r,\theta,\varphi,t) \qquad \text{eq-27}$$

Under certain physics condition (e.g., hydrogen atom, etc.), Schrodinger equation (as a linear partial differential equation) can be solved by separating the variables so that we can find solutions that are simple products of

$$\Psi(r,\theta,\varphi,t) = R(r)\,\Theta(\theta)\,\Phi(\varphi)\,T(t) \qquad \text{eq-28}$$

In developing {N,n} QM (as shown in the SunQM series articles [1] ~ [20]), we discovered that our Solar system can also be described by Schrodinger equation and solution (as shown in eq-27 and eq-28). Furthermore, we hypothesized that all the re-classified force fields (G/RFg-force, E/RFe-force, S/RFs-force) can also be described by Schrodinger equation and solution (see SunQM-6). Also, we realized the rotation diffusion (or RotaFusion, or RF, see SunQM-2 for details) in θφ-2D-dimension, and it explained why Ψ function in θ- and φ-dimensions are usually grouped together as spherical harmonics

$$\Theta(\theta)\,\Phi(\varphi) = Y_{\theta\varphi}(l,m) = Y(l,m) \qquad \text{eq-29}$$

so that the traditional time-independent probability density formula for Schrodinger equation is usually written as

$$r^2\,|\Psi(r,\theta,\varphi)|^2 = r^2\,|R_r(n)|^2\,|Y_{\theta\varphi}(l,m)|^2 = r^2\,|R(n)|^2\,|Y(l,m)|^2 \qquad \text{eq-30}$$

In SunQM-4, we showed that the general time-dependent probability density formula for Schrodinger equation should be something like

$$r^2\,|\Psi(r,\theta,\varphi,t)|^2 = r^2\,|R(r)|^2\,|\Theta(\theta)|^2\,|\Phi(\varphi)|^2\,|T(t)|^2 \qquad \text{eq-31}$$

In the current article, we further assumed that T(t) function can be simplified as the direct production of

$$T(t) = T(t_r)T(t_\theta)T(t_\varphi) \qquad \text{eq-32}$$

where and $T(t_r)$ is the time-dependent function of the radial wave function R(r), $T(t_\theta)$ is the time-dependent function of the wave function Θ(θ), and $T(t_\varphi)$ is the time-dependent function of the wave function Φ(φ). This leads to a more simplified time-dependent probability density formula for Schrodinger equation:

$$r^2|\Psi(r,\theta,\varphi,t)|^2 = r^2|R(r,t)|^2\,|\Theta(\theta,t)|^2\,|\Phi(\varphi,t)|^2 = r^2|R(r)|^2|T(t_r)|^2\,|\Theta(\theta)|^2|T(t_\theta)|^2\,|\Phi(\varphi)|^2\left|T(t_\varphi)\right|^2 \qquad \text{eq-33}$$

Notice that eq-33 can be either Born probability or NBP.

In SunQM-4, for the time-dependent orbital movement of planets around Sun, we actually studied a special case of eq-33 with $T(t_r) = T(t_\theta) = 1$,

$$r^2|\Psi(r,\theta,\varphi,t)|^2 = r^2|R(r)|^2\,|\Theta(\theta)|^2\,|\Phi(\varphi,t)|^2 = r^2|R(r)|^2\,|\Theta(\theta,t)|^2\,|\Phi(\varphi,t)|^2\left|T(t_\varphi)\right|^2 \qquad \text{eq-34}$$

This is because in our simplified model, a circular orbital moving planet must be in nLL QM state (meaning in |n,*l*,m>, *l* = n-1 and m = n-1, see SunQM-3s1), and it has no time-dependency in either r-dimension or θ-dimension, and only has the time-dependency in φ-dimension. Also, because Born probability's conjugated-squaring calculation cancels out all φ-dimensional function, and automatically degenerated a θφ-2D QM into a θ-1D QM, we cannot use Born probability to describe a planet's circular orbital movement in φ-dimension. Therefore, we have to use the non-Born probability $|\Phi(\varphi)|^2_{NBP}|T(t_\varphi)|^2_{NBP}$ to describe. Then to keep the described planet as a spherical shape, we have to use NBP for both r- and θ-dimensional probability calculation. Therefore, eq-34 becomes

$$r^2|\Psi(r,\theta,\varphi,t)|^2_{NBP} = r^2|R(r)|^2_{NBP}\,|\Theta(\theta)|^2_{NBP}\,|\Phi(\varphi,t)|^2_{NBP} = r^2|R(r)|^2_{NBP}\,|\Theta(\theta)|^2_{NBP}\,|\Phi(\varphi)|^2_{NBP}|T(t_\varphi)|^2_{NBP} \quad \text{eq-35}$$

where t_φ is limited only in φ-dimension.

II-b. A time-dependent probability density formula for a photon's emission and propagation

In the current section, we want to use Schrodinger equation (eq-27) and solution (eq-33) to describe a photon's emission and propagation process (from a hydrogen atom). We can treat a photon as a particle (or a 3D wave packet) with its movement trajectory determined by the electric force field and magnetic force field (or E/RFe-force field, see SunQM-6 for definition) of a transitional electron in a Bohr atom, and this E/RFe-force field follows the Schrodinger equation (and it was named as {N,n} QM field theory in SunQM-6). (Note: This is like that a planet's movement trajectory is determined by the G/RFg-force field of the Solar system, and the G/RFg-force field also follows the Schrodinger equation).

Initially, we believe that a photon's emission (from a Bohr atom) and propagation must be in r-dimension, and there should be no θ- or φ-dimensional time-dependency, so $T(t_\theta) = T(t_\varphi) = 1$ in eq-33. Then we have

$$r^2|\Psi(r,\theta,\varphi,t)|^2 = r^2|R(r,t)|^2\,|\Theta(\theta)|^2\,|\Phi(\varphi)|^2 = r^2|R(n,l,t)|^2|Y(l,m)|^2 \quad \text{eq-36}$$

Comparing eq-35 to eq-36, we see the former one has the probability peak's time variation only in φ-dimension (to describe a planet's orbital movement), and the later one has the probability peak's time variation only in r-dimension (to describe a photon's r-dimensional propagation), it seems reasonable (see section V for more discussion). However, later on, we believed that a photon emission and propagation process should be described by eq-36 through the quantum number n increasing from n=1 to high number, and with $r_n = r_1 n^2$, so that n is the function of t, or n = n(t). Because *l* = 0 … n-1, and m = -*l*, … +*l*, so if n = n(t), then *l* = *l*(t), m = m(t), all three quantum numbers (n, *l*, m) are time dependent. Then, eq-36 need to be re-written as

$$r^2|\Psi(r,\theta,\varphi,t)|^2 = r^2|R(r,t)|^2\,|\Theta(\theta)|^2\,|\Phi(\varphi)|^2 = r^2|R(n(t),l(t))|^2|Y(l(t),m(t))|^2 \quad \text{eq-37}$$

We will discuss more on eq-37 later on.

Now, let's first choose which direction (in θφ-2D) the photon is emitted (from a Bohr atom), because this determines which Y(*l*,m) formula and what kind of probability method we should use in eq-37. Figure 2 showed the plots of spherical harmonics of Y(0,0), Y(1,m(=0,±1)), Y(2,m(=0,±1, ±2)), and Y(3,m(=0,±1, ±2, ±3)). For the photon (or particle) emission related {N,n} QM field theory, we only interested to use either nLL or n*l*0 QM modes for the description (simply because they are relatively easy to explain and calculate).

In section I, we have showed that a photon emitted from a Bohr-RF model can be either in x or in z direction (note: the y direction is equivalent to x direction for the emission). From the previous knowledge, for a standard xyz and rθφ 3D coordinate system (see wiki "Spherical coordinate system", figure "Spherical coordinates (r, θ, φ) as commonly used in physics (ISO convention)"), we know that if choosing x direction, then we need to use nLL QM mode to describe the emission, and if choosing z direction, then we need to use n*l*0 QM mode to describe the emission. Choosing n*l*0 mode has a significant disadvantage because its Y(*l*,m=0) at each *l* number has very different formula, and we can only find Y(*l*,m=0) formula up to *l* = 10 (see wiki "Table of spherical harmonics") while we need to use *l* >> 1×10^9. However, choosing nLL mode has no this kind of problem. So nLL mode is more doable than n*l*0 mode for this purpose.

For the nLL QM mode, its Born probability density formula is (see eq-34-SunQM-3s11, meaning SunQM-3s11's eq-34)

$$\left|Y\left(l = n-1, \pm m = \pm(n-1)\right)\right|^2 = [\sin(\theta)]^{2(n-1)}[\cos(\varphi)]^{2(n-1)} \quad \text{eq-38}$$

The nLL QM mode's non-Born probability (NBP) density formula has four versions (see eq-56a-SunQM-4, eq-56b-SunQM-4, eq-56c-SunQM-4, and eq-56d-SunQM-4). After using these versions several times (in paper SunQM-4, SunQM-4s1, and SunQM-4s2), we realized that the version-c is our favorite one. Thus, here we used eq-56c-SunQM-4 (see SunQM-4's Appendix C) and modified the formula to remove the φ-dimensional time-dependency (because that t is t(φ) only, and in our photon emission/propagation model, t(φ)≡0), then we obtain the final (θφ-2D) NBP density formula as

$$|Y(l = n-1, m = n-1)|^2_{NBP} \propto [\sin(\theta)]^{(n-1)}[\cos(\varphi)]^{n-1} \quad \text{eq-39}$$

with the limitation that $\frac{-\pi}{2} \le \varphi \le \frac{\pi}{2}$, and manually set NBP=0 for both $\varphi > \frac{\pi}{2}$ and $\varphi < \frac{-\pi}{2}$, to manually eliminate the extra peak of $[\cos(\varphi)]^{n-1}$ at φ=±π.

Here we need to add more explanation on Born probability (names as BP here) vs. NBP: in SunQM-4, for an orbital moving planet, it has a unidirectionally movement in φ-dimension so that we have to use NBP for φ-dimensional description. However, it has a fixed r (= r_n) and θ (= π/2), that means it has +/- bi-directionally movement that is in equilibrium (or in standing wave) in both r- and θ-dimensions (so it is good for BP description). To produce a 3D spherical probability density peak, we have to choose rθφ-3D probability either all NBP or all BP. If choosing BP, then we end with eq-56d-SunQM-4 (the version-d of nLL QM state's NBP formula) or eq-56b-SunQM-4 (the version-b of nLL QM state's NBP formula). If choosing NBP, then we end with eq-56c-SunQM-4 (the version-c of nLL QM state's NBP formula) or eq-56a-SunQM-4 (the version-a of nLL QM state's NBP formula). All these four formulas have the similar accuracy in describe the planet's orbital movement in Solar system (see SunQM-4 Tables 1, 2, 3's standard deviation), although different formula has different Eigen n' value. We also mentioned (in SunQM-4) that the version-c is our favorite because that it directly uses the wave function as its NBP function, and significantly simplified the NBP calculation (see SunQM-4s2). Similarly, in the current paper, a photon is emitted in the fixed direction at θ = π/2 and φ = 0, that means it has +/- bi-directionally movement that is in equilibrium (or in standing wave) in both θ- and φ-dimension (good for using BP description), although it has a unidirectional movement in r-dimension (good for using NBP description). Again, to produce a 3D spherical probability density peak, we have to choose rθφ-3D probability either all NBP or all BP. So here we can choose either completely BP, or completely NBP to describe this photon. In this paper, we decided to use NBP to describe a photon's emission and propagation process because that it is consistent with the (favorited) version-c of nLL QM state's NBP formula eq-56c-SunQM-4, and it directly uses the wave function as its NBP function so that it significantly simplified the NBP calculation. Furthermore, in the future, to describe a particle or a celestial body's movement, as long as it has one (or more) dimension among rθφ-3D that is in unidirectional movement, we suggest to use NBP to describe this particle or a celestial body's movement in {N,n} QM. Therefore, in this paper, we decided to choose the nLL QM mode and NBP to describe a photon's (maybe also a general particle's) emission and propagation process (in +x direction).

In SunQM-4 series articles, we have showed that for NBP, we can directly use Y(*l*,m) wave function to represent the NBP. There, NBP represents mass density, so that Y(*l*,m) positive wave represents NBP's high mass density, and Y(*l*,m) negative wave represents NBP's low mass density. In the current section, for the photon emission and propagation, the Y(*l*,m) positive wave also represents a photon's high NBP density, and Y(*l*,m) negative wave represents a photon's low NBP density.

Note-1: However, in the general case, if we are dealing with a {N,n} QM field related particle emission and propagation, we may need to define Y(*l*,m) =0 as the zero mass density. Therefore, we need to define that **a Y(*l*,m) positive wave related NBP peak represents a mass particle, and a Y(*l*,m) negative wave related NBP peak represents an anti-mass particle**. So in Figure 2 (notice that we only interesting in nLL QM mode, like |1,0,0>, |2,1,1>, |3,2,2>, |4,3,3>, etc.), the positive wave 3D peaks (equal or close to a spherical shape, in blue) represent the emitted mass particles, and the negative wave 3D peaks (also equal or close to a spherical shape, in yellow) represent the emitted anti-mass particles.

Note-2: Figure 2 revealed that for nLL mode, a Y(*l*,m=*l*) has *l* = n-1 of positive 3D (blue) peaks (may correspond to *l* = n-1 of emitted mass-particles), plus equal amount of negative 3D (yellow) peaks (may correspond to *l* = n-1 of anti-mass-particles emitted in the opposite directions of the mass particles' directions). For n*l*0 mode, when *l* is an odd number, Y(*l*,m) can be used to represent the emission of one mass particle in +z direction, and one anti-mass particle in the -z direction; and when *l* is an even number, Y(*l*,m) can be used to represent the emission of two (same) mass particle in opposite directions.

Note-3: The physical meaning of the matter wave's wave function (as Schrodinger equation's solution) was unclear until Born defined its conjugated-square as the probability. However, with the discovery of NBP, we finally find the true physical meaning of the wave function: it is the probability itself. So the Schrodinger equation describes a particle/celestial body's movement, with its movement trajectory as the (NBP) probability 3D distribution, and this NBP 3D distribution is composed by many 3D wave modes, and these 3D waves modes are the solution of Schrodinger equation, and we call this NBP 3D distribution as the wave function.

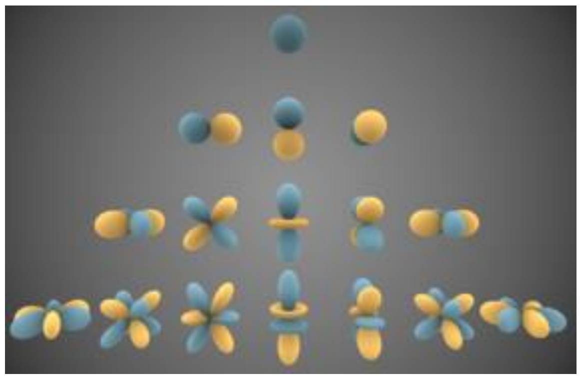


Figure 2. Visual representations of the spherical harmonics Y(0,0), Y(1,m(=0, ±1)), Y(2,m(=0, ±1, ±2)), and Y(3,m(=0, ±1, ±2, ±3)). (Notice that these are the original Y(*l*,m) wave function plot, not the Born probability plot). Blue portions represent regions where the function is positive, and yellow portions represent where it is negative. The distance of the surface from the origin indicates the absolute value of $Y_l^m(\theta,\varphi)$ in angular direction (θ,φ). Copied from wiki "Spherical harmonics". Author: Inigo.quilez. Copyright: CC BY-SA 3.0.

By now, we have decided to use NBP to describe a photon emission and propagation at +x (or at θ = π/2 and φ = 0) direction with {N,n} QM field's nLL mode and with n(t) increasing from n = 2 to n >> 2. From eq-56c-SunQM-4 (and set t(φ)≡0), we can obtain the formula for a nLL QM mode's (rθφ-3D dimensional) NBP as

$$r^2\,|\Psi(r,\theta,\varphi,t)|^2_{NBP} = r^2|R(n,L)|^2_{NBP}|Y(L,L)|^2_{NBP} \propto \left[\frac{r}{r_n}e^{\left(1-\frac{r}{r_n}\right)}\right]^n [\sin(\theta)]^{(n-1)}[\cos(\varphi\,)]^{n-1}$$

eq-40

where L = n-1, and with the limitation that $\frac{-\pi}{2} \le \varphi \le \frac{\pi}{2}$, and manually set NBP=0 for both $\varphi > \frac{\pi}{2}$ and $\varphi < \frac{-\pi}{2}$, to manually eliminate the extra peak of $[\cos(\varphi)]^{n-1}$ at φ=±π (Note: for photon emission only, not for the general particle emission). The next job is to plot out eq-40 for n = 1, 2, 3, etc., so that we can directly see how the photon emission looks like in a real 3D NBP density map (or even animated). However, it needs a true radial-plus-spherical 3D plotting software (in comparison, the MathStudio's (http://mathstud.io/) spherical 3D plotting software only plots θφ function, no r function. Also see the Appendix). We don't know whether this kind of software exist or not (if readers know, please tell me). Or even it exists, we (as a citizen scientist) probably are not able to afford it. So instead of 3D, here we plot eq-40 in rθ-2D at φ ≡ 0. When φ ≡ 0, eq-40 becomes

$$r^2|R(n,L)|^2_{NBP}|Y(L,L)|^2_{NBP} \propto \left[\frac{r}{r_n}e^{\left(1-\frac{r}{r_n}\right)}\right]^n [\sin(\theta)]^{(n-1)} \qquad \text{eq-41}$$

In a Excel spread sheet, we calculated eq-41 for n = 1, 2, 3, 6, and 14, each by using $r_1 = 0.5$, $r_n = r_1 n^2$, in range of $0 \le \theta \le \pi$, and $0 \le r \le 127.5$, and directly presented the Excel spread sheet with the color contoured NBP peaks as the rθ-2D plot (see Figure 3).

Discussions on Figure 3:
1) Under {N,n} QM field's description, we can see (intuitively) that when a photon is initially emitted at n = 2 {N,n} QM field state, and then it is propagated (from the left to the right) by increasing its {N,n} QM field's n quantum number to n=3, 4, 5, 6, etc.

2) Figure 3 only plotted eq-40 at φ = 0. Figure 2 showed at *l* = n-1 > 1, or n > 2, {N,n} QM field has more than one positive NBP peaks (in directions other than +x axis). For the Bohr-RF atom emitted photon, it started from n = 2 where there was only one NBP peak at +x direction, so for the later propagation we can reasonably ignore all other directions' NBP peaks at high n, simply because they did not exist at the initial n = 2 {N,n} QM emission field (also see section-V for a second description).

3) The NBP peaks in Figure 3 appeared not in circle, because this is the distorted rθ-2D plot (where the θ spanning is expanded at low r and compressed at high r). In Table 2, by calculating NBP in {N,n} QM field, we checked how far (or at what n) an emitted and propagated photon will become a spherical shape. (Note: In eq-21- SunQM-3s11 and eq-28- SunQM-3s11, the similar calculation method had been used for the Born probability peak's 1% max width in r- and θ-dimension). Now we used NBP in eq-40 and modified them as eq-44 (for θ-dimensional peak at 10% max width)

$$|\Theta(\theta)|^2_{\mathrm{NBP}} \propto \sin(\theta)^{(n-1)} = 0.1 \qquad \text{eq-42}$$

$$\theta' = \mathrm{acrcos}\left[0.1^{1/(n-1)}\right] \qquad \text{eq-43}$$

$$b(\theta) = r_n \sin(\theta') = r_n \sin\left(\mathrm{acrcos}\left[0.1^{1/(n-1)}\right]\right) \qquad \text{eq-44}$$

where b is the (body-size) radius of a spherical photon measured from the center of the photon to the out-surface of the photon (ball) at position r_n. In eq-44, the b is in θ-dimension only, so in Table 2 we use b(θ) to specify. Also for the φ-dimension's NBP peak at 10% max width

$$b(\varphi) = r_n \sin(\varphi) = r_n \sin\left(\mathrm{acrcos}\left[0.1^{1/(n-1)}\right]\right) \qquad \text{eq-45}$$

where b(φ) is the b is in φ-dimension only. Notice that b(φ) has the same formula as that of b(θ), so they always projected in θφ-2D dimension as a perfect circle (as a planet always projected in θφ-2D dimension as a perfect circle). Also for the r-dimension's NBP peak at 10% max width

$$r^2|R(n,L)|^2_{NBP} = \left(\frac{r_n+b}{r_n} e^{1-\frac{r_n+b}{r_n}}\right)^n = \left(\frac{r_n+b}{r_n} e^{\frac{b}{r_n}}\right)^n = 0.1 \qquad \text{eq-46}$$

Notice that both b(θ) and b(φ), or eq-44 and eq-45, are analytical results, so that we can directly calculate them in Table 2. However, for b(r), we are not able to deduce out the analytical result. So in Table 2, we can only obtain b(r) by manually adjusting its value to make eq-46 to become 0.1 (or 10%).

Using eq-44, the θ-dimensional NBP peak width b(θ) (at 10% max) is calculated for all n(s) as shown in the column 9 of Table 2. It is naturally symmetric in θ-dimension around the peak at θ = π/2 (based on the formula). In φ-dimension, it should have the same result as that of the θ-dimension (see eq-40, and column 10 of Table 2), so b(θ) ≡ b(φ). Therefore, we can use b(θ) as the averaged value for all of b(r), b(θ) and b(φ).

For b(r), we manually adjust +b value to make eq-46 to become 0.1 (see Table 2 columns 5 and 6), so that we obtained the photon's radius (of 10% maximum intensity) at r_n + b side. Then by manually adjusting -b value to make eq-46 to become 0.1, we obtain the photon's radius (of the same 10% maximum intensity) at r_n - b side (see Table 2 columns 7 and 8). We see both +b(r) and -b(r) deviates from an averaged value b(θ) = b(φ). We defined that when [±b(r) / b(θ)] ≤ 1.00 ±0.01, the NBP peak is symmetric (around the peak at r_n at 10% max). So the result of Table 2's column 11 revealed that when a photon is initially emitted at n = 2, its +b(r) (of 10% peak max) is 2.37x larger than that of b(θ). When this emitted photon propagated to n = 6^5, or about 3.2 millimeters away from the hydrogen atom, its [±b(r) / b(θ)] ≤ 1.00 ±0.01, and it is considered to be r-dimensional symmetric (around the peak at 10% max). If a NBP peak has the same b value (around its peak) in all rθφ-3D, then it is considered to be in a spherical 3D shape. So columns 5 through 12 of Table 2 showed that when a (hydrogen atom) emitted photon propagated to n = 6^5, or about 3 mm away, it became a spherical shape (at 10% peak max, under the {N,n} QM field description). Notice that this symmetry depends on what % max we used to calculate. If we use 50% max for calculation, then it will show a higher symmetry of NBP peak (than that of 10% max calculation).

4) In a more careful looking, we can see that in Table 2's calculation, the origin of the coordinate is expected to be on the electron that starting to emit the photon (or, here the n is the {N,n} QM emission field's n, named as n_{field}). In reality, it is impossible to do so. So we have to set the origin of the coordinate in Table 2 at the center of the hydrogen atom (or, here the n is the Bohr atom's n, named as n_{atom}). Obviously, $n_{field} \neq n_{atom}$. However, at high n value (e.g., $n_{field} \geq 36$ and $n_{atom} \geq 36$), $n_{field} \approx n_{atom}$. The higher the n, the more accurate they equal. So, for a Bohr atom's n=3 to n=2 transition emitted photon, the first few n(s) in Table 2 is not accurate to describe this emitted photon. Only at n ≥ 36, then Table 2 has the good accuracy to describe the emitted photon. Therefore, we greyed out the first few rows in Table 2.

5) As the result, we can say that before the photon emission, the pre-photon's {N,n} QM field (of this electron) is at ground state n=1, or |1,0,0>. During the photon emission, the photon's {N,n} QM field (of this electron) is transitioned from the ground state |1,0,0> to the 1st excited state n=2, or |2,1,1>. During the photon propagation, the photon's {N,n} QM field (of this electron) is further transitioned from the 1st excited state |2,1,1> to the higher excited states n=3, n=4, or |3,2,2>, |4,3,3>, …, one-by-one. On the contrary, a photon's absorption (by a Bohr atom) process can be explained as a photon's {N,n} QM field (of a Bohr atom's electron) from high excited nLL QM state to the lowest excited state |2,1,1>, then to the ground state |1,0,0>.

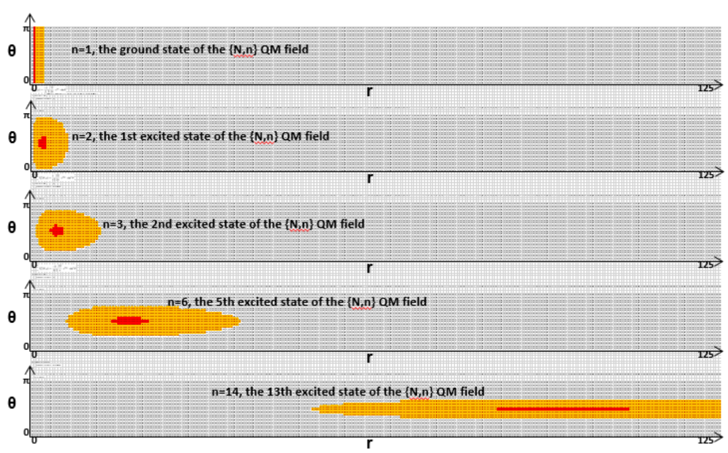


Figure 3. Calculation and plot of eq-41 by using Excel spread sheet to show a photon's emission and propagation process in rθ-2D. From top to bottom: n = 1, 2, 3, 6, and 14. The NBP value is presented as the color contour with: red > 0.9, orange > 0.4, grey < -0.4, and blue < -0.9.

Table 2. Check how far (or at what n) an emitted photon will become a spherical shape (using NBP and {N,n//6} QM field theory)

				check for the spherical shape of an emitted photon								**fix the size of an emitted photon after n=6^5**					
				b(r) fit to 10% max								**b(r) fit to 10% max**					
	r_1 =	5.29E-11	meter	**[(1 + b / r_n) * exp(- b / r_n)]^n = 0.1**								**[(1 + b / r_n) * exp(- b / r_n)]^n' = 0.1**					
				b(θ) = r_n * sin(θ') = r_n * sin(arccos{0.1^[1/(n-1)]})								**b(θ) = r_n * sin(θ') = r_n * sin(arccos{0.1^[1/(n'-1)]})**					
				b(ϕ) = r_n * sin(ϕ) = r_n * sin(arccos{0.1^[1/(n-1)]})								**b(ϕ) = r_n * sin(ϕ) = r_n * sin(arccos{0.1^[1/(n'-1)]})**					
N=	n=	$r_n = r_1 n^2$	r_n	+b(r)=	%=	-b(r)=	%=	b(θ) = r_n * sin(θ')	b(ϕ) = r_n * sin(φ)	[+b(r)] / b(θ)	[-b(r)] / b(θ)	N'=	n'=	+b(r)=	%=	b(θ) = r_n * sin(θ')	b(ϕ) = r_n * sin(φ)
		m	ly	m		m		m	m	m/m	m/m			m		m	m
0	1	5.29E-11		2.06E-10	10.0%	-5.09E-11	9.9%					0	1	2.06E-10	10.0%		
0	2	2.12E-10		5.00E-10	10.0%	-1.84E-10	10.0%	2.11E-10	2.11E-10	2.37	-0.87	0	2	5.00E-10	10.0%	2.11E-10	2.11E-10
0	3	4.76E-10		8.55E-10	10.0%	-3.76E-10	9.9%	4.52E-10	4.52E-10	1.89	-0.83	0	3	8.55E-10	10.0%	4.52E-10	4.52E-10
0	4	8.46E-10		1.26E-09	10.1%	-6.17E-10	10.0%	7.50E-10	7.50E-10	1.67	-0.82	0	4	1.26E-09	10.1%	7.50E-10	7.50E-10
0	5	1.32E-09		1.71E-09	10.0%	-9.00E-10	10.0%	1.09E-09	1.09E-09	1.56	-0.82	0	5	1.71E-09	10.0%	1.09E-09	1.09E-09
1	6	1.90E-09		2.19E-09	10.0%	-1.22E-09	10.1%	1.48E-09	1.48E-09	1.48	-0.83	1	6	2.19E-09	10.0%	1.48E-09	1.48E-09
2	36	6.86E-08		2.75E-08	10.0%	-2.17E-08	10.0%	2.41E-08	2.41E-08	1.14	-0.90	2	36	2.75E-08	10.0%	2.41E-08	2.41E-08
3	216	2.47E-06		3.78E-07	10.0%	-3.43E-07	10.0%	3.59E-07	3.59E-07	1.05	-0.95	3	216	3.78E-07	10.0%	3.59E-07	3.59E-07
4	1296	8.89E-05		5.40E-06	10.0%	-5.20E-06	9.9%	5.29E-06	5.29E-06	1.02	-0.98	4	1296	5.40E-06	10.0%	5.29E-06	5.29E-06
5	7776	3.20E-03		7.85E-05	10.0%	-7.72E-05	10.0%	7.78E-05	7.78E-05	1.01	-0.99	5	7776	7.85E-05	10.0%	7.78E-05	7.78E-05
6	46656	1.15E-01	1.2E-17	1.15E-03	9.9%	-1.14E-03	10.0%	1.14E-03	1.14E-03	1.01	-1.00	9	1.01E+07	7.85E-05	9.6%	7.78E-05	7.78E-05
7	2.80E+05	4.15E+00	4.4E-16	1.68E-02	10.1%	-1.68E-02	10.0%	1.68E-02	1.68E-02	1.00	-1.00	13	1.31E+10	7.85E-05	9.6%	7.78E-05	7.78E-05
8	1.68E+06	1.49E+02	1.6E-14	2.47E-01	10.0%	-2.47E-01	10.0%	2.47E-01	2.47E-01	1.00	-1.00	17	1.69E+13	7.85E-05	9.6%	7.78E-05	7.78E-05
12	2.18E+09	2.51E+08	2.6E-08	1.15E+04	10.0%	-1.15E+04	10.0%	1.15E+04	1.15E+04	1.00	-1.00						
18	1.02E+14	5.46E+17	5.8E+01	1.16E+11	10.1%	-1.16E+11	10.1%	1.16E+11	1.16E+11								
24	4.74E+18	1.19E+27	1.3E+11	1.17E+18	10.0%	-1.17E+18	10.0%										

Note: WolframAlpha was used for the blue cells' calculation, because those values are too large for Excel. Note: for the extreme large values (N > 12), Excel calculation gives big error, so they were omitted in the table. Note: after n = 6^6, or r > 0.1 meter, $r_{n=6}$ / $r_{n=1}$ = 14.7, and $r_{n=10}$ / $r_{n=1}$ = 31.6 (calculations not shown here).

II-c. The initial inflation of the emitted photon during the early propagation, and the ending of inflation at the later propagation

The{N,n} QM emission field description revealed that the emitted photon keeps increasing its size as long as the propagation keeps going (e.g., see columns 5, 9, and 10 in Table 2). We know that a photon's size should not grow forever. But can we get some rough idea (from Table 2's calculation) that when the size growing stops? For a Bohr atom's n=3 to n=2 transition emitted photon (λ= 656 nm), let's assume that it (as a spherical NBP peak) has the radius (b in Table 2) of around 100x of the wavelength, or, b ≈ 6.56E-5 meter. Then check Table 2, we found that at n = 6^5 =7776, or at ~3 mm away from the Bohr atom, the emitted photon will grow its size to about (7.78E-5 / 656E-9 =) 119x of its wavelength. Thus, we can make the simplest assumption that a Bohr atom's n=3 to n=2 transition emitted photon (λ= 656 nm) will have the initial inflation of its size to ~ 112x of the wavelength within the first 3 mm propagation, and then it will slow-down or even stop the size growing (at n > 6^5). (Note: this is only one kind of description, and it does not mean that a 656 nm photon has a measurable size of 656 * 119 nm = 7.78E-5 meters).

Then, how to use {N,n} QM field theory to describe a propagating photon that has a fixed size? In eq-40, we know that the exponent index n (or n-1) determines the NBP peak width. The higher the n, the narrower the peak. In SunQM-3s11's eq-47 through eq-54, and SunQM-4's eq-66 through eq-73, we used the multiplier n' to describe all eight planet's sizes while using the base n to describe their orbits' r_n. Here we can use the same trick to fix the size of a photon while it is still propagating. According to eq-65-SunQM-4, we modified eq-40 as

$$r^2\,|\Psi(r,\theta,\varphi,t)|^2_{NBP} = r^2|R(n,L)|^2_{NBP}|Y(L,L)|^2_{NBP} \propto \left[\frac{r}{r_n}e^{\left(1-\frac{r}{r_n}\right)}\right]^{n'}[\sin(\theta)]^{(n'-1)}[\cos(\varphi)]^{n'-1} \qquad \text{eq-47}$$

or,

$$b(\theta) = r_n \sin(\theta') = r_n \sin\left(\mathrm{acrcos}\left[0.1^{1/(n'-1)}\right]\right) \qquad \text{eq-48}$$

$$b(\varphi) = r_n \sin(\varphi) = r_n \sin\left(\mathrm{acrcos}\left[0.1^{1/(n'-1)}\right]\right) \qquad \text{eq-49}$$

$$r^2|R(n,L)|^2_{NBP} = \left(\frac{r_n+b}{r_n} e^{1-\frac{r_n+b}{r_n}}\right)^{n'} = \left(\frac{r_n+b}{r_n} e^{\frac{b}{r_n}}\right)^{n'} = 0.1 \qquad \text{eq-50}$$

where r_n uses the base n, the n' is the multiplier n'. Then, in Table 2 columns 13 through 18, we used eq-47 through eq-50 (and using N') to calculate the expected (or the fixed) photon size (in comparison with that in Table 2 columns 1 through 12, where we used eq-40 through eq-45 and N to calculate the inflating photon size). The result showed that with eq-40, when N (in column 1) increasing from 1 to 2, … 5, 6, 7, …, the photon size b (in column 9) increased from 1.48E-9 meters, to 2.41E-8 meters, … 7.78E-5 meters, 1.14E-3 meters, 1.68E-2 meters, … . However, we expect at N > 5, or n > 6^5, the photon size b will keep as that at N=5, or b= 7.78E-5 meters. So using eq-47, we fixed b= 7.78E-5 meters (see columns 15-18) at N > 5, and we can do that by adjusting N' to = 9 for N=6, N' = 13 for N=7, and N' = 17 for N=8, etc. (see column 13 and column1). So, by using the eq-40, we can describe an inflating photon size at the early stage of photon emission and propagation, and by using the eq-47 and the appropriate multiplier n', we can describe a matured photon (with a fixed size) at its later stage of propagation.

III. A hypothesized physical structure of a photon based on the {N,n} QM, and the origin of the wave-particle duality

In section-II, we used a Bohr atom (or, more accurately, an electron in the Bohr atom that is transiting from n=3 to n=2)'s single nLL QM field state to describe an emitted and propagated photon, with a single n quantum number at any time (notice that this n approximately equals to Bohr atom's n only at n >> 2), and this n is increasing with time (during propagation). However, because that the superposition of many QM states at any time is one of many natural attributes of QM, here we should also describe an emitted and propagating photon by using a collection of (or the superposition of) many QM states

$$\sum_{n=1,l,m}^{\infty} a_{nlm}\,|n,l,m\rangle \qquad \text{Eq-51}$$

(where l = 0, … n-1; m = -l, … +l). Note: In eq-1-SunQM-6, we also used this superposition formula to describe both $\vec{\mathbf{E}}$ electric force field and $\vec{\mathbf{B}}$ magnetic force (or E/RFe-force) field simultaneously. Note: In {N,n//q} QM, the r_1 (of n = 1) can be moved inward to n = 1/q^j (which equivalent to {N=-j,n=1//q}, where both q and j are positive integers). If apply this to eq-51, then the SUM of n (in eq-51) should be from n = 1/q^j (at j → ∞, or n → 0) to n → ∞.

We hypothesis that eq-51 may describe the actual physical structure of a photon. In the following description, the origin of the coordinate can be either at the center of a Bohr atom that the photon is emitted (see section III-a). or at the center of photon itself (see section III-b).

III-a. The (hypothesized) physical structure of a photon based on {N,n//6} QM field description with the coordinate center at Bohr atom

In a Bohr atom centered photon description, a photon is a nLL QM state (or a 3D wave packet) of a Bohr atom's {N,n} QM field (which means it has the < 1% mass occupancy character) that emitted out of the Bohr atom and propagating away from the Bohr atom. It has a 3D spherical NBP probability peak (not a Born probability), and it has an onion-like structure (see Figure 4a, and we call it the "physical structure" of a photon), that means it is a superposition of many QM states, or many sizes.

To build a (superposition) photon based on eq-51 (with the center at Bohr atom), we still use eq-47 (or eq-48 through eq-50). In Table 3, columns 1 through 18 are copied from Table 2, with columns 5 through 12 showed an always inflating photon, and columns 13 through 18 showed an initial inflating photon but stopped inflation at N=5, or 3.2 mm away from the Bohr atom. Now, let's (randomly) choose a photon that propagated to N=7, or n=6^7, or r_n = 4.15 meters away, with a fixed size ($r_{photon\text{-}surface}$ = b = 7.78E-5 meters), and let's build a detailed physical structure for this photon based on {N,n//6} QM field description with the coordinate center at Bohr atom (see columns 19 through 27 in table 3). Notice that for columns 19 through 27's calculation, we replaced n' by n" in eq-47 through eq-50, because n' has been used for columns 13 through 18's calculation. First, we started from a N=7, or n=6^7, or r_n = 4.15 meters away, with a fixed size ($r_{photon\text{-}surface}$ = b = 7.78E-5 meters, or N'=13) photon (see the yellow row in columns 19 through 27). Then we try to describe the same photon with the size of one level smaller ($r_{photon\text{-}surface}$ = b = 5.29E-6 meters, or N=4 (see column 10), notice that the fix-sized N=7 photon has an actual size of N=5). We found that after adjusting N" to =16 (in column 22), or n" = 2.82E+12 (in eq-47, with r_n = 4.15 meters), then we can describe the same (N=7) photon (with N=5 originally fixed size) with a one-level smaller size ($r_{photon\text{-}surface}$ = b = 5.30E-6 meters, see columns 19 through 27 and one row above the yellow row). Next, we found that by adjusting N" to =19, we can describe the same (N=7) photon (with N=5 originally fixed size) with a two-level smaller size ($r_{photon\text{-}surface}$ = b = 3.60E-7 meters, see columns 19 through 27 and two rows above the yellow row), and so on so forth. In Table 3 columns 19 through 27, we have showed the calculations of the same photon with different sizes down to $r_{photon\text{-}surface}$ = b = 7.72E-12 meters, and up to $r_{photon\text{-}surface}$ = b = 3.22E+00 meters.

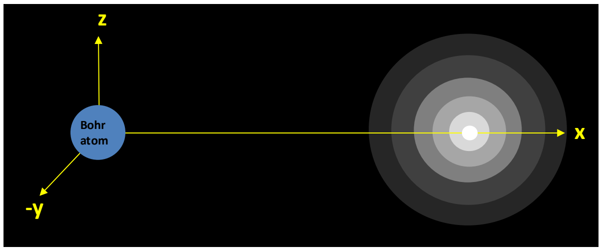
Notice that when N" decreased to =0 (or < 0), n" = 1, and n" - 1 = 0, so eq-48 no longer work due to the denominator = 0. In that case, we changed the exponent index n"-1 into n" so that we can still estimate the photon size (see the pink colored cells in Table 3). It resulted that the maximum b_{max} = 4.15 meters = r_n, that means the maximum size of an emitted photon can't be larger than the propagated distance r_n, and it does make sense. (Note: it means that when this photon (propagated to N=7 with r_n = 4.15 meters) further propagated to N=8 with r_n = 149 meters, its maximum size will increase to $r_{photon\text{-}surface,max}$ = b_{max} = r_n = 149 meters, and this property will be used in section IV 's explanation).

The same calculations can be applied to a photon that propagated not only to N=7, but also to any N number. In this way, we are able to describe the physical structure of a (emitted) photon based on {N,n//6} QM field with the coordinate centered at Bohr atom. With the assumption that a 656 nm photon has a fixed size at around $r_{photon\text{-}surface}$ = b ≈ 656 * 100 nm, for the (onion-like physical structural) shells larger than that, we call them the "out-shells" of the 656 nm photon, and for the (onion-like physical structural) shells smaller than that, we call them the "inner-shells and core" of the 656 nm photon. We can see that the "out-shells" will have the extremely low value of NBP (<< 10% of NBP peak).

Table 3. Check the physical structure of a photon based on {N,n//6} QM description with the coordinate center at Bohr atom

				check for the spherical shape of an emitted photon								fix the size of an emitted photon after n=6^5						a photon propagated to n=6^7 with a superposition of many QM states and sizes								
				b(r) fit to 10% max								b(r) fit to 10% max						b(r) fit to 10% max								
	r_1 =	5.29E-11	meter	[(1 + b / r_n) * exp(- b / r_n)]^n = 0.1								[(1 + b / r_n) * exp(- b / r_n)]^n' = 0.1						[(1 + b / r_n) * exp(- b / r_n)]^n" = 0.1								
				b(θ) = r_n * sin(θ') = r_n * sin(arccos{0.1^[1/(n-1)]})								b(θ) = r_n * sin(θ') = r_n * sin(arccos{0.1^[1/(n'-1)]})						b(θ) = r_n * sin(θ') = r_n * sin(arccos{0.1^[1/(n"-1)]})								
				b(ϕ) = r_n * sin(ϕ) = r_n * sin(arccos{0.1^[1/(n-1)]})								b(ϕ) = r_n * sin(ϕ) = r_n * sin(arccos{0.1^[1/(n'-1)]})						b(ϕ) = r_n * sin(ϕ) = r_n * sin(arccos{0.1^[1/(n"-1)]})								
N=	n=	$r_n = r_1 n^2$	r_n	+b(r)=	%=	-b(r)=	%=	b(θ) = r_n * sin(θ')	b(ϕ) = r_n * sin(φ)	[+b(r)] / b(θ)	[-b(r)] / b(θ)	N'=	n'=	+b(r)=	%=	b(θ) = r_n * sin(θ')	b(ϕ) = r_n * sin(φ)	N=	n=	$r_n = r_1 n^2$	N"=	n"=	+b(r)=	%=	b(θ) = r_n * sin(θ')	b(ϕ) = r_n * sin(φ)
		m	ly	m		m		m	m	m/m	m/m			m		m	m			m			m		m	m
0	1	5.29E-11		2.06E-10	10.0%	-5.09E-11	9.9%					0	1	2.06E-10	10.0%											
1	6	1.90E-09		2.19E-09	10.0%	-1.22E-09	10.1%	1.48E-09	1.48E-09	1.48	-0.83	1	6	2.19E-09	10.0%	1.48E-09	1.48E-09									
2	36	6.86E-08		2.75E-08	10.0%	-2.17E-08	10.0%	2.41E-08	2.41E-08	1.14	-0.90	2	36	2.75E-08	10.0%	2.41E-08	2.41E-08									
3	216	2.47E-06		3.78E-07	10.0%	-3.43E-07	10.0%	3.59E-07	3.59E-07	1.05	-0.95	3	216	3.78E-07	10.0%	3.59E-07	3.59E-07									
4	1296	8.89E-05		5.40E-06	10.0%	-5.20E-06	9.9%	5.29E-06	5.29E-06	1.02	-0.98	4	1296	5.40E-06	10.0%	5.29E-06	5.29E-06									
5	7776	3.20E-03		7.85E-05	10.0%	-7.72E-05	10.0%	7.78E-05	7.78E-05	1.01	-0.99	5	7776	7.85E-05	10.0%	7.78E-05	7.78E-05									
6	46656	1.15E-01	1.2E-17	1.15E-03	9.9%	-1.14E-03	10.0%	1.14E-03	1.14E-03	1.01	-1.00	9	1.01E+07	7.85E-05	9.6%	7.78E-05	7.78E-05									
																		7	2.80E+05	4.15E+00	31	1.33E+24	7.72E-12	10.0%	7.72E-12	7.72E-12
																		7	2.80E+05	4.15E+00	28	6.14E+21	1.13E-10	10.3%	1.34E-10	1.34E-10
																		7	2.80E+05	4.15E+00	25	2.84E+19	1.78E-09	10.2%	1.67E-09	1.67E-09
																		7	2.80E+05	4.15E+00	22	1.32E+17	2.45E-08	10.0%	2.45E-08	2.45E-08
																		7	2.80E+05	4.15E+00	21	2.19E+16	6.18E-08	8.8%	6.18E-08	6.18E-08
																		7	2.80E+05	4.15E+00	19	6.09E+14	3.60E-07	10.0%	3.60E-07	3.60E-07
																		7	2.80E+05	4.15E+00	16	2.82E+12	5.30E-06	10.0%	5.30E-06	5.30E-06
7	2.80E+05	4.15E+00	4.4E-16	1.68E-02	10.1%	-1.68E-02	10.0%	1.68E-02	1.68E-02	1.00	-1.00	13	1.31E+10	7.85E-05	9.6%	7.78E-05	7.78E-05	7	2.80E+05	4.15E+00	13	1.31E+10	7.78E-05	10.0%	7.78E-05	7.78E-05
																		7	2.80E+05	4.15E+00	9	1.01E+07	2.80E-03	10.0%	2.80E-03	2.80E-03
																		7	2.80E+05	4.15E+00	5	7.78E+03	1.01E-01	10.4%	1.01E-01	1.01E-01
																		7	2.80E+05	4.15E+00	1	6.00E+00	4.76E+00	10.0%	3.22E+00	3.22E+00
																		7	2.80E+05	4.15E+00	0	1.00E+00			4.13E+00	4.13E+00
																		7	2.80E+05	4.15E+00	-1	1.67E-01			4.15E+00	4.15E+00
																		7	2.80E+05	4.15E+00	-2	2.78E-02			4.15E+00	4.15E+00
8	1.68E+06	1.49E+02	1.6E-14	2.47E-01	10.0%	-2.47E-01	10.0%	2.47E-01	2.47E-01	1.00	-1.00	17	1.69E+13	7.85E-05	9.6%	7.78E-05	7.78E-05									

Note: for the blue cells, WolframAlpha was used for calculation, because the values are too large for Excel.
Note: for pink cells, due to n" <= 0, the exponent index (n"-1) is replaced by n" for the (approximate) calculation of eq-47.



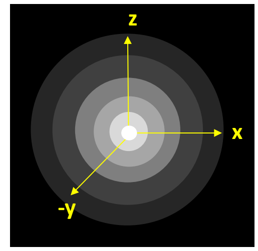


Figure 4a (left). Illustration of the physical structure of a photon based on {N,n//q} QM field description with the coordinate center at Bohr atom. The r-dimension is drawn on an arbitrary scale.
Figure 4b (right). Illustration of the physical structure of a photon based on {N,n//q} QM field description with the coordinate center at photon's center. The r-dimension is drawn on an arbitrary scale.

III-b. The (hypothesized) physical structure of a photon based on {N,n//6} QM field description with the coordinate center at photon's center

In a self-centered photon physical structure description, a photon is a |n,*l*,m> QM field state (where *l* = 0, … n-1; m = -*l*, … +*l*, which means it has the ~ 100% mass occupancy character). It can be described by either a 3D spherical Born probability peak or a NBP peak, and it has an onion-like structure (see Figure 4b), that means it is a superposition of many QM states (or many sizes). If using Born probability, then we can use the famous Bohr formula $r_n = r_1 n^2$ to describe the size of the photon (see Table 4' columns 1 through 3), except that the true size of the photon at QM state n is $r_{n+1} = r_1(n+1)^2$. This is because for a ~ 100% mass occupancy QM state, there is a rule says "all mass between r_n and r_{n+1} belongs to orbit n " (see paper SunQM-3s2, although here we need to use NBP probability rather than mass). However, if using Born probability for description, it will always have a zero probability at the very center, while if using NBP for description, then it may not have this problem (see QM text book, Prob. ~ r plot, John S. Townsed, A Modern Approach to Quantum Mechanics, 2nd ed., 2012. p357, Figure 10.5).

Table 4. The physical structure of a photon based on {N,n//q} QM with the coordinate center at photon's center.

	r_1 =	5.29E-11	m		
N(q=6)	n = 6^N	$r_n = r_1 n^2$	N'(q=2)	n' = 2^N'	$r_n = r_1 n'^2$
		m			m
-5	1.29E-04	8.75E-19	-16	1.53E-05	1.23E-20
-4	7.72E-04	3.15E-17	-8	3.91E-03	8.07E-16
-3	4.63E-03	1.13E-15	-4	0.0625	2.07E-13
-2	0.027778	4.08E-14	-2	0.25	3.31E-12
-1	0.166667	1.47E-12	-1	0.5	1.32E-11
0	1	5.29E-11	0	1	5.29E-11
0	2	2.12E-10	1	2	2.12E-10
0	3	4.76E-10	2	4	8.46E-10
0	4	8.46E-10	3	8	3.39E-09
0	5	1.32E-09	4	16	1.35E-08
1	6	1.90E-09	5	32	5.42E-08
2	36	6.86E-08	6	64	2.17E-07
3	216	2.47E-06	7	128	8.67E-07
4	1296	8.89E-05	8	256	3.47E-06
5	7776	3.20E-03	12	4096	8.88E-04
6	46656	1.15E-01	16	65536	2.27E-01
7	2.80E+05	4.15E+00	20	1.05E+06	5.82E+01
8	1.68E+06	1.49E+02	24	1.68E+07	1.49E+04

III-c. Should we use {N,n//6} QM or {N,n//2} QM to describe a photon's physical structure?

{N,n//6} QM is valid for the description from a quark{-17, 1//6} to the Virgo Super Cluster {10,1//6}, (see SunQM-1s2's Table 1). Therefore, {N,n//6} QM is the best choice for the photon description. However,{N,n//2} QM is valid for the description all eight planet's structures in Solar system (see SunQM-3s6's Table 2), and a planet (which has a {N,n//2} structure) is a small accessory of a star (which has a {N,n//6} structure). Because an emitted photon is a small accessory of a Bohr atom (or a Bohr atom's electron), it may be possible that a photon's physical structure should be described by a {N,n//2} QM (see Table 4's columns 4 through 6).

III-d. The origin of the wave-particle duality, and the explanation of the Double-slit experiment

QM text books taught us that a photon has the wave-particle duality. After the physical structure of a photon is described as a NBP 3D peak with all kinds of sizes simultaneously, now we can explain the origin of the wave-particle duality easily. We can explain the large size of NBP 3D spherical peak (the out-shells, with extremely low NBP density) as photon's wave property, and the small size of NBP 3D spherical peak (the core, with very high NBP density) as the same photon's particle property. For example, for a Bohr atom's electron transition from n=3 to n=2 emitted photon (with wavelength 656 nm) that propagated to 4.15 meters away (with N=7), we can use N"=31 and $r_{photon\text{-}surface}$ = b = 7.72E-12 meter (see Table 3 row 15) to describe this photon's particle property, and meanwhile use N"=1 and $r_{photon\text{-}surface}$ = b = 3.22 meters (see Table 3 row 25) to describe this photon's wave property.

With this, we can explain double-slit experiment as: a propagating photon uses its large size (but low density) NBP 3D peak (e.g., $r_{photon\text{-}surface}$ = b = 3.22 meters) to detect the obstacle in the front of propagation. After this wave-front passing through a double-slit, this large size NBP 3D peak (wave) will interfere to make a new NBP peak (interfered) pattern, and this new NBP peak (interfered) pattern will guide the core part (or the particle part) of the photon to pass through one of the two slits, and to end on a screen as an interference pattern (based on the NBP probability). Does this explanation favor de Broglie's "pilot wave theory" (see wiki "Wave–particle duality" section "de Broglie–Bohm theory")?

This explanation also supports the Simultaneous-Multi-Eigen-Description (SMED) theory (shown in SunQM-4 section-V, and in SunQM-7).

IV. Is it possible that the redshift is a nature attribute of photon's propagation?

Here we discuss one type of (a hypothetic) photon redshift mechanism that is caused by the QM's uncertainty principle $\sigma_x\sigma_p \geq \frac{\hbar}{2}$ (where σ_x is the standard deviation in the propagation distance x, and σ_p is the standard deviation in the momentum p). From QM text books, we learned that a propagating photon will increase its position uncertainty by increasing σ_x (see wiki "Quantum mechanics", "… *the wave packet will also spread out as time progresses, which means that the position becomes more uncertain with time*"). By using Figure 4a and Table 3, we translate this increasing of σ_x as increasing the size of the photon's out-shells (by increasing $r_{photon\text{-}surface,max} = b_{max} = r_n$, and by keeping N" =1) during propagation (by increasing r_n, or by increasing N, see Table 3's explanation). However, we don't expect the maximum size of a photon's out-shells can grow forever. For example, in Table 2, an emitted photon propagated to N=18, or r_n = 5.46E+17 meters, or 58 light years away, its maximum size of out-shell is unlikely to grow to $r_{photon\text{-}surface,max}$ = 58 lys. Now let's make a hypothesis that when the $r_{photon\text{-}surface,max}$ bigger than a certain size, this photon's outmost shell will be rip-off (or spit-out, to become a new photon with very low energy or frequency, named as "low-f photon"), the rest shells and core will become the entire (main) photon with limited size (and with the slightly lower energy than that of the original photon, or it is redshifted). In Table 5, we try to search for that at what distance during the propagation a 656 nm photon will spit-out a low-f photon, and at what frequency this low-f photon will be.

In Table 5 columns 1 through 4, we listed all possible N(s), n(s), total n(s), and the r_n(s) for a propagating photon that emitted from a Bohr atom (up to N=16). From Table 3 (see pink cells)'s result, we learned that a photon (emitted from a Bohr atom to distance r_n away) will have the maximum size of out-shell with $r_{photon\text{-}surface,max} = b_{max} = r_n$. We assume that this outmost shell of the photon (described under {N,n} QM field theory) will be ripped-off if it gets too big. Then, we assume that the ripped-off outer shell will become a new low-f photon, with $r_{photon\text{-}surface,max} = b_{max}$ equals to 100x of the wavelength of this newly created low-f photon. Thus, in Table 5 column 5, we have the wavelength for the low-f photon at each r_n (if it is spit-out at this r_n). Column 6 is the calculated frequency of this low-f photon. Column 7 is the low-f photon's energy in Joule. Columns 8 through 11 showed the emitted photon λ(em) = 656 nm (from a Bohr atom's n=3 to n=2 transition), its energy (J), the after-redshift energy (after spit-off the E(low-f)), and the observed (redshifted) photon wavelength λ(ob). Columns 13 and 14 calculated the redshift z from formula z+1 = λ(ob) / λ(em). Column 15 calculated the radial velocity of a galaxy that is determined from the redshift z as $V_r = cz$ (where c is the light speed, according to http://zebu.uoregon.edu/2000/ph123/hub1.html). Column 17 calculated the value of $V_r/(r_n-r_{n-1})$ and changed the unit to (km/s)/Mpc, so that it can be directly compared with the Hubble constant. Thus, the whole Table 5 is designed to search at what r_n, a propagating photon (656 nm) will spit-out a low-f photon and cause a redshift that matches the Hubble constant (~70 (km/s)/Mpc). The search result is: a propagating (656 nm) photon's max-size of out-shell is p{N,n//6} = p{13,3//6}, or $b_{max} = r_n$ = 8.12E+10 meters (see Table 5 row 19. Notice p{N,n} means this {N,n} is centered at the photon, not at Bohr atom, see definition in SunQM-1's section-VII item 14). When it propagates further to n+1, or {13,4//6} (see Table 5 row 20 in yellow), or $r_{n+1} - r_n$ = 1.44E+11 - 8.12E+10 = 6.32E+10 meters away (see column 16, a distance similar as from Sun to Mercury), with increased max-size of out-shell to p{13,4//6}, or $b_{max} = r_n$ = 1.44E+11 meters, it will spit-out its outmost shell as a 0.2 Hz photon, and redshifted to 656 + 2.98E-13 nm that equivalent to 67 (km/s)/Mpc (and comparable to Hubble constant ~70 (km/s)/Mpc). After ripping-off the outmost shell, the (main) photon's out-shell size goes back to p{13,3//6}, or $b_{max} = r_n$ = 8.12E+10 meters. Then, after propagating another Δr = 1.44E+11 - 8.12E+10 = 6.32E+10 meters away, the main photon's out-shell size will increase to p{13,4//6}, or $b_{max} = r_n$ = 1.44E+11 meters again, so it will spit-out its outmost shell as a 0.2 Hz photon again, and redshifted to 656 + 2* 2.98E-13 nm, and so on so forth. In this way, this main photon will spit-out a 0.2 Hz low-f photon for every 6.32E+10 meters it propagated, and causing a redshift equivalent to the Hubble constant. If this hypothesis is correct, then the redshift is the natural attribute of a photon, and the cosmological redshift can be explained by it (see the discussion of the "rhodopsin-type universe model" in SunQM-6 section-V). In other words, if this hypothesis is correct, then those low-f photons are equivalent to the "dark energy".

Discussions of section IV:

1) If this hypothesis is correct, then there must have many 0.2 Hz low-f photons (λ ≈ 1E+9 meters, ~ 1E-11 K°, from 656 nm photon's propagation only) in the space (like CMB, although CMB's peak is at 160 ~ 282 GHz, λ ≈ 1 mm, ~ 2.7 K°). Can we detect these low-f photons (not only from 656 nm, but also from all other wavelength of photons' propagation)?

2) The process of ripping-off and forming a new 0.2 Hz low-f photon could be either a spontaneous emission, or a stimulated emission (see David J. Griffiths, Introduction to Quantum Mechanics, 2nd ed., 2015. Figure 9.4). In the later case it could be bumped-off by another pre-existing 0.2 Hz low-f photon.

3) This is a programmed (not a random) spit-out. All 656 nm photons will get the same redshift after propagated 6.32E+10 meters distance. So it should not (significantly) blur the images of distant objects. In comparison, the random inelastic scattering caused redshift will blur the images of distant objects (see wiki "Tired light").

4) Those 0.2 Hz low-f photons in the space can be re-absorbed by matter (atoms, electrons) at any time.

5) If both universe expansion and low-f rip-off contribute to the redshift, then the low-f (rip-off) photon may have much lower frequency.

Table 5. To search for the frequency and the distance of the newly formed low-f photon that spit-out (or ripped-off) from a propagating photon.

		r_1 =	5.29E-11													
N(q=6)	n=	total n = 6^N	$r_n = r_1 n^2$	$\lambda = r_n/100$	low-f photon f=c/λ	E(low-f) = hf	λ(em) 656	656nm photon's E=hf=hc/λ	redshifted E = E(656)-E(low-f)	λ(ob): λ= hc/[E(656)-E(low-f)]	λ(ob) - λ(em)	z+1=λ(ob)/λ(em)	z=	V_r = cz	$r_n - r_{n-1}$ =	$V_r/(r_n-r_{n-1})$ * (Mpc/Mpc) = V_r *Mpc/$(r_n - r_{n-1})$
			m	m	Hz, 1/s	J	nm	J	J	nm	nm	nm/nm		km/s		(km/s)/Mpc
0	1	1	5.29E-11	5.29E-13	5.67E+20	3.76E-13	656	3.03E-19	-3.76E-13	-5.29E-04	-6.56E+02	-8.06E-07	-1.00E+00	-3.00E+05		
1	1	6	1.90E-09	1.90E-11	1.58E+19	1.04E-14	656	3.03E-19	-1.04E-14	-1.90E-02	-6.56E+02	-2.90E-05	-1.00E+00	-3.00E+05		-5.01E+36
2	1	36	6.86E-08	6.86E-10	4.38E+17	2.90E-16	656	3.03E-19	-2.90E-16	-6.86E-01	-6.57E+02	-1.05E-03	-1.00E+00	-3.00E+05		-1.39E+35
3	1	216	2.47E-06	2.47E-08	1.22E+16	8.05E-18	656	3.03E-19	-7.75E-18	-2.56E+01	-6.82E+02	-3.91E-02	-1.04E+00	-3.12E+05		-4.01E+33
4	1	1296	8.89E-05	8.89E-07	3.38E+14	2.24E-19	656	3.03E-19	7.93E-20	2.51E+03	1.85E+03	3.82E+00	2.82E+00	8.46E+05		3.03E+32
5	1	7776	3.20E-03	3.20E-05	9.38E+12	6.21E-21	656	3.03E-19	2.97E-19	6.70E+02	1.37E+01	1.02E+00	2.09E-02	6.28E+03		6.24E+28
6	1	46656	1.15E-01	1.15E-03	2.61E+11	1.73E-22	656	3.03E-19	3.03E-19	6.56E+02	3.74E-01	1.00E+00	5.70E-04	1.71E+02		4.72E+25
7	1	279936	4.15E+00	4.15E-02	7.24E+09	4.80E-24	656	3.03E-19	3.03E-19	6.56E+02	1.04E-02	1.00E+00	1.58E-05	4.75E+00		3.64E+22
8	1	1.68E+06	1.49E+02	1.49E+00	2.01E+08	1.33E-25	656	3.03E-19	3.03E-19	6.56E+02	2.88E-04	1.00E+00	4.40E-07	1.32E-01		2.81E+19
9	1	1.01E+07	5.37E+03	5.37E+01	5.58E+06	3.70E-27	656	3.03E-19	3.03E-19	6.56E+02	8.01E-06	1.00E+00	1.22E-08	3.66E-03		2.17E+16
10	1	6.05E+07	1.93E+05	1.93E+03	1.55E+05	1.03E-28	656	3.03E-19	3.03E-19	6.56E+02	2.22E-07	1.00E+00	3.39E-10	1.02E-04		1.67E+13
11	1	3.63E+08	6.96E+06	6.96E+04	4.31E+03	2.85E-30	656	3.03E-19	3.03E-19	6.56E+02	6.18E-09	1.00E+00	9.42E-12	2.83E-06		1.29E+10
12	1	2.18E+09	2.51E+08	2.51E+06	1.20E+02	7.93E-32	656	3.03E-19	3.03E-19	6.56E+02	1.72E-10	1.00E+00	2.62E-13	7.85E-08		9.96E+06
13	1	1.31E+10	9.02E+09	9.02E+07	3.32E+00	2.20E-33	656	3.03E-19	3.03E-19	6.56E+02	4.77E-12	1.00E+00	7.33E-15	2.20E-09		7.74E+03
13	2	2.61E+10	3.61E+10	3.61E+08	8.31E-01	5.51E-34	656	3.03E-19	3.03E-19	6.56E+02	1.19E-12	1.00E+00	1.82E-15	5.46E-10	2.71E+10	622
13	3	3.92E+10	8.12E+10	8.12E+08	3.69E-01	2.45E-34	656	3.03E-19	3.03E-19	6.56E+02	5.30E-13	1.00E+00	8.08E-16	2.42E-10	4.51E+10	166
13	4	5.22E+10	1.44E+11	1.44E+09	2.08E-01	1.38E-34	656	3.03E-19	3.03E-19	6.56E+02	2.98E-13	1.00E+00	4.54E-16	1.36E-10	6.32E+10	67
13	5	6.53E+10	2.26E+11	2.26E+09	1.33E-01	8.81E-35	656	3.03E-19	3.03E-19	6.56E+02	1.19E-13	1.00E+00	2.91E-16	8.73E-11	8.12E+10	33
14	1	7.84E+10	3.25E+11	3.25E+09	9.23E-02	6.12E-35	656	3.03E-19	3.03E-19	6.56E+02	1.32E-13	1.00E+00	2.02E-16	6.06E-11	9.93E+10	18.9
15	1	4.70E+11	1.17E+13	1.17E+11	2.57E-03	1.70E-36	656	3.03E-19	3.03E-19	6.56E+02	0.00E+00	1.00E+00	0.00E+00	0.00E+00		0.00E+00
16	1	2.82E+12	4.21E+14	4.21E+12	7.13E-05	4.72E-38	656	3.03E-19	3.03E-19	6.56E+02	0.00E+00	1.00E+00	0.00E+00	0.00E+00		0.00E+00

Note: Blue cells were calculated by using WolframAlpha. For example, for N=13, n=4, V_r * Mpc / $(r_n - r_{n-1})$ = 300000000 * (1/(1/(656E-9)-1/(5.29E-11*(4*6^13)^2/100)) / (656E-9) -1) * 3.09E+19 / (5.29E-11*(4*6^13)^2 - 5.29E-11*(3*6^13)^2) = 67 (km/s)/Mpc. We should point out that this calculation has very low resolution. If we assume that $r_{photon-surface,max} = b_{max}$ equals to 110x (instead of 100x) of the wavelength of the newly created low-f photon, then the calculated V_r * Mpc / $(r_n - r_{n-1})$ = 73 (km/s)/Mpc.

Note: Grey cells are calculated by Excel but lack of the enough precision.

V. A second method to describe a photon's propagation

There is a second way to describe a photon's propagation by using the {N,n} QM field theory. In this way, we only use the ground state |1,0,0> and the excited state |2,1,1> to describe the {N,n} QM field state (see Figure 2's Y(0,0) and Y(1,1) plot), with a variable $r_1 = c * t$ (where c is the light speed) to describe a photon's propagation from $r_1 = 0$ to $r_1 = \infty$. Notice that when the photon propagated to $r_1 = \infty$ (along x-axis), the whole x > 0 space would be filled with this photon's |2,1,1> QM field (the NBP of the positive wave) if uncontrolled. Then, to control this photon's size within a limitation, we need to move r_1 inward to become r_1' (notice that this is allowed in {N,n//q} QM theory), and also increase the multiplier n' to very high, so that we can use eq-47 through eq-50 to decrease the size of a photon to whatever size we want. The advantage of this method is: 1) It only uses two QM states (the ground state and the excited state) to describe the photon's {N,n} QM force field; 2) It directly uses speed of light to describe the photon propagation. Now let's give an example (by using the data we have generated in Table 3). For a Bohr atom's n=3 to n=2 transition emitted (656 nm) photon that is propagated in +x direction, we use a (single) |2,1,1> QM field state with $r_1 = c * t$ to describe its propagation. When this photon propagated to 4.15 meters away from the Bohr atom, the size of its |2,1,1> QM field is increased with the r_1 = 4.15 meters. When this photon propagated to 149 meters away from the Bohr atom, the size of its |2,1,1> QM field is increased again with the r_1 = 149 meters. Now we want to describe this 656 nm photon (4.15 meters away from the Bohr atom) with a size of ~ 100x times of its wavelength (or $r_{photon-surface} = b \approx$ 6.56E-5 meters). To do that, we can move r_1 inward from 4.15 meters to r_1' = 5.29E-11 meters (by a factor of 1/(6^7)^2), then use N'=13, n' = 6^13 = 1.31E+10, and use eq-47 through eq-50, to obtain a $r_{photon-surface}$ = b = 7.78E-5 meters (see columns 13 through 18 in Table 3). In this way, we used speed of light (by using $r_1 = c * t$) to describe the photon propagation under a single excited QM state |2,1,1>. On the contrary, the photon absorption process (by a Bohr atom) is photon's {N,n} QM field (of a Bohr atom's electron) from the excited QM state |2,1,1> to the ground QM state |1,0,0>.

VI. Explanation of a spinning and moving charge's |n,*l*,m> mode in {N,n} QM field theory.

(Note: this section should be put in SunQM-6). In the {N,n} QM field theory (see SunQM-6), for a positive point charge produced $\vec{\mathbf{B}}$ field's |n,*l*,m> QM mode, we know that a +z direction (translational) moving $\vec{\mathbf{E}}$ vector of a positive charge produces a $\vec{\mathbf{B}}$ vector field in nLL QM mode (see Figure 5a), a spinning (in +z direction) $\vec{\mathbf{E}}$ vector of a positive charge produces a $\vec{\mathbf{B}}$ vector field in n*l*0 QM mode (see Figure 5b). In general, it is very difficult to determine the $\vec{\mathbf{B}}$ vector field's |n,*l*,m> QM mode if the $\vec{\mathbf{E}}$ vector of a positive charge is doing both translation and spin simultaneously.

In one special case, when the $\vec{\mathbf{E}}$ vector is moving and spinning both in +z direction simultaneously (see Figure 5c), we can build its $\vec{\mathbf{B}}$ vector field first based on n*l*0 QM mode (at $\vec{\mathbf{s}}$ > 0 and $\vec{\mathbf{v}}$ = 0, as shown in Figure 5b), and then slowly increase $\vec{\boldsymbol{v}_z}$ so that its field shape compressed in z dimension to the center (as shown in Figure 5c). This shape change can be described by a |n,*l*,m> QM mode start with m = 0, then increase the m to 1, 2, … up to *l* - 1, depends on how fast the velocity $\vec{\boldsymbol{v}_z}$ vector is. For example, if we initially use |4,3,0> to describe a z-spinning and v = 0 charge's $\vec{\mathbf{B}}$ vector field, then as $\vec{\boldsymbol{v}_z}$ increased to > 0, its $\vec{\mathbf{B}}$ vector field should be described by |4,3,1>, or by |Y(3,1)|^2, and then as $\vec{\boldsymbol{v}_z}$ further increased to >> 0, its $\vec{\mathbf{B}}$ vector field should be described by |4,3,2>, or by |Y(3,2)|^2, etc. (see the shape of |Y(3,0)|^2, |Y(3,1)|^2, |Y(3,2)|^2 in Figure 6).

Here we can also use the nLL and n*l*0 inter-changeable QM mode property (mentioned in SunQM-6's section I-d) to explain. A higher $\vec{\boldsymbol{v}_z}$ (of the $\vec{\mathbf{E}}$ vector translational movement) produces more purer nLL QM mode (meaning the m quantum number value become more larger, or in SunQM-6's Table 2, it contains more of m = n-1 components) of the $\vec{\mathbf{B}}$ vector field. After this $\vec{\mathbf{E}}$ vector topologically changed from the $\vec{\boldsymbol{v}_z}$ translational movement into the spin movement (see SunQM-6's figure 5a), the $\vec{\boldsymbol{v}_z}$ speed become the spin speed, so that its $\vec{\mathbf{B}}$ vector field topologically changed from nLL mode to n*l*0 mode, and the higher the original $\vec{\boldsymbol{v}_z}$, now means the higher spin speed, it translated into the lower m quantum number (or m becomes more closer to zero, or in SunQM-6's Table 2, it contains more of m = 0 components).

However, when the $\vec{\mathbf{E}}$ vector spins in the z direction and simultaneously translates in the x direction, we really have no idea what its $\vec{\mathbf{B}}$ field's |n,*l*,m> QM mode should be.

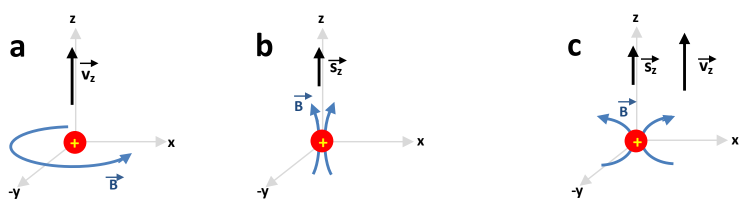
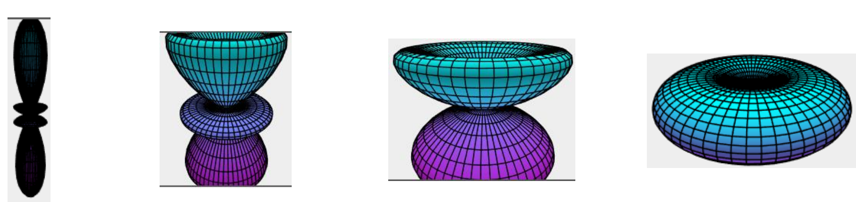


Figure 5a. A (+z) translational moving $\vec{\mathbf{E}}$ vector of a positive charge produces a $\vec{\mathbf{B}}$ vector field in nLL QM mode.
Figure 5b. A spinning (in +z direction) $\vec{\mathbf{E}}$ vector of a positive charge produces a $\vec{\mathbf{B}}$ vector field in n*l*0 QM mode.
Figure 5c. A positive point charge spinning and moving in the same direction (+z) is guessed to have its $\vec{\mathbf{B}}$ vector field lines spread more away from z-axis than that in Figure 5b.



|Y(3,0)|² |4,3,0> |Y(3,1)|² |4,3,1> |Y(3,2)|² |4,3,2> |Y(3,3)|² |4,3,3>

Figure 6. Plots of |Y(3,0)|^2, |Y(3,1)|^2, |Y(3,2)|^2, and |Y(3,3)|^2 by using MathStudio (http://mathstud.io/) software. Note: Here we use Born probability, and not use non-Born probability (NBP), because we only need to display $\vec{\mathbf{B}}$ field's θ-dimensional info, and omit φ-dimension's info. Note: the size and orientation of each plot is readjusted by the author due to the technical limitation. (Also see John S. Townsed, A Modern Approach to Quantum Mechanics, 2nd ed., 2012. Page 335, Figure 9.11).

VII. Can we use {N,n} QM field theory for other particles?

During last ~ 100 years, the modern QM field theory has successfully built up the particle physics. We believe that the particle physics can also be described by the {N,n} QM field theory as well, just like QM can be described by either the wave mechanics or the matrix mechanics, or, both thermodynamics and statistical physics explain the same thing.

For example, section III can be used directly to explain the double-slit experiment for the electron (and other particles). In the case of the pair production (a photon disappears and produces an electron and a positron, see Giancoli, Physics for Scientists & Engineers with Modern Physics, 4th ed. 2009. Figure 37-9), we may be able to use the |2,1,1> QM field state in Figure 2 (and Figure 3) to describe, with the 3D positive wave (NBP) peak (in blue, see Figure 2) represents the electron, and the 3D negative wave (NBP) peak (in yellow) represents the positron, and with the coordinate origin at the reduced mass center of electron-positron pair.

Conclusion

The equations used to calculate the photon frequency (emitted from a Bohr atom) can be used directly to calculate planet's orbit movement in the Solar system. {N,n} QM field theory is able to describe a photon's emission and propagation from a Bohr atom. The onion-like physical structure of a photon makes us able to explain not only the origin of wave-particle duality, but also the double-slit experiment. There is a (small) possibility that the redshift is a nature attribute of the photon's propagation.

References

[1] Yi Cao, SunQM-1: Quantum mechanics of the Solar system in a {N,n//6} QM structure. http://vixra.org/pdf/1805.0102v2.pdf （replaced on 2018-05-23, submitted on 2018-05-03）

[2] Yi Cao, SunQM-1s1: The dynamics of the quantum collapse (and quantum expansion) of Solar QM {N,n} structure. http://vixra.org/pdf/1805.0117v1.pdf （submitted on 2018-05-04）

[3] Yi Cao, SunQM-1s2: Comparing to other star-planet systems, our Solar system has a nearly perfect {N,n//6} QM structure. http://vixra.org/pdf/1805.0118v1.pdf （submitted on 2018-05-04）

[4] Yi Cao, SunQM-1s3: Applying {N,n} QM structure analysis to planets using exterior and interior {N,n} QM. http://vixra.org/pdf/1805.0123v1.pdf （submitted on 2018-05-06）

[5] Yi Cao, SunQM-2: Expanding QM from micro-world to macro-world: general Planck constant, H-C unit, H-quasi-constant, and the meaning of QM. http://vixra.org/pdf/1805.0141v1.pdf （submitted on 2018-05-07）

[6] Yi Cao, SunQM-3: Solving Schrodinger equation for Solar quantum mechanics {N,n} structure. http://vixra.org/pdf/1805.0160v1.pdf （submitted on 2018-05-06）

[7] Yi Cao, SunQM-3s1: Using 1st order spin-perturbation to solve Schrodinger equation for nLL effect and pre-Sun ball's disk-lyzation. http://vixra.org/pdf/1805.0078v1.pdf （submitted on 2018-05-02）

[8] Yi Cao, SunQM-3s2: Using {N,n} QM model to calculate out the snapshot pictures of a gradually disk-lyzing pre-Sun ball. http://vixra.org/pdf/1804.0491v1.pdf （replaced on 2018-05-08, submitted on 2018-04-30）

[9] Yi Cao, SunQM-3s3: Using QM calculation to explain the atmosphere band pattern on Jupiter (and Earth, Saturn, Sun)'s surface. http://vixra.org/pdf/1805.0040v1.pdf （submitted on 2018-05-01）

[10] Yi Cao, SunQM-3s6: Predict mass density r-distribution for Earth and other rocky planets based on {N,n} QM probability distribution. http://vixra.org/pdf/1808.0639v1.pdf (submitted on 2018-08-29)

[11] Yi Cao, SunQM-3s7: Predict mass density r-distribution for gas/ice planets, and the superposition of {N,n//q} or |qnlm> QM states for planet/star. http://vixra.org/pdf/1812.0302v2.pdf (submitted on 2019-03-08)

[12] Yi Cao, SunQM-3s8: Using {N,n} QM to study Sun's internal structure, convective zone formation, planetary differentiation and temperature r-distribution. http://vixra.org/pdf/1808.0637v1.pdf (submitted on 2018-08-29)

[13] Yi Cao, SunQM-3s9: Using {N,n} QM to explain the sunspot drift, the continental drift, and Sun's and Earth's magnetic dynamo. http://vixra.org/pdf/1812.0318v2.pdf (replaced on 2019-01-10, submitted on 2018-12-18)

[14] Yi Cao, SunQM-3s4: Using {N,n} QM structure and multiplier n' to analyze Saturn's (and other planets') ring structure. http://vixra.org/pdf/1903.0211v1.pdf (submitted on 2019-03-11)

[15] Yi Cao, SunQM-3s10: Using {N,n} QM's Eigen n to constitute Asteroid/Kuiper belts, and Solar {N=1..4,n} region's mass density r-distribution and evolution. http://vixra.org/pdf/1909.0267v1.pdf (submitted on 2019-09-12)

[16] Yi Cao, SunQM-3s11: Using {N,n} QM's probability density 3D map to build a complete Solar system with time-dependent orbital movement. https://vixra.org/pdf/1912.0212v1.pdf (replaced on 2020-03-23, submitted on 2019-12-11)

[17] Yi Cao, SunQM-4: Using full-QM deduction and {N,n} QM's non-Born probability density 3D map to build a complete Solar system with orbital movement. https://vixra.org/pdf/2003.0556v2.pdf (replaced on 2021-0203, submitted on 2020-03-25)

[18] Yi Cao, SunQM-4s1: Is Born probability merely a special case of (the more generalized) non-Born probability (NBP)? https://vixra.org/pdf/2005.0093v1.pdf (submitted on 2020-05-07)

[19] Yi Cao, SunQM-4s2: Using {N,n} QM and non-Born probability to analyze Earth atmosphere's global pattern and the local weather. https://vixra.org/pdf/2007.0007v1.pdf (submitted on 2020-07-01)

[20] Yi Cao, SunQM-6: Magnetic force is the rotation-diffusion (RF) force of the electric force, Weak force is the RF-force of the Strong force, Dark Matter may be the RF-force of the gravity force, according to a newly designed {N,n} QM field theory. https://vixra.org/pdf/2010.0167v1.pdf (replaced on 2020-12-17, submitted on 2020-10-21)

[21] David J. Griffiths, "Introduction to Quantum Mechanics", 2nd ed., 2015, pp67, eq-2.108.

[22] John S. Townsed, "A Modern Approach to Quantum Mechanics", 2nd ed., 2012, pp 180, eq-5.34.

[23] A series of my papers that to be published (together with current paper):
SunQM-4s3: Schrodinger equation and {N,n} QM ... (drafted in January 2020).
SunQM-4s4: More explanations on non-Born probability (NBP)'s positive precession in {N,n}QM.
SunQM-5: A new version of QM based on interior {N,n}, multiplier n', |R(n,*l*)|^2 * |Y(*l*,m)|^2 guided mass occupancy, and RF, and its application from string to universe (drafted in April 2018).
SunQM-5s1: White dwarf, neutron star, and black hole re-analyzed by using the internal {N,n} QM (drafted in April 2018).
SunQM-7: Can we use {N,n} QM and Simultaneous-Multi-Eigen-Description (SMED) to describe our universe?
SunQM-7s1: Relativity and {N,n} QM
SunQM-9s1: Addendums, Updates and Q/A for SunQM series papers.

[24] Major QM books, data sources, software I used for this study:
Douglas C. Giancoli, Physics for Scientists & Engineers with Modern Physics, 4th ed. 2009.
David J. Griffiths, Introduction to Quantum Mechanics, 2nd ed., 2015.

John S. Townsed, A Modern Approach to Quantum Mechanics, 2nd ed., 2012.
Stephen T. Thornton & Andrew Rex, Modern Physics for scientists and engineers, 3rd ed. 2006.
James Binney & David Skinner, The Physics of Quantum Mechanics, 1st ed. 2014.
Wikipedia at: https://en.wikipedia.org/wiki/
(Free) online math calculation software: WolframAlpha (https://www.wolframalpha.com/)
(Free) online spherical 3D plot software: MathStudio (http://mathstud.io/)
(Free) offline math calculation software: R
Microsoft Excel, Power Point, Word.
Public TV's space science related programs: PBS-NOVA, BBC-documentary, National Geographic-documentary, etc.
Journal: Scientific American.

Appendix

A request from the user to the Spherical 3D plot software providers: we need a true rθφ 3D plot software that can plot:
1) a spherical NBP peak at r_n (see Figure 4a, based on eq-40) in a true rθφ 3D plot;
2) a (donut shaped) NBP ring at r_n (based on eq-41) in a true rθφ 3D plot.