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A Modified Bohr Model: Mechanism of Atomic Luminescence and Quantum Entanglement

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ABSTRACT

In his doctoral thesis in 1911, Bohr reached the conclusion that at thermal equilibrium metal atom has no magnetic effect. Therefore, when establishing the hydrogen atom model in 1913, he did not consider the Lorentz force, but only the Coulomb force. The radius of the hydrogen atom he obtained is half smaller, and the orbital rotation frequency is twice larger. It must be multiplied by 1/2 to be consistent with the value of the Rydberg experiment. He proposed to calculate the photon frequency by using the average value of the zero frequency of infinite quantum number and the basic frequency, but it is not applicable to the energy levels for the ordinary quantum numbers, and later he called it the correspondence principle. In our modified Bohr model, we eliminate and solve Bohr's half frequency problem; The photon energy is equal to the difference between the two energy levels, and the photon frequency is equal to the difference between the two rotation frequencies of the electron; All excited states of hydrogen atom are elliptical orbits, and the nucleus is located in the center of the ellipse; The microscopic model of photonic structure is established, and the microscopic mechanism of atomic luminescence and quantum entanglement is given.

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Introduction

Bohr Model and his Half Frequency Puzzle (Conundrum)

In 1913, Bohr published three articles on atomic structure [1]. Under the assumption of discontinuous atomic energy levels, he claimed to derive the empirical formula of Rydberg hydrogen atomic spectrum from some basic physical constants. This is the first time in human history to establish a theoretical model of atomic structure based on atomic spectrum. The first formula he proposed in his first article is

$$\omega = \frac{\sqrt{2}}{\pi}\frac{W^{\frac{3}{2}}}{eE\sqrt{m}}, \quad 2a = \frac{eE}{W} \qquad (1)$$

where ω, W, e, E, m, a are the revolution frequency, energy, electron electric quantity, proton electric quantity, electron mass and orbital radius of the electron in the ground state hydrogen atom, respectively. Bohr uses the electrostatic unit system, in which the Coulomb constant is 1. The potential energy of the electron at radius a is eE/a, (or e^2/a). W is also the ionization energy of the hydrogen atom. Bohr believes that the energy of the photon released when the electron jumps from the energy level at infinity with the rotation frequency of 0 to the lowest energy level with the rotation frequency of ω

$$W = \tau h\frac{\omega}{2}, \qquad (2)$$

where τ and h are quantum numbers and Planck constants, respectively. Bohr derived the formulas for calculating W, ω, and $2a$ from formula (1)

$$W = \frac{2\pi^2 me^2E^2}{\tau^2h^2}, \quad \omega = \frac{4\pi^2 me^2E^2}{\tau^3h^3}, \quad 2a = \frac{\tau^2h^2}{2\pi^2 meE} \qquad (3)$$

Considering that the proton's charge equals electron's charge, that is, E = e, The ground state τ = l, and the known constant values at that time e =4.7 × 10^{-10}, e/m = 5.31 × 10^{17}, and h = 6.5 × 10^{-27} are substituted into equation (3), Bohr got

$2a$ = 1.1 × 10^{-8} cm., ω = 6.2 × 10^{15} sec^{-1}, W /e = 13 volt

On page 8, he assumed that the radiation problems are similar, and the photon energy and frequency v of the radiation when the electron transitions from τ_2 level to τ_1 level are respectively

$$W\tau_2 - W\tau_1 = hv$$

$$v = \frac{2\pi^2 me^4}{h^3} \cdot \left(\frac{1}{\tau_2^2} - \frac{1}{\tau_1^2} \right) \quad (4)$$

On page 9 of his paper, Bohr calculated the value outside the brackets of formula (4)

$$\frac{2\pi^2 me^4}{h^3} = 3.1 \times 10^{15} \quad (5)$$

The calculated value 3.1×10^{15} above is very close to the observed value 3.290×10^{15} in the experiment at that time, and Bohr is relatively satisfied. He wrote: "We agreement between the theoretical and observed values is inside the uncertainty due to experimental errors in the constants entering in the expression for the theoretical value". But he felt that there were still problems, so he wrote the next sentence; "We shall in§3 return to consider the possible importance of the agreement in question". The problem is really troublesome, and it lies in his formula (2).

According to the law of conservation of energy, the energy of emitted photons must be equal to the energy difference between the two corresponding energy levels of the atom. Because the energy is linear with the frequency, the frequency of photons should also be the difference between the two rotation frequencies of the electron. His derivation did not get the correct mathematical relationship of frequency difference. His formula (2) means that when an electron transitions from an infinite energy level with frequency 0 to the lowest energy level with rotation frequency ω, the frequency of emitted photons is equal to half of the lowest energy level frequency, that is, $\nu = \omega/2$. To get $\omega/2$ between 0 and ω, mathematically we can only take the average of the two, that is, $\nu = (\omega + 0)/2 = \omega/2$. This relationship is only applicable to transitions involving one energy level with an infinite quantum number (frequency 0), and transitions between all other two energy levels are not the average of their frequencies. In 2013, Dr. Martin Janat of Max Planck Institute for the History of Science in Germany also believed that "Bohr introduced the relation in his first of three derivations of the Balmer formula [2]. Considering the binding of a free electron from infinity into a stationary state inside the atom, he equated the emitted radiation frequency ν with the mean value of the orbiting frequencies of the free electron and of the electron bound within the atom". For example, the difference between the values A and B is A-B, and their average value is (A+B)/2. The difference is completely different with their average value in physics and mathematics. When B = 0, (A+B)/2=A/2, the 1/2 factor required by Bohr can be obtained. But in most cases, A and B are not equal to 0. How can we get A/2? Because of this 1/2 factor, Bohr replaced the difference between the frequencies of the two energy levels with the average value in his formula (2). This is obviously wrong.

The mistake is 1/2 of his formula (2). The radius of the ground state electron orbit he deduced was exactly half smaller (Bohr used $2a = 1.1 \times 10^{-8}$ cm instead of his atomic radius a when deriving the formula), and the electron rotation frequency was exactly twice larger (Bohr obtained the ground state rotation frequency $\omega = 6.2 \times 10^{15}$ sec^{-1}, instead of the observed value 3.1×10^{15} sec^{-1}), and it must be multiplied by this 1/2 factor to fully match the frequency of the Rydberg empirical formula. To solve this half frequency problem, he changed his quantum number (τ) into a quantum number function, $f(\tau)$. Bohr's model encountered a particularly big half frequency problem here, and he spent nearly 4 pages (P12-15) in the third section without explaining it clearly. This almost became Bohr's lifelong worry. After 1926, the Schrodinger equation and Heisenberg's uncertainty principle seemed to have rescued Bohr. Later Bohr simply gave up his half frequency problem and called it the correspondence principle, that is, only when the quantum number tends to infinity, can the classical theory be consistent with the quantum theory. So, the correspondence principle seemed to become a law of quantum mechanics, but people always questioned the correspondence principle [3].

Modified Bohr Model

Except for half frequency problem, Bohr model is very successful in other aspects. Now when we look back, why does the Bohr model have half frequency problem? The Bohr model only considers the Coulomb force in the hydrogen atom, and does not consider the Lorentz force of the magnetic interaction. Why didn't Bohr consider the Lorentz force on the electron in the hydrogen atom? There are historical reasons for this. In his doctoral thesis in 1911, he came to the conclusion that "a piece of metal in electric and thermal equilibrium will not possess any magnetic properties whatever due to the presence of free electrons" [4]. His reason is that as long as there is a state of equilibrium, the existence of magnetic force will not affect the classical statistical distribution of electrons. He believes that since the electron velocity in any volume element is evenly distributed in all directions, this volume element will not produce magnetic effects. Is these macroscopic classical thermodynamics suitable for the analysis of the force on the internal electrons of atoms?

The orbital magnetic effect in atoms is different from the Coulomb effect, which does not depend on the movement of charges. When an atom is ionized into cation and electrons, their macroscopic Coulomb effect can still be measured. However, the magnetic effect is dependent on the movement of electric charges. Before the atoms are ionized, their orbital magnetic moment related magnetic effects cancel each other, showing no macroscopic magnetic effect; After ionization, their orbital magnetic moments disappear, and there is no macroscopic magnetic effect. The absence of macroscopic magnetic effects does not mean that there is no microscopic orbital magnetic moment in the atom. In short, the movement of electric charges in atoms must produce magnetic fields; The moving electron must be subjected to Lorentz force in the magnetic field. The research conclusion of Bohr's doctoral thesis is not suitable for the analysis of the force on the internal electrons of atoms.

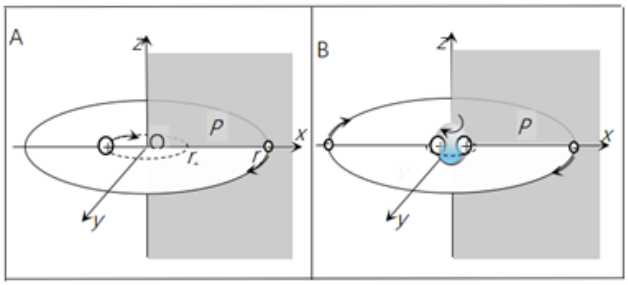

Figure 1: In the ground state hydrogen atom (A) and helium atom (B), their proton current is equal to their electron current, but the direction of two currents is opposite.

As shown in Figure 1A, in the ground state hydrogen atom, both electron and proton are moving in a circle around their common center of mass. The number of positive and negative charges passing through the half plane P in unit time is equal. Although the orbital radii of proton and electron are different, their rotational frequencies are equal, their charges are equal and their signs are opposite. Therefore, two ring currents with equal size and opposite symbols are generated. Figure 1B shows that in the ground state helium atom, two electrons are in the same circular orbit. The two protons in the nucleus and the two electrons outside the nucleus rotate at the same frequency around the central axis of the nucleus, and also generate two ring currents of equal size and opposite symbols on the nucleus and the electron orbit. In both hydrogen and helium atoms, two ring currents produce equal magnetic induction in the same ring region, and the magnetic poles are opposite. All the magnetic lines of force generated by the orbital magnetic moment are closed inside the atom, so there is no macroscopic magnetic effect.

If there is only coulomb force in the ground state hydrogen atom, it will establish a balance with the centrifugal force on the electron, that is

$$\frac{ke^2}{r^2} = \frac{m\upsilon^2}{r} \tag{5}$$

Equation (5) is also the basic formula for the establishment of Bohr model, and its Coulomb force does not depend on the motion of the electron. If an electron moving at the speed υ enters a uniform magnetic field B, this uniform magnetic field does not need the existence of nuclear charges, and the Lorentz force on this electron also establishes a balance with the centrifugal force

$$e(\upsilon \times B) = \frac{m\upsilon^2}{r} \tag{6}$$

As analyzed above, the Coulomb force and Lorentz force coexist in the ground state hydrogen atom. Their resultant force becomes the centripetal force of the electron, and the balance with the centrifugal force of the electron is established as follows

$$\frac{ke^2}{r^2} + e(\upsilon \times B) = \frac{m\upsilon^2}{r} \tag{7}$$

If two forces can balance the third force when they exist alone, then when these two forces as a combined force balance the third force, they can balance half of the third force respectively. Therefore, in equation (7) the Coulomb force must be equal to the Lorentz force because of equations (5) and (6). Equation (7) can be rewritten as

$$\frac{2ke^2}{r^2} = 2e(\upsilon \times B) = \frac{ke^2}{r^2} + e(\upsilon \times B) = \frac{m\upsilon^2}{r} \tag{8}$$

From equation (8), we can get

$$\frac{2ke^2}{r} = m\upsilon^2, \text{ or } 2ke^2 = m\upsilon r \cdot \upsilon \tag{9}$$

In the Bohr model,

$$\frac{ke^2}{a} = m\upsilon^2, \text{ or } ke^2 = m\upsilon a \cdot \upsilon \tag{10}$$

By comparing equations (9) and (10), we can see that the left side of the two equations differs by a factor of 2, which is the reason for the half frequency problem of Bohr model. The radius r in equation (9) should be equal to twice the Bohr radius a in equation (10), that is, $r = 2a$. In Bohr model expressed by equation (10), the orbital angular momentum $m\upsilon a$ is a constant, which is also the quantization condition he uses,

$$m\upsilon a = \frac{h}{2\pi}; \quad \text{or quantization condition:} \quad m\upsilon a_n = \frac{\boldsymbol{h}}{2\pi} \tag{11}$$

where h is the Planck constant and n is an integer, that is, a quantum number. The orbital angular momentum or quantization condition we get according to equation (9) is

$$m\upsilon r = \frac{h}{\pi}; \quad \text{or quantization condition:} \quad m\upsilon r_n = \frac{\boldsymbol{h}}{\pi} \tag{12}$$

According to de Broglie's standing wave principle, the wavelength of any standing wave should be an integral multiple of the basic wavelength, that is, $r_n = nr$. The comparison equations (9) to (12), and the electron velocity υ is probably a constant, which is also consistent with the research results of Sommerfeld in 1916 ($\upsilon = \alpha c$), where α is the fine structure constant, and c is the speed of light in vacuum. Substitute Eq. (12) and $\upsilon = \omega n\, rn$ into Eq. (9), where ωn is the angular velocity of the n-th level electron revolution, we get

$$2ke^2 = m\upsilon r_n \cdot (\omega_n r_n) = \frac{nh}{\pi} \cdot \omega_n \cdot nr = \frac{n^2 hr}{\pi} \cdot 2\pi f_n = n^2 r \cdot 2hf_n = -n^2 r \cdot 2E_n \tag{13}$$

where f_n and E_n are the electron rotation frequency and energy of the nth energy level respectively.

Considering that E is a negative value, by formula (13) we get

$$E_n = -\frac{ke^2}{n^2 r} = -\frac{1}{n^2} \cdot \frac{8.988 \times 10^9 \times (1.602 \times 10^{-19})^2}{2 \times 5.3 \times 10^{-11}} = -\frac{1}{n^2} \times 2.176 \times 10^{-18}\,(\mathrm{J}), \quad \text{or} -\frac{1}{n^2} \times 13\,\mathrm{eV} \tag{14}$$

Here we get the same energy level expression as Bohr model. But in our modified model, the photon energy ΔE is equal to the difference between the energies of the two energy levels, and the photon frequency v is equal to the difference between the electron rotation frequencies of the two energy levels, that is

$$\Delta E = E_2 - E_1; \text{ and } v = f_2 - f_1 = \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \cdot \frac{ke^2}{hr} \tag{15}$$

In our model, Bohr's correspondence principle is no longer needed, and Bohr's half frequency problem is completely solved. The essence of quantization is discontinuity. Of course, the most accurate description of quantization should not use continuous functions. Therefore, calculus is not suitable for the treatment of hydrogen atoms. Our modified model still follows Bohr's idea and does not use differential equations at all. We can completely

solve all the correct quantized solutions of hydrogen atom by using simple algebraic equations [5-9].

Electronic Transition

The radiation mechanism of atoms is missing in quantum mechanics. According to the modified Bohr model, it is easy to deduce the detailed mechanism of atomic absorption or radiation of photons and the microscopic structure of single photons. Because photons are transverse waves, their velocity, electric field and magnetic field vectors are orthogonal to each other, forming a spatial configuration that can be represented by the left or right hand. When a photon with an electric field in the *y* direction shoots at a ground state hydrogen atom in the *x* direction, if the orbital radius of the hydrogen atom is *r*, the orbital plane is also in the *xy* plane, and the intrinsic frequency *v* of this photon happens to match the difference between the two rotation frequencies of the electron in the atom, this photon is absorbed. The electric and magnetic field vectors of the photon absorbed can only increase the orbital radius of the hydrogen atom in the *y* direction, but cannot change the orbital radius in the *x* direction. Starting from the first intersection of the *x*-axis of the photon with the circular orbit, the first half of the circle of the electron is slowed down, the orbit is lengthened, and then accelerated under the action of the photon. When the electron returns to the second intersection with the *x*-axis, it just resumes its original speed. This is also true for the second half of the cycle that began thereafter.

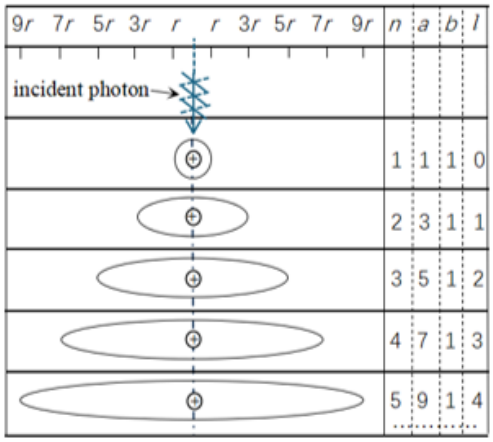

Figure 2: Schematic diagram of orbital shapes and orbital parameters in hydrogen atom.

A photon wave train usually contains tens of millions of waves. Each time the electron absorbs a wave, it increases a very small distance along the semi major axis of the two-way orbit of *y*. But each time the electron returns to the intersection with the *x*-axis, it will return to its original speed. Obviously, the speed of the electron at the short half axis in each excited state is still the same as that in the ground state. So in 1916, Sommerfeld obtained that the electron velocity was constant, that is, $v = \alpha c$, where α is the fine structure constant. In our model, after a photon is completely absorbed, the ground state hydrogen atom changes from a circular orbit to an elliptical orbit, and the nucleus is located in the center of the ellipse, rather than a focus. This is different from Kepler's first law, which describes the motion of planets in the solar system liking Sommerfeld's elliptical orbit. The semi minor axis *b* of the elliptical orbit is along the *x* direction, and $b = r$. The semi major axis *a* is along the *y* direction. After tens of millions of times of continuous small increase of the semi major axis, the electron completes the transition to the high energy level. The transition process of an electron is a continuous change process. The orbital radius, wavelength, orbital angular momentum, energy, and even quantum number are all continuous changes. Therefore, calculus can be used to calculate and describe the transition process.

In 1925, de Broglie put forward the matter wave hypothesis. He believed that the electron wave in the atom must be in phase with the orbital movement of the electron. Therefore, the electron circles the nucleus to complete a wavelength. In addition, according to the standing wave principle in physics, the wavelength of the standing wave must be an integral multiple of the basic wavelength. As shown in Figure 2, the average radius of the elliptical orbit of the hydrogen atom can be an integral multiple of the ground state radius *r*, that is, 1*r*, 2*r*, 3*r*,.... *nr*, where *n* is equal to the principal quantum number in quantum mechanics. It can be calculated from (a +b)/2 = *n*, $n = 1$, $a = 1, b = 1, n = 2, a = 3, b = 1$; $n = 3, a = 5, b = 1; n = 4$, $a = 7, b = 1$;.....;$n = n, a = 2n - 1, b = 1$. In the hydrogen atom, only the ground state orbit is a circular orbit, all other excited states are elliptical orbits, and the atomic nucleus is either at the center of a circle or at the center of an ellipse.

Although the orbital parameters of the hydrogen atom in each steady state are quantized, and the functions representing each parameter are not continuous functions, calculus is not suitable for solving these parameters. But these parameters of the electron in the transition process are continuously changing, so we can use calculus to deal with the transition process of the electron. In equation (14), only energy *E* and quantum number *n* are variables, and others are constants. In the process of electron transition, both *E* and quantum number *n* are continuous changes, which can be regarded as continuous functions. We use *x* to represent the continuously changing *n*, and then differentiate the two sides of equation (14) respectively to get

$$dE = d\left(-\frac{ke^2}{rx^2}\right) = \frac{2ke^2}{rx^3}\cdot dx \qquad (n_1 \le x \le n_2, \text{ or } n_1 \ge x \ge n_2) \tag{16}$$

If an electron absorbs a photon and transitions from n_1 to n_2, the energy ΔE of the photon can be calculated by the following

$$\Delta E = \int_{E_1}^{E_2} dE = \int_{x_1}^{x_2} \frac{2ke^2}{rx^3}\cdot dx = \frac{-ke^2}{rx^2}\Big|_{x_1=n_1}^{x_2=n_2} = \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)\cdot\frac{ke^2}{r} \qquad (n_1 < n_2) \tag{17}$$

If the electron releases photon, $n_1 > n_2$, the value of ΔE is negative, indicating that the corresponding atomic system emits energy.

Polarized Light

Photon is a transverse wave, and its electric field direction and magnetic field direction are perpendicular to its direction of motion. These three vectors form a chiral spatial configuration, which can be represented by the left hand or the right hand. It was once called the spin of a photon and expressed by the spin quantum number +1 or -1. It is easy to misunderstand that spin means photons move forward like spirals. In fact, the photon is neither a ring nor a spiral [10], but a long wave train. All polarization experiments can prove that photons do not rotate when propagating in isotropic media. Polarization experiment or optical rotation experiment are based on polarizer. The polarizer is composed of dichroic substances, which only allow the light vibrating in one direction to pass through.

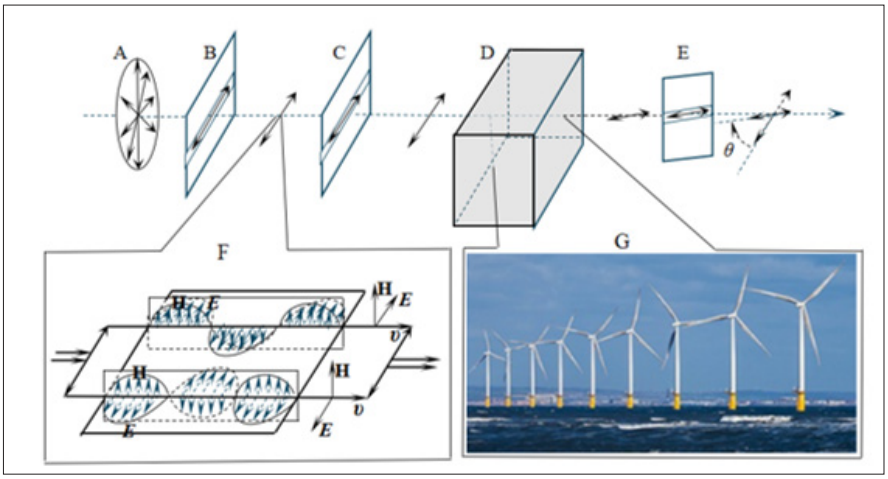

Figure 3: . A) is a natural light source without specific polarization direction, B) polarizer, C) first analyzer, D) sample cell with optically active substance solution, E) second analyzer. The rotation θ angle of polarized light is caused by the optically active material in the sample cell. It shows that photons do not rotate in isotropic media. F) shows a pair of entangled photons having the same polarization direction in the opposite directions of the left hand and the right hand. G) shows that the reason for the rotation of the wind blade is not the rotation of the wind, but the chiral structure of the blade; Same as polarized light.

Before 1950, expensive Nicol prisms were used. The polarizer used now is usually a knife shaped polarizer. It is formed by nonlinear crystal or by dichroic organic crystals, such as iodine quinine sulfate, tourmaline or polyvinyl alcohol film, which are soaked in iodine solution, stretched and dried at high temperature, and then stuck between two glass sheets. These organic polymer crystals are stretched in a certain direction at high temperature, and can form intermolecular gaps along the stretching direction that allow polarized light vibrating in that direction to pass through. The stretching direction is called the polarization direction of the polarizers, also called the light transmission axis.

The intermolecular gap (light transmission axis) of a polarizer or analyzer can allow the electric field vector of photons for parallel to it to pass through, but does not prevent the magnetic vector of photons to pass through. Because the gap of the polarizer or analyzer has a certain width range, the obtained linearly polarized light also has a certain linewidth. In quantum communication, people can choose 0° reference line as the light transmission axis, create horizontal and vertical (0° and 90°), 45° and 135° as the linear polarization conjugate basis, and also choose left and right chirality as the conjugate basis for encoding and transmitting information.

The upper part of Figure 3 shows the detection or optical activity experiment of linearly polarized light. The A is a natural light source with the same amplitude in all directions, which does not show a special polarization direction. If no optically active substance is placed between polarizers B and C, slowly rotates polarizer C. Bright light can be observed only when the transmissive axis of C is parallel to of B. The sample cell D containing a solution of optically active substances (such as glucose) is placed between C and E. When the light transmission axes of C and E are parallel, a dark scene is observed. Turn E slowly, and the brightest is observed when turning to θ angle. The direction of θ angle is determined by the type of optically active substance in the sample cell, and the size of θ angle is proportional to the concentration of optically active substance and the thickness of the sample cell. The polarimeter used in sugar industry to measure the concentration of sucrose solution is designed according to this principle [11].

The rotation of the polarization plane of linearly polarized light is due to the effect of the optically active material in the sample cell. The optical activity substance in the sample cell determines the rotation direction of linearly polarized light. Figure 3F shows 1.5 Poynting wavelengths of two chiralically opposite photons moving in the same direction. When propagating in isotropic media, the spatial direction of the electric and magnetic vectors of photons remains unchanged.

Figure 3G takes the impeller of wind power generation as an example, again emphasizing that photons do not rotate when they move forward in an isotropic medium. It is the same reason that photons pass through optically active materials and wind passes through the impeller of wind power generation. The air flow through the impeller has no obvious rotation, and there is no left and right rotation. Because the blades of the fan have the same chiral distortion, the impeller rotates in the same direction under the action of the wind. The blade can be made into two kinds of chiral twist, and the impeller can also get two different rotation directions. We saw rows of wind turbine impellers rotating in the same direction in the field because they were all equipped with the same chiral twisted blades.

Microstructure of Photons

The microstructure of a pair of photons is shown in the Figure 3F. A photon is a long wave train. In the figure, only 1.5 wavelengths of spatial configuration of a pair of photons with left-handed and right-handed chirality is drawn. Photons have chirality but do not rotate. The word chirality is very appropriate. The human body has a left hand and a right hand, but it does not mean that the left hand is always rotating to the left and the right hand is always rotating to the right. People wear left gloves on their left hand and right gloves on their right hand; The left foot wears the left shoe, and the right foot wears the right shoe; This is chirality. It can be seen from stereoorganic chemistry that the optically active substances are determined by chiral molecules, and the chiral molecules are determined by chiral carbon atoms. Photon has chirality, and its transverse vector will rotate when it meets with chiral optically active material. Although the photon along the moving direction cannot change the orbit radius of *x direction* of the electron, the

light beam can make the mica vane wheel in the vacuum tube rotate, which proves that the photon has momentum along the moving direction (x). The momentum of the absorbed photon can change the movement of the entire hydrogen atom along the x direction, and it obeys the momentum conservation principle in the whole process of action. The absorption or release of a photon is completed in a free path between two effective collisions of atoms absorbing or emitting photon. In other words, the transverse vector of photons changes the transverse radius of the electronic orbit, and the longitudinal velocity vector of photons changes the longitudinal motion of atoms.

A photon length is the length L of a photon wave train and is also the coherent length of photons [12]. The time when a photon is absorbed or emitted by an atom is its coherence time τ. The energy of a photon is equal to the difference between the two energy levels of the emitting atom, and its frequency is equal to the difference between the two rotation frequencies of the electron. The energy level difference of an atom determines the frequency or wavelength of photon absorbed or emitted, but cannot determine the length of the photon wave train. For gaseous atoms emitting or absorbing photons, the emission or absorption of a photon must be completed in a free path of motion (vibration) of the atoms. If the average rate of the thermal motion of the gaseous atom is υ, and the time for it to complete a free path (S) is equal to the coherent time τ of the photons, then

$$\frac{L}{c} = \frac{S}{\upsilon} = \tau \tag{18}$$

If the free path of an atom emitting photon is extremely short, the emitted photon wave train will be short, the emitted pulse time will be short, and the radiation power will be large if photons of the same frequency or energy are emitted. The length L of a photon wave train has the following relationship with wavelength λ and linewidth $\Delta\lambda$ [13]

$$L = \frac{\lambda^2}{\Delta\lambda}, \text{ or } \quad \frac{L}{\lambda} = \frac{\lambda}{\Delta\lambda} = N \tag{19}$$

Equation (19) shows that L/λ is the wave number (N) contained in a photon wave train. The line width $\Delta\lambda$ can be regarded as the difference between two adjacent wavelengths in the photon wave train. It can also be seen from Formula (19) that the wavelength of the train head and train tail of a photon wave train is different. Because the photon emission starts at the high energy level and ends at the low energy level. High energy level corresponds to low frequency and long wavelength, while low energy level corresponds to high frequency and short wavelength. Therefore, we know that the train head wavelength (λ_h) of a photon wave train is longer and the train tail wavelength (λ_t) is shorter. If N is not very large, there are (N-1) $\Delta\lambda$ in the wave train. Generally, N is up to tens of millions. We can approximately think that N-1≈N. Therefore, $N \cdot \Delta\lambda = \lambda$, $\lambda_h - \lambda_t = \lambda$. The λ is the intrinsic wavelength of the photon wave train or the average wavelength. Let $\lambda_h = \lambda + x$, $\lambda_t = \lambda - x$, then solve it, get

$$\begin{aligned} &(\lambda + x) - (\lambda - x) = \lambda; \quad \text{solve it, get} \quad x = \frac{1}{2}\lambda \\ &\lambda_h = \frac{3}{2}\lambda; \quad \lambda_t = \frac{1}{2}\lambda; \quad \text{or} \quad \frac{\lambda_h}{\lambda_t} = 3 \end{aligned} \tag{20}$$

Einstein's photon energy formula $E = h\nu$, where the frequency ν is only the average frequency or eigen-frequency of the photon wave train; Similarly, Einstein's photon wavelength λ is only the average wavelength or the eigen-wavelength of the photon wave train. It can be seen from Formula (20) that the first wavelength at the head of any photon wave train is 1.5 times of the eigen-wavelength; The last wavelength at the tail is half of the eigen-wavelength; The first wavelength of the head is three times the last wavelength of the tail. We can also see that the wavelength or frequency of photons absorbed or released by atoms or molecules can be selected as long as they are between 0.5 and 1.5 times. Similarly, in radio communication, the compatibility of the channel with the radio frequency can change at least in the range of 0.5~1.5 times of the main frequency.

Compared with natural visible light, for the same wavelength, the laser has a particularly large L, a particularly small $\Delta\lambda$ and a particularly easy coherence [14]; On the contrary, entangled light has a very small L, a very large $\Delta\lambda$, a very difficult coherence, a very short launch time and a very large launch power. Photons of the same wavelength (or frequency) have the same energy, but can have different photon lengths. For example, $L_{laser} > L_{natural} > L_{entagement}$. Therefore, the coherent entangled photons can be obtained only by preparing mutually entangled and synchronized atoms emitting light. As the laser source for pumping photons, most of the light-emitting atoms are in the gas state and have a large free path, so the pumping laser has a large wave train length L and a small linewidth $\Delta\lambda$. After being absorbed by a nonlinear crystal (such as β - BaB2O4) or a photonic crystal fiber (PCF), or GaP OPA when the frequency or wavelength is roughly unchanged, because the free path of the light-emitting atoms in the crystal is far less than the free path of the gas atoms of the light source of the pump laser, the wave train length L of the emitted photons is shorter, the linewidth $\Delta\lambda$ is larger, the photon pulse is shorter, and the transmission power is larger [15]. Based on this, the ultrahigh power laser weapon can be developed. A small number of entangled photons with roughly equal frequency (difficult to coherent) are mixed in the optical fiber communication, which is difficult to be detected by ordinary communication equipment, so it constitutes invisible state transmission - **"Quantum Teleportation"**. According to this characteristic, the quantum key distribution can be developed.

Conclusion

In 2021, one of the authors of this article, Xiao En Wang submitted a paper to Nature magazine with the title of "New Hydrogen Atom Model and Radiation Absorption Mechanism", and the editor sent it to the external reviewer. Because one reviewer did not recognize the speed of electrons, the paper was rejected. Therefore, this article is only published in the form of preprint on the preprint platform of Nature magazine. In 2024, X. E. Wang published two articles about atomic structure in the Japanese Journal of Japanese Studies: "A Rydberg Bohr de Broglie hydrogen atom algebraic model" and "On atomic structure"; In the same year, he published two articles about atomic structure in the American Journal of Physical and Optical Sciences: "Schrodinger equation uses the wrong energy relationship", "On magnetism: qualitative description". On April 25, 2025, we were invited to Barcelona of Spain to participate in the International Conference on Wave Equations, Optical Engineering and Quantum Mechanics (ICWOQ 2025). At the conference, we made a speech entitled "On Quantum Physics Without Schrödinger Equation".

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