

# EXPLAINING QUANTUM ENTANGLEMENT WITH AN INFERENCE FROM EINSTEIN'S MASS-ENERGY EQUIVALENCE RELATION

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**Abstract:** We proved that the photon entanglement system and the independent photon system have the same intrinsic time based on the "mass-energy equivalence" inference of Einstein's relativity theory. From this result, we revealed the feature of the non-flowing intrinsic time of quantum entanglement system. Based on this feature, we deciphered the phenomenon of quantum entanglement and its non-locality.

**Keywords:** quantum entanglement, mass-energy equivalence, intrinsic time

## Background

The physical system of quantum entanglement has two distinct features. First, as the system follows an integrated behavior model, there is no independence in the parts of the system. Second, the non-locality revealed from the system measurement determines the correlation among all parts of the system, which results in the incompatibility with the local symmetry of electromagnetic force, strong nuclear force, weak nuclear force and gravitation.

Non-local correlation is a controversial concept presented in the EPR paper [1] in the form of an ideal experiment, and this concept has been proved by experiments to be a physical reality. Since the physical world accepts the existence of non-locality, there must be a reason for that. In this paper, we adopted the theory of "mass-energy equivalence" to analyze the intrinsic properties of entanglement system and identify the key to explaining the quantum entanglement phenomenon.

## Results

### 1. The leading role of photons

The quantum entanglement system is very complicated. It can be classified into two-particle and multi-particle systems, and each system involves fermions and bosons. It is critical to find the key element and simplify the framework. The quantum entanglement occurs in the electromagnetic field, in which the only normalized boson is photon. Therefore, photons should play the dominant role of electromagnetic field. We emphasize the leading role of photons in our study without engaging the wave-particle duality of microscopic particles. We propose the assumption that the wave of microscopic particles is derived from the wave of photons. Our study became simplified under the leading role of photons.

We take electrons as an example of microscopic particles. Electrons can be divided as single-electron systems and two-electron systems.

#### 1.1 Single-electron system:

In quantum mechanics, single electrons have the property of De Broglie waves, and expressed in the formula of De Broglie:

$$P = \frac{h}{\lambda} \tag{1}$$

(Note: P is momentum, h is the Planck constant,  $\lambda$  is wavelength)

Based on formula (1) and Einstein's dispersion equation  $E^2 = (PC)^2 + (m_0C^2)^2$ , we calculated the wave velocity U of de Broglie wave as:

$$U = E / P = \frac{mC^2}{mV} = \frac{C}{V} C \quad (2)$$

(Note: E is energy, P is momentum,  $m_0$  is stationary mass, m is motion mass, V is velocity, C is the speed of light)

Provided that V is always less than C, U is always greater than C, which means U is always superluminal. This result is inconsistent with relativity, thus the wave velocity U is implausible.

According to the assumption that the wave of microscopic particles is derived from the wave of photons, if a stationary electron absorbs a photon, the photon will give momentum to the electron while conferring the wave property to the electron. Adopting Bohr's concept of energy levels, we assume the ground state for stationary electrons with the energy  $E_0$ . After absorbing photons, the electrons enter the excited state with corresponding energy as E. The energy difference between the excited state and the ground state is  $\Delta E = E - E_0$ , that is,

$$\Delta E = mC^2 - m_0C^2 = \Delta mC^2 \quad (3)$$

According to the Planck formula, the frequency  $\nu$  of the electron can be derived from:

$$\Delta E = h\nu \quad (3-1)$$

Combined with the De Broglie formula (1), we get the result:

$$\frac{\Delta E}{P} = \frac{\Delta mC^2}{mV} \quad (4)$$

$$\frac{\Delta E}{P} = \frac{h\nu}{h/\lambda} = \lambda\nu \quad (5)$$

Taking equation (4) and expanding in power series, we get equation:

$$\frac{\Delta E}{P} = \frac{\Delta mC^2}{mV} = \left(1 - \frac{m_0}{m}\right) \frac{c^2}{V} = \left(1 - \frac{m_0}{m_0 / \sqrt{1 - \frac{V^2}{c^2}}}\right) \frac{c^2}{V}$$

$$= \left( 1 - \sqrt{1 - \frac{V^2}{c^2}} \right) \frac{c^2}{V} = \left( 1 - \left( 1 - \frac{1}{2} \left( \frac{V^2}{c^2} \right) - \frac{1 \cdot 1}{2 \cdot 4} \left( \frac{V^2}{c^2} \right)^2 - \frac{1 \cdot 1 \cdot 3}{2 \cdot 4 \cdot 6} \left( \frac{V^2}{c^2} \right)^3 - \dots \right) \right) \frac{c^2}{V}$$

The velocity V has two scenarios, low and high. When  $V \ll C$ , the high-order items are removed and we get the equation:

$$\frac{\Delta E}{P} = \left( \frac{1}{2} \frac{V^2}{C^2} \right) \frac{C^2}{V} = \frac{1}{2} V \quad (6)$$

When  $V \rightarrow C$ , we make the summation of series and get the equation:

$$\frac{\Delta E}{P} = \left( \frac{V^2}{C^2} \right) \frac{C^2}{V} = V \quad (7)$$

Bringing (6) and (7) into (5), we get the equation:

$$V = 2\lambda\nu \quad (8)$$

$$V = \lambda\nu \quad (9)$$

Equation (8) and (9) describe the relationship between velocity and wave parameters for electrons in low velocity and high velocity situations. The two equations are consistent with empirical facts. Equation (9) reflects the general applicability of microscopic particles. Its form can be generalized to the light velocity C of photons.

## 1.2 Dual-electron system

Two electrons may form a dual-electron entanglement system under certain conditions. The key condition to form this system is that the two electrons must complete two successive processes of collision and separation. The process of elastic collision is shown as follows:

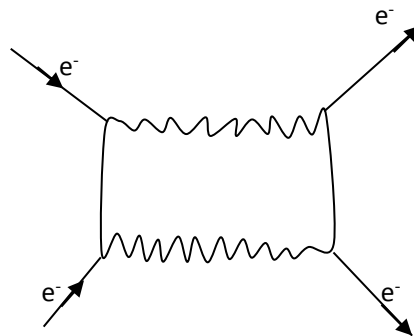


Figure 1. Collision and separation process of two electrons

As shown in Figure 1, if the causal law is still effective for electromagnetic action, then the description of the unmeasurable process is natural, and it is helpful to place the quantum entanglement system in the same physical mode. When two independent electrons collide, the two enter the *fixed point* and stand still. At this time, the collision energy is transformed into a stationary mass transition form with zero spin at the collision center point, and the form is regularly split into two entangled photons, then the two photons are absorbed by the electrons, so that the two electrons regain the energy to achieve complete elastic separation. In this way the dual-electron entanglement system forms. However, the system also needs to meet the requirements of no changes in the parity and zero total spin. Based on this, we use the Feynman's notation [2] where the symbol "+" represents electron movement upward along the z axis with  $+\frac{1}{2}\hbar$  spin, and "-" represents electron movement downward along the z axis with  $+\frac{1}{2}\hbar$  spin. Let the total state of the dual-electron entanglement system be  $|\phi\rangle$ , then

$$|\phi\rangle = |+, -\rangle + |-, +\rangle$$

The formula is written more precisely as:

$$|\phi\rangle = \frac{\sqrt{2}}{2} (|+\rangle_1 \otimes |-\rangle_2 + |-\rangle_1 \otimes |+\rangle_2)$$

Applying the parity operator  $p$  to  $|\phi\rangle$ , we will get:

$$P|\phi\rangle = |\phi\rangle$$

Now, the dual-electron entanglement system meets the requirement of no changes in the parity and zero total spin. In short, the photons' dominating role is so significant that the entanglement property of the two physical particles is derived from the entanglement property of the absorbed entangled photon pair. Moreover, in the process in Figure 1, the two entangled photons, which are generated from the splitting of full resting mass, reach electrons in the velocity of light. Therefore, the initial intrinsic time of dual-electron entanglement system is the intrinsic time of the dual-photon entanglement system. Therefore, we can reasonably postulate that the physical particle entanglement system has the identical intrinsic time as the photon entanglement system.

## 2. Complete process of mass-energy conversion

Mass-energy equivalence is an important inference of the relativity theory, expressed as the formula  $E = mc^2$ . It is applicable to all forms of mass-energy relationship in independent physical systems, as well as the complete mass-energy conversion system that we discuss here.

According to the standard theory, the basic particles of matter and antimatter in the physical universe correspond to each other, such as electrons and anti-electrons (positrons). The profound implication is that it is impossible to achieve complete mass-energy conversion for neither material particles nor anti-matter particles alone; rather, the conversion can only be realized through counterpart particle pairs. For example, the positronium system is composed of electrons and anti-electrons. Positronium is a hydrogen-like atom consisting of an electron and an anti-electron. It is unstable and can quickly annihilate to two entangled photons (Figure 2).

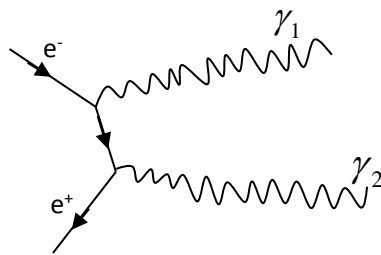


Figure 2. Positronium annihilation to two photons

As shown in Figure 2, the two photons generated by the annihilation of the positronium is an entanglement system. The dual-photon entanglement system can form through annihilation of opposite particles, or through the transition form in the process of complete elastic collision of two particles (Figure 1), as well as the spontaneous parametric down conversion (SPDC) performed in laboratory experiments. SPDC is shown in Figure 3.

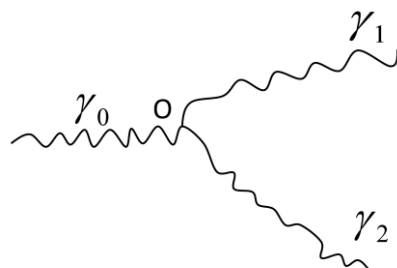


Figure 3. Splitting of the mother photon into two entangled photons

As we know, it is impossible for a photon to "split" into two photons spontaneously. Otherwise, it would disobey the conservation of angular momentum. Hence, something unusual must have happened at the bifurcation point O in Figure 3. By carefully considering the three aforementioned methods, we believe that the physical state before the formation of the dual-photon entanglement system should resemble the transition form with full resting mass that exists prior to the positronium annihilation. What could that be?

If the objects of our study obey the law of causality, it is natural that the dual-photon entanglement system originates from the same type of transitional form. Taking the annihilation of positronium as an example, when the process reaches the key point where the positive and negative charges cancel off, a complete resting mass state will form a material form where the charge is zero, the spin is zero, the momentum is zero, the energy is zero, the difference between matter and antimatter is zero, and the parity is unchanged. We call this state *pure resting mass state*. Accordingly, the dual-photon entanglement system can be named *pure resting energy state* (the charge is zero, the spin is zero, the momentum is zero, the rest mass is zero, the difference between matter and antimatter is zero, and the parity is unchanged). The word *resting* in these names refers to both the still status of the spatial position and the existence of a motionless center in the space expanding spherically at a light speed. *Pure* refers that the equal quality of matter and antimatter.

We note that pure resting mass state and pure resting energy state are symmetrical. However, neither of the states is boson or fermion; instead, it is the Bell state. The corresponding mass and energy can be converted completely. According to the invariable property of time inversion in an electromagnetic field, we consider that complete mass-energy conversion is a reversible process. We use  $|m^0\rangle$  to represent pure resting mass state, and use  $|\varepsilon^0\rangle$  to represent pure resting energy state, then the reversible process can be expressed as

$$|m^0\rangle \rightleftharpoons |\varepsilon^0\rangle \quad (10)$$

In addition, the pure resting mass  $m^0$  in  $|m^0\rangle$  and the pure resting energy  $\varepsilon^0$  in  $|\varepsilon^0\rangle$  follow Einstein's mass-energy equation:

$$\varepsilon^0 = m^0 C^2 \quad (11)$$

Therefore, the mass-energy equivalence inferred from the relativity theory and the process of complete mass energy conversion should have certain connection, which is exactly what we want to elucidate.

### 3. Intrinsic time of photon and photon entanglement system

An independent photon system has its own intrinsic space-time coordinates. The intrinsic time of an independent photon system has some important features. Symmetrical transformations in physics, e.g., transformation of invariant action, is applicable to the objects we investigate. Firstly, for a charged particle with  $m_0$  rest mass moving in an electromagnetic field, its action of symmetrical transformation is expressed as:

$$\int \mathcal{L} dt = \int \gamma \mathcal{L} d\tau \quad (12)$$

(Note:  $\gamma = \frac{1}{\sqrt{1 - \frac{V^2}{C^2}}}$ ,  $t$  is observation time,  $\tau$  is intrinsic time)

The action is the integral of the Lagrangian function density  $\mathcal{L}$  over time.

For free particles,  $\gamma \mathcal{L} = a$  ( $a$  is constant). Substituting it into (12), we get:

$$\int \sqrt{1 - \frac{V^2}{C^2}} dt = \int d\tau \quad (12-1)$$

For independent photons,  $\sqrt{1 - \frac{V^2}{C^2}} = 0$ , thus:

$$\int 0 dt = \int d\tau \quad (12-2)$$

On the left of equation (12-2), the left integrand is 0 so that the integral is 0, whereby the right hand side  $\int d\tau = 0$ , which is equivalent to  $\int_{\tau_1}^{\tau_2} d\tau = 0$ , namely,  $\tau_1 = \tau_2$ . Therefore, it may be represented as a general form:

$$\Delta\tau = 0 \quad (12-3)$$

Equation (12-3) indicates that any physical event that happens to an independent photon is instantaneous for the reason that its intrinsic interval  $\Delta\tau$  is always 0. It is irrelevant to observation time interval  $\Delta t$ . In other words, the intrinsic time of an independent photon does not flow, and any "speed" in the internal space and time is infinite.



Now we can discuss the intrinsic time of the photon entanglement system. According to equation (10),  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state are the different forms of the same entity, and can also be considered as two different physical states of one physical existence. Either of the two physical states can be obtained from the other by a "virtual rotation" of the nature. Therefore, the conversion between  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state is a symmetric transformation with unchanged amount of action. Based on the property of the  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state, it is reasonable to compare them to the symmetry of Heisenberg isospin. The latter theory was proposed to reconcile the inability of strong interaction to distinguish protons and neutrons, and it successfully depicted the symmetric transformation between protons and neutrons using the SU(2) group. As the analogy, we propose the concept of *equivalent spin* (equivalent refers to mass-energy equivalence) to describe the symmetric transformation of the  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state. We depict equivalent spin with the SU(2) group.

Assuming the quantum state of the same physical entity for  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state as  $|I\rangle$ , we have:

$$|I\rangle = a|m^0\rangle + b|\varepsilon^0\rangle \quad (13)$$

In the equation, the coefficients **a** and **b** are complex numbers, which follow the relationship  $|a|^2 + |b|^2 = 1$ . The left two variables represent the probability of generating  $|m^0\rangle$  and  $|\varepsilon^0\rangle$ . When expressed in matrix symbols,  $|m^0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ ,  $|\varepsilon^0\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$ . Substituting them into equation (13), we get:

$$|I\rangle = a \begin{pmatrix} 1 \\ 0 \end{pmatrix} + b \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} a \\ b \end{pmatrix} \quad (14)$$

Analogous to the isospin matrix, we derive the equivalent spin matrix. From the Pauli matrices  $\sigma$ , we get:

$$D_1 = \frac{1}{2}\sigma_x = \frac{1}{2} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad D_2 = \frac{1}{2}\sigma_y = \frac{1}{2} \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \quad D_3 = \frac{1}{2}\sigma_z = \frac{1}{2} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

D1, D2, and D3 are the three components of vector D in the equivalent spin space. Therefore:

$$D^2 = D_1^2 + D_2^2 + D_3^2 = \frac{3}{4} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$D_1^2 = D_2^2 = D_3^2 = \frac{1}{4} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Next, we calculate the eigenvalue of equivalent spin and get:

$$D^2 |m^0\rangle = \frac{3}{4} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \frac{3}{4} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \frac{3}{4} |m^0\rangle$$

$$D^2 |\varepsilon^0\rangle = \frac{3}{4} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \frac{3}{4} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \frac{3}{4} |\varepsilon^0\rangle$$

$$D_3 |m^0\rangle = \frac{1}{2} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = +\frac{1}{2} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = +\frac{1}{2} |m^0\rangle$$

$$D_3 |\varepsilon^0\rangle = \frac{1}{2} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = -\frac{1}{2} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = -\frac{1}{2} |\varepsilon^0\rangle$$

From the above formulas, we can see that  $|m^0\rangle$  and  $|\varepsilon^0\rangle$  are the eigenstate when the eigenvalue of  $D^2$  is  $\frac{3}{4}$ , and the eigenstate when the eigenvalue of  $D_3$  is  $\pm \frac{1}{2}$ . Meanwhile, the equivalent spin  $D$  of both  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state is  $\frac{1}{2}$ , but the third component of the equivalent spin is different: for  $|m^0\rangle$  state, it is  $+\frac{1}{2}$ ; for  $|\varepsilon^0\rangle$  state, it is  $-\frac{1}{2}$ .

Further,  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state have the following features: (1) Both  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state are Bell state with zero spin. (2)  $|m^0\rangle$  state is extremely unstable and annihilates quickly to  $|\varepsilon^0\rangle$  state. (3) Even though both  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state are Bell state, both have the tendency to polymerize. Under the premise of not violating the conservation of parity,  $|\varepsilon^0\rangle$  state can merge into a single multi-photon entanglement system, especially when  $n$  is a natural number with odd parity,  $|m^0\rangle$  state and  $|\varepsilon^0\rangle$  state have the following two different forms of combination:

$$|m_1^0\rangle + \dots + |m_n^0\rangle = |m_1^0 \dots m_n^0\rangle \quad (15)$$

$$|\varepsilon_1^0\rangle + \dots + |\varepsilon_{2n-1}^0\rangle = |\varepsilon_1^0 \dots \varepsilon_{2n-1}^0\rangle = |\varepsilon^0\rangle \quad (16)$$

Equation (15) is the polymerization mode of a number of  $|m^0\rangle$  state. Equation (16) is the spontaneous merging mode of a number of  $|\varepsilon^0\rangle$  state.

In short, the modes of combination like shown above indicate that the equivalent spin symmetry and isospin symmetry are not completely identical. In a specific physical process, the conservation law corresponding to the equivalent spin symmetry does not exist, that is, the equivalent spin symmetry breaks spontaneously. Equation (16) depicts the merging of multiple dual-photon entanglement systems into a multi-photon entanglement system. Therefore, the equation can be abstracted in math as  $1 + 1 + 1 + \dots = 1$ , which can find the counterpart in the Cantor Infinite Set. The Cantor Infinite Set has a theorem that adding several infinite sets together with the same cardinality are an infinite set with same cardinality. Take the following infinite set as an example:

$$\left(\aleph_0\right)_1 + \left(\aleph_0\right)_2 + \dots + \left(\aleph_0\right)_n = \aleph_0 \quad (17)$$

In consequence, we believe that the photon entanglement system includes an infinite physical property. In order to continue elucidating the equivalent spin symmetry of two objects' symmetric transformation, we adopt the concept of SU(2) group.

For a symmetric transformation of equivalent spin, each new state is considered a linear combination of  $|m^0\rangle$  and  $|\varepsilon^0\rangle$ , i.e.

$$\begin{cases} |m^{0'}\rangle = a|m^0\rangle + b|\varepsilon^0\rangle \\ |\varepsilon^{0'}\rangle = -b^*|m^0\rangle + a^*|\varepsilon^0\rangle \end{cases}$$

To simplify, we get:

$$\begin{pmatrix} m^{0'} \\ \varepsilon^{0'} \end{pmatrix} = u \begin{pmatrix} m^0 \\ \varepsilon^0 \end{pmatrix} \quad (18)$$

$$u = \begin{pmatrix} a & b \\ -b^* & a^* \end{pmatrix} \quad (19)$$

u is a  $2 \times 2$  matrix with a unitary condition as  $u^\dagger u = \mathbf{1}$  ( $\det u = 1$ ;  $a^2 + b^2 = 1$ ).  $a^*$  and  $b^*$  are the conjugate complex number of a and b, respectively. u matrix is first transposed and then complex

conjugated, expressed as  $(u^\dagger)_n^m = (u_n^m)^*$ . The set  $\{u\}$  of all the  $u$  matrices constitutes the SU(2) group. For this group, the group elements of the component index label without field quantity is denoted as:

$$(20)$$

Since we use SU(2) group to depict the equivalent spin symmetry, the generator  $T^\alpha$  should be the equivalent spin operator. Correspondingly, the equivalent spin has three components including D1, D2, D3. Analogous to the isospin, the equivalent spin should belong to the overall normative symmetry. Namely,  $\theta$  in the group element  $u(\theta)$  is irrelevant to the space-time coordinates.

Now, we can make the discussion whether the equivalent spin conservation, required by Noether's theorem, exists. Suppose in the rotation of the inner space of the equivalent spin, the transformation of the field quantity  $\Phi(x)$  is simplified as [3]:

$$\phi(x) \rightarrow \phi'(x) = \exp(-i\theta^\alpha T^\alpha) \phi(x) \quad (21)$$

Due to the independence of  $\theta$  to the time and space coordinates, the derivative of space and time of field quantity  $\Phi(x)$  is transformed with field quantity  $\phi(x)$  itself, i.e.,

$$\phi_{,u}(x) \rightarrow \phi'_{,u}(x) = \exp(-i\theta^\alpha T^\alpha) \phi_{,u}(x) \quad (22)$$

In the equation,  $\phi_{,u}(x) = \frac{\partial \phi(x)}{\partial X^u}$ , hence the symbols can be simplified as:

$$\phi = \phi(x)$$

$$\phi_{,u} = \phi_{,u}(x)$$

Suppose the Lagrangian function density of the photon entanglement system  $\mathcal{L} = \mathcal{L}(\Phi, \Phi_{,u})$ , under norm transformation, the Lagrangian function density remains invariant, hence:

$$\mathcal{L}(\Phi, \Phi_{,u}) = \mathcal{L}(\Phi', \Phi'_{,u}) \quad (23)$$

If the group parameter  $\theta^\alpha$  is an infinitesimal, equation (21) becomes:

$$\phi' = (1 - i\theta^\alpha T^\alpha) \phi$$

Therefore, we get  $\delta\phi = \phi' - \phi = -i\theta^\alpha T^\alpha \phi$

From equation (23), we get:  $\mathcal{L}(\Phi', \Phi'_{,u}) - \mathcal{L}(\Phi, \Phi_{,u}) = 0$ . Consequently, we arrive:

$$\mathcal{L}(\phi + \delta\phi, \phi_{,u} + \delta\phi_{,u}) - \mathcal{L}(\phi, \phi_{,u}) = 0 \quad (24)$$

To make expansion of the first term on the left side of the equation (24) in the  $\delta\phi$  and  $\delta\phi_{,u}$  power series, and considering that  $\delta\phi$  and  $\delta\phi_{,u}$  are infinitesimal, we abandon the quadratic term and higher order terms, and obtain that:

$$\frac{\partial\mathcal{L}}{\partial\phi} \delta\phi + \frac{\partial\mathcal{L}}{\partial\phi_{,u}} \delta\phi_{,u} = \frac{\partial}{\partial X^u} \left( \frac{\partial\mathcal{L}}{\partial\phi_{,u}} \delta\phi \right) = 0 \quad (25)$$

For the part  $\frac{\partial\mathcal{L}}{\partial\phi_{,u}} \delta\phi$  in equation (25), bring in  $\delta\phi = \phi' - \phi = -i\theta^\alpha T^\alpha \phi$ , and pay

attention to the arbitrariness of  $\theta^\alpha$ , then

$$\frac{\partial\mathcal{L}}{\partial\phi_{,u}} \delta\phi = \frac{\partial\mathcal{L}}{\partial\phi_{,u}} (-i\theta^\alpha T^\alpha \phi) = J_u^\alpha \quad (26)$$

$J_u^\alpha$  is the conservation flow of the field, which is brought into equation (25), and then we obtain that:

$$\frac{\partial}{\partial X^u} (J_u^\alpha) = 0 \quad (27)$$

Generally speaking, it is possible to derive further related laws of conservation on the basis of equation (27). However, the boson characteristics of the photon entanglement system determines that it is different from proton and neutron systems. The latter follow the isospin conservation law. By contrast, the equivalent spin of the photon entanglement system is not conserved. What we need to do is to find the reason of the spontaneous break of the symmetry for equivalent spin.

According to the expression of action, in each of the continuous symmetric transformation, the variation  $\delta S$  of the action  $S$  is equal to zero, that is,

$$\int_R \frac{\partial}{\partial X^u} (J_u^\alpha) d^4 X = 0$$

(28)

Expanding the left side of equation (28), we get:

$$\int_R \frac{\partial}{\partial X^u} (J_u^\alpha) d^4 X = \int_R \left( \frac{\partial J_1^\alpha}{\partial X^1} + \frac{\partial J_2^\alpha}{\partial X^2} + \frac{\partial J_3^\alpha}{\partial X^3} \right) d^4 X + \int_R \frac{\partial J_0^\alpha}{\partial X^0} d^4 X \quad (29)$$

Note:  $d^4 X = dX^0 dX^1 dX^2 dX^3 = d\tau dx dy dz$

Using Gaussian theorem, the equation (29) becomes (30):

$$\int_R \frac{\partial}{\partial X^u} (J_u^\alpha) d^4 X = \oint_{\partial R} J_l^\alpha dS_l + \frac{\partial}{\partial \tau} \int_R J_0^\alpha d^4 X \quad (30)$$

In the above formula,  $dS_l$  is the surface area element,  $\tau$  is the intrinsic time. The integration is over the four-dimensional volume  $R$  which is surrounded by the three-dimensional curve surface  $\partial R$ . In addition, although the inner space and time of the equivalent spin expands at the speed of light, on the entire surface of the inner space of the field, the total flux of conserved flow  $J$  going in and out  $\partial R$  is zero. Hence, the first term at the right-hand of equation (30) is zero. As a result, the second term on the right-hand of the equation becomes a key term. The result of second term is chosen by the physical world: it is either zero or non-zero, no exceptions. The result of zero would indicate that the conservation law of the equivalence spin is valid, and by contrast, the result of non-zero would indicate that the conservation law is invalid. The deeper implication of the non-zero result is the spontaneous break of the equivalent spin symmetry. In conclusion, since there is no general conservation law of the equivalent spin in physics, the second term has to be of a non-zero result, which requires a mathematical proof. To this end, we expand the second term and get the equation:

$$\begin{aligned} \frac{\partial}{\partial \tau} \int_R J_0^\alpha d^4 X &= \frac{\partial}{\partial \tau} \int_R J_0^\alpha d\tau dx dy dz \\ &= \frac{\partial}{\partial \tau} \left( \int_{\tau_1}^{\tau_2} d\tau \int_{x_1(\tau)}^{x_2(\tau)} dx \int_{x_1(\tau, x)}^{x_2(\tau, x)} dy \int_{Z_1(\tau, x, y)}^{Z_2(\tau, x, y)} J_0^\alpha dz \right) \end{aligned} \quad (31)$$

From the analysis of equation (31), the necessary and sufficient condition to get a non-zero result is that the integral part is zero. To do this, only when  $\int_{\tau_1}^{\tau_2} d\tau = 0$ , i.e.,  $\tau_1 = \tau_2$ . We substitute it into equation (31) and get the equation (32):

$$\frac{\partial}{\partial \tau} \int_R J_0^\alpha d^4 x = \frac{\partial O}{\partial \tau} \quad (32)$$

To get a  $\frac{0}{0}$  type non-zero result, it is imperative to make  $\partial\tau = 0$ . However, the theory of relativity indicates that, although there exists physical systems with infinitely slow time in the observable space-time,  $\partial t$  of such systems may never be zero. Hence,  $\partial\tau = 0$  is the essential difference between the intrinsic space-time of a photon entanglement system and the observable space-time. Therefore, the essential property of a photon entanglement system is that the intrinsic time does not flow, which can be described mathematically as:

$$\Delta\tau \equiv 0 \quad (33)$$

Taken together, for the symmetric transformation between the two objects  $|m^0\rangle$  photon and  $|\epsilon^0\rangle$  photon, the non-flowing property of the intrinsic time for an entanglement system will lead to spontaneous break of the equivalent spin symmetry. The physical world makes this happen by compressing the dimension of the intrinsic time. We emphasize that, due to the dominant role of photons, a quantum entanglement system composed of either photons or physical particles has the same non-flowing property for the intrinsic time. This property is equivalent to that of free photons.

## Conclusion and Discussion

In this paper, we elucidate the key feature of the non-flowing intrinsic time in a quantum entanglement system. On the one hand, this feature can be used to explain the phenomenon of quantum entanglement. On the other hand, this feature can be used to figure out the relationship between locality and non-locality. The quantum entanglement phenomenon is equivalent to the EPR effect and the non-locality phenomenon. It is a physical system where two particles interact and then separate. Disturbance at point 1 will immediately cause variation at point 2, and the variation at point 2 depends precisely on the disturbance at point 1, no matter how far away they

are. Regarding the non-locality nature of the entanglement phenomenon, based on its feature of non-flowing intrinsic time, we make the following explanation: despite separated in space, the components in the quantum entanglement system are not separated in the intrinsic time. In this way, the system always exists as an integrated entity and its components are not independent of each other. Rather, the components are connected instantaneously in a non-locality manner, forming an entangled system. The non-locality phenomenon revealed by Aspect's experiment on quantum non-locality [4] and Zeilinger's experiment on quantum teleportation [5] can be explained accordingly.

As to the question of the relationship between locality and non-locality, we herein propose a hypothesis that local symmetry demands the existence of non-local symmetry. In other words, to ensure the validity of local symmetry, the nature must permit the existence of non-local symmetry. For example, in vacuum, a photon leaves the starting point and arrives at the detector in one second, which completes the transmission of a certain quantum state. This process clearly meets the requirement of the locality. In a second scenario, a parental photon forms a dual-photon entanglement system; one second later, one of the derived photons arrives at the detector. In order to complete the transmission of a certain quantum state, these derived photons must overcome the space limitation. Because the quantum state is carried by the dual-photon entanglement system, the quantum state is actually observed by us at the same time. If this meets the requirements of locality, the only possible explanation is occurrence of a wave-packet collapse of the quantum state. This process precisely indicates the non-local symmetry of the entangled system, a notion consistent with our hypothesis. Therefore, we believe that at the most basic level of the physical world, locality and non-locality are compatible and are the opposite sides of a coin.

## Summary

- (1) We propose the predominant role of photons in particles, in that the wave property of particles originates from the wave property of absorbed photons. This role leads to two consequences. First, it establishes the relationship between the velocity of the free particles, represented by electrons, and the wave parameter. The new formula  $V = \lambda\nu$  is applicable to high-speed motion (up to the light speed  $C$  of the photons). Second, the intrinsic time of an entanglement system of physical particles is now equated with the intrinsic time of an entanglement system of photons.



- (2) By comparing the quantum entanglement system with the annihilation process of positronium, we propose two concepts: the pure resting mass state and the pure resting energy state, represented respectively by quantum  $|m^0\rangle$  and  $|\varepsilon^0\rangle$ . The relationship of mass  $m^0$  and energy  $\varepsilon^0$  follows the formula  $\varepsilon^0 = m^0 c^2$ , consistent with the Einstein mass-energy formula. Furthermore, based to their property of complete mass and energy transformation, the reversible transformation process is denoted as  $|m^0\rangle \rightleftharpoons |\varepsilon^0\rangle$ .
- (3) Based on the symmetric transformation of two objects  $|m^0\rangle$  and  $|\varepsilon^0\rangle$  and the resemblance to the isospin symmetry, we propose the concept of equivalent spin symmetry. By integrating the mathematical form of SU(2) group, the overall normative symmetry, the Bell state property of the studied objects, and the empirical facts, we prove that, under the condition of spontaneous break of the equivalent spin symmetry, the quantum entanglement system is featured by the non-flowing intrinsic time with the formula  $\Delta\tau \equiv 0$ .
- (4) On the basis of the series of arguments inferred from Einstein mass-energy equivalence, we provide a reasonable explanation of the quantum entanglement. Finally, we hypothesize that local symmetry demands the existence of non-local symmetry, a speculation that warrants future investigation.

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