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A Vortex Formulation of Quantum Physics Setting Discrete Quantum States into Continuous Space-time

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ABSTRACT

Any quantum state can be described by a vortex, which is mathematically a multi-vector and physically a united-measure. When the vortex formulation of quantum physics is introduced, Hamil-ton principle keeps its core position in physical analysis. While the global characteristics are described by Lagranrian function for dynamics and double complex core function for stable states, Schrödinger equation and gauge symmetries reveal local char-acteristics. The vortex-based physics provides a new unified understanding of wave-particle duality and uncertainty, quantum entanglement and teleportation, as well as quantum information and computation, with setting discrete quantum states into con-tinuous space-time for keeping concordance of methodology in processing micro-particle and macro-galaxy. Two fundamental experiments are suggested to correct and verify the physical for-mulation.

Keywords: Vortex; vortex formulation; quantum mechanism; quantum state; quantum physics; space-time

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INTRODUCTION

There are a few famous formulations of quantum physics, in which we mention three main representative formulations: Schrödinger wave formulation, Heisenberg matrix formulation and Feynman path integral formulation [1].

In wave formulation, the state of a system at a given time is described by a complex wave function, also referred to as state vector in a complex vector space. The Schrödinger equation describes how wave functions change in time. In the formulation, the operators stay fixed while the Schrödinger equation changes the basis with time. However, the wave packet will also spread out as time progresses, which means that the position becomes more uncertain with time. This also has the effect of turning a position eigenstate, which can be thought of as an infinitely sharp wave packet, into a broadened wave packet that no longer represents a definite position eigenstate [2].

In matrix formulation, it is the operators which change in time while the basis of the space remains fixed. A fixed basis is, in some ways, more mathematically pleasing. This formulation also generalizes more easily to relativity. Matrix mechanics was the first conceptually autonomous and logically consistent formulation of quantum physics.

Dirac's interaction gave a link of matrix formulation and wave formulation, via manifest in Dirac's bra–ket notation [3], where matrix formulation and wave formulation are equivalence of both the basis and the operators, carrying time-dependence. The interaction picture allows for operators to act on the state vector at different times and forms the basis for quantum field theory and other methods.

The path integral formulation of quantum mechanics is a description of quantum theory that generalizes the action principle of classical mechanics [4]. It replaces the classical notion of a single, unique classical trajectory for a system with a sum, or functional integral, over an infinity of quantum-mechanically possible trajectories to compute a quantum amplitude. This formulation has proven crucial to the subsequent development of theoretical physics, because manifest Lorentz covariance (time and space components of quantities enter equations in the same way) is easier to achieve than in the operator formalism of canonical quantization. Unlike previous methods, the path integral allows a physicist to easily change coordinates between very different canonical descriptions of the same quantum system. Another advantage is that it is in practice easier to guess the correct form of the Lagrangian of a theory, which naturally enters the path integrals, than the Hamiltonian.

In this paper, a vortex formulation is suggested, and the bracket notations are including three main types as follows.

(1) Dirac bra–ket notation < | and | >: the left part < |, called "bra", represents a row vector, while the right part | >, called "ket", denotes a column vector; and < | > represents an inner product, producing a scalar, while the | > < | denotes an outer product, producing a tensor.

(2) Commutated notation: It is defined that [X, Y] = XY – YX for measures X and Y. Mostly, [X, Y] ≠ [Y, X]. Particularly, following non-commutation relation contributes quantum mechanism

$$[X,Y] = XY - YX = i\hbar \tag{1}$$

in which i is the imaginary unit and $\hbar$ is the reduced Planck's constant ($\hbar$ =h/2π).

(3) Poisson bracket notation { }: It is defined that {f, g} = $\partial_\mu \partial_\nu - \partial_\nu \partial_\mu$ = -{g, f} for functions f and g.

The differential operators of one order derivatives are defined as

$$\partial_\mu = \frac{\partial}{\partial x_\mu}; \nabla = \gamma^\mu \partial_\mu \quad (2)$$

in which four Dirac matrices are viewed as four orthonormal basis vectors for real space-time

$$\gamma^0 = \begin{pmatrix} I & 0 \\ 0 & -I \end{pmatrix}, \gamma^k = \begin{pmatrix} 0 & -\sigma^k \\ \sigma^k & 0 \end{pmatrix} \quad (3)$$

where γ^0 is time-like vector and $\gamma^k (k=1,2,3)$ space-like vectors. Similarly, the three Pauli matrices $\sigma^k = (\sigma^1, \sigma^2, \sigma^3)$ are viewed as three orthonormal basis vectors for three dimensional Euclidean space

$$\sigma^1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \sigma^2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \sigma^3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \quad (4)$$

Both $\{\gamma^k\}$ and $\{\sigma^k\}$ are to be interpreted geometrically as meaningful space-time bivectors and not as operators.

When we use space-time multi-vectors [5-6], for each space-time point x on Dirac frame $\{\gamma^\mu, \mu = 0,1,2,3\}$, there exists

$$x = x_\mu \gamma^\mu, x_\mu = \gamma^\mu x \quad (5)$$

The coordinates' transformation will be

$$x_\mu \to x'_\mu = \alpha_\mu^\nu x_\nu; \gamma^\mu \to \gamma'^\mu = \alpha_\nu^\mu \gamma^\nu \qquad with \qquad \alpha_\nu^\mu \alpha_\lambda^\nu = \delta_\lambda^\mu$$

(6)

The covariant derivative and the differential operators of two order derivatives are defined respectively as

$$D_\mu = (\partial_\mu - \omega_\mu); \nabla^2 = g^{\mu\nu} \partial_\mu \partial_\nu; g^{\mu\nu} = \gamma^\mu \cdot \gamma^\nu \quad (7)$$

where we see that space-time metric $g^{\mu\nu}$ is naturally generated. In the paper, we use Greek subscripts μ, ν to denote 1, 2, 3, 4 and Latin subscripts i, j to do 1, 2, 3. This is a foundational mathematical framework of physics.

Now we introduce some new ideas to understand quantum states via vortex, which can visually combine point particle, wave vector and spin together, for setting discrete quantum states into continuous space-time.

THEORETICAL FOUNDATIONS: Vortex-based physics

A vortex is mathematically represented by a multi-vector, and physically describes linked-measure [7-9], which contributes a new math-physical methodology to understand physical reality [10].

Vortex formulation

Mathematically, a vortex can be simply expressed by using a multi-vector M_k (k = 0, 1, 2, 3, 4) as follows

$$\begin{aligned} M &= M_0 + M_1 + M_2 + M_3 + M_4 = \\ &\varphi + V + B + iU + i\theta = \psi + A + B = (\psi, A, B) \end{aligned} \quad (9)$$

where ψ=φ+iθ is a complex scalar function (wave function, but it describes mass), while A=V+iU means a complex vector function (potential function, but it describes field) and B = $(1/2)B_{\mu\nu}\gamma^\mu \wedge \gamma^\nu$ as a unique bivector (spin function, it can form spinor). One scalar ψ,one vector A and one bivector B just describe a vortex and construct a physical united-measure.

Its revision (revised conjugation) is denoted as $\tilde{M}$

$$\begin{aligned}\tilde{M} &= \tilde{M}_0 + \tilde{M}_1 + \tilde{M}_2 + \tilde{M}_3 + \tilde{M}_4 = \\ &\varphi + V - B - iU + i\theta = (\psi, \bar{A}, -B)\end{aligned} \tag{10}$$

And its space-time conjugation is

$$\begin{aligned}\bar{M} &= -iMi = M_0 - M_1 + M_2 - M_3 + M_4 \\ &= \psi - A + B = (\psi, -A, B)\end{aligned} \tag{11}$$

Physically, a linked-measure means that ψ, A, and B can be meantime measured, which just constructs the mass-energy structure, including mass, momentum and angular momentum (spin), of a vortex. At micro-particle level, a vortex M and its space-time conjugation $\bar{M}$ describe particle and anti-particle, while the M and its revised conjugation $\tilde{M}$ reveal entanglement. At macro-cosmos level, M means total mass-energy, and the energy-mass conservation is extended to energy-mass-momentum-angular momentum joint conservation. For forming complete system, we define $\tilde{\tilde{M}} = M$ and $\bar{\bar{M}} = M$.

Taking an orthonormal pair of basis |↑> and <↓| representing right-handed spin and left-handed spin or the “up” and “down” directions respectively, with using Dirac bra-ket notation, we define basic states

$$|M\rangle = |\psi, A, B\rangle = |(\psi, A, B)|\uparrow\rangle = |M|\uparrow\rangle \tag{12}$$

$$\langle M| = \langle \psi, A, B| = \langle\downarrow|(\psi, A, B)| = \langle\downarrow|M| \tag{13}$$

$$|\tilde{M}\rangle = |\psi, \bar{A}, -B\rangle = |(\psi, \bar{A}, -B)|\uparrow\rangle = |\tilde{M}|\uparrow\rangle \tag{14}$$

$$\langle\tilde{M}| = \langle\psi, \bar{A}, -B| = \langle\downarrow|(\psi, \bar{A}, -B)| = \langle\downarrow|\tilde{M}| \tag{15}$$

$$|\bar{M}\rangle = |\psi, -A, B\rangle = |(\psi, -A, B)|\uparrow\rangle = |\bar{M}|\uparrow\rangle \tag{16}$$

$$\langle\bar{M}| = \langle\psi, -A, B| = \langle\downarrow|(\psi, -A, B)| = \langle\downarrow|\bar{M}| \tag{17}$$

The addition, subtraction, and multiplication of multi-vectors produce also multi-vectors. With definitions

$\langle M| - |M\rangle = \langle\tilde{M}| - |\tilde{M}\rangle = \langle\bar{M}| - |\bar{M}\rangle = 0$ and $|M\rangle - \langle M| = |\tilde{M}\rangle - \langle\tilde{M}| = |\bar{M}\rangle - \langle\bar{M}| = 0$, the addition and multiplication will lead to various composite and superposition states, such as

$$\langle M| + |M\rangle = 2\psi\langle\downarrow|\uparrow\rangle + 2A\langle\downarrow|\uparrow\rangle + 2B\langle\downarrow|\uparrow\rangle \tag{18}$$

$$\langle\tilde{M}| + |\tilde{M}\rangle = 2\psi\langle\downarrow|\uparrow\rangle + 2\bar{A}\langle\downarrow|\uparrow\rangle - 2B\langle\downarrow|\uparrow\rangle \tag{19}$$

$$\langle\bar{M}| + |\bar{M}\rangle = 2\psi\langle\downarrow|\uparrow\rangle - 2A\langle\downarrow|\uparrow\rangle + 2B\langle\downarrow|\uparrow\rangle \tag{20}$$

$$|M\rangle + \langle M| = 2\psi\langle\uparrow|\downarrow\rangle + 2A\langle\uparrow|\downarrow\rangle + 2B\langle\uparrow|\downarrow\rangle \tag{21}$$

$$|\tilde{M}\rangle + \langle\tilde{M}| = 2\psi\langle\uparrow|\downarrow\rangle + 2\bar{A}\langle\uparrow|\downarrow\rangle - 2B\langle\uparrow|\downarrow\rangle \tag{22}$$

$$|\bar{M}\rangle + \langle\bar{M}| = 2\psi\langle\uparrow|\downarrow\rangle - 2A\langle\uparrow|\downarrow\rangle + 2B\langle\uparrow|\downarrow\rangle \tag{23}$$

The inner product $\langle M|M\rangle$ produces scalar, outer product $|M\rangle\langle M|$ and $|M\rangle|M\rangle = |M\rangle \otimes |M\rangle$ leads to tensor, such as

$$\langle M|M\rangle = (\psi, A, B)\begin{pmatrix}\psi \\ A \\ B\end{pmatrix} = \psi^2 + A^2 + B^2 \tag{24}$$

$$\langle M|\tilde{M}\rangle = (\psi, A, B)\begin{pmatrix}\psi \\ \bar{A} \\ -B\end{pmatrix} = \psi^2 + A\bar{A} - B^2 \tag{25}$$

$$|M\rangle\langle\tilde{M}| = \begin{pmatrix}\psi \\ A \\ B\end{pmatrix}(\psi, \bar{A}, -B) = \begin{pmatrix}\psi\psi & \psi\bar{A} & \psi(-B) \\ A\psi & A\bar{A} & A(-B) \\ B\psi & B\bar{A} & B(-B)\end{pmatrix}$$

(26)

$$|M\rangle|\tilde{M}\rangle = \begin{pmatrix}\psi\\A\\B\end{pmatrix}\otimes\begin{pmatrix}\psi\\\overline{A}\\-B\end{pmatrix} \quad (27)$$

where $\psi^2=(\varphi+i\theta)(\varphi+i\theta)$ or ψψ produces scalar, $A^2=(V+iU)(V+iU)$ or $A\overline{A}$ constructs tensor, and B^2 or B(-B) introduces spinor.

The entangled states are formed between M and $\tilde{M}$, similarly to Bell states

$$\langle M|+|\tilde{M}\rangle = 2\psi\langle\downarrow|\uparrow\rangle + 2\overline{A}\langle\downarrow|\uparrow\rangle \quad (28)$$

$$|M\rangle+\langle\tilde{M}| = 2\psi\langle\uparrow|\downarrow\rangle + 2\overline{A}\langle\uparrow|\downarrow\rangle \quad (29)$$

$$|M\rangle-|\tilde{M}\rangle = (A-\overline{A})\langle\uparrow|\uparrow\rangle + 2B\langle\uparrow|\uparrow\rangle \quad (30)$$

$$\langle M|-\langle\tilde{M}| = (A-\overline{A})\langle\downarrow|\downarrow\rangle + 2B\langle\downarrow|\downarrow\rangle \quad (31)$$

Meanwhile, we can define an orthonormal function F and a double complex function Z as the associated function and the core function of M, respectively, as follows

$$F = assoc(M) = \psi + jA + kB = (\varphi+i\theta) + j(V+iU) + kB$$

(32)

$$Z = core(M) = X + jY = \varphi + i\theta + j(V+iU) \quad (33)$$

where we keep Hamilton symbols $i^2=j^2=k^2=ijk=-1$. In Eq. (33), X is just ψ and Y just A of Eqs. (10) and (11).

It is expected that we can apply the vortex formulation to process both classical and quantum physics, including standard model [11], EPR paradox [12], teleportation [13], quantum information and computation [14-15]. The associated function F and double complex function [16] Z may be useful for assisting physical analysis.

Global analytical principles

When we defined linked-energy E as well as linked-momenta p_μ with linking Hamilton function H and Lagrangian function L, the analytical principle keeps Hamilton principle as follows

$$\delta\int_s d^4x(\Sigma L - k\Omega)\sqrt{-g} = 0 \;\;;\;\; L = p_\mu x_\mu - H \quad (34)$$

where ΣL is total Lagrangians of all states, Ω is curvature of space-time, k is constant and g is the determinant of the metric tensor $g_{\mu\nu}$. Totally, the mathematical physical equation should be a balance between left discrete quantum matter and right continuous curvature of space-time, as follows

$$-\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} - \frac{1}{4}B^b_{\mu\nu}B^{b\mu\nu} + \overline{\psi_q}(i\gamma^\mu D_\mu - m_q)\psi_q =$$
$$\Sigma L = k\Omega = \frac{1}{8\pi G}(R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda)$$

(35)

in which R is the trace of the Ricci tensor, G is the gravitational constant, and Λ is the cosmological constant. With including 8 duplicates (a) in 3 generations, the field strength is

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu - gf_{abc}A^a_\mu A^a_\nu;\, f_{abc}t^c = [t^a, t^b] \quad (36)$$

A^a_μ correspond to the gluon fields (a=1,…,8, as there are eight kinds of gluon) and the $\psi_{q,c}$ are quark-field spinors for a quark of flavor q and mass m_q with a color-index c (c=1,2,3), where the $t^a_{\mu\nu}$ correspond to eight 3 × 3 matrices and are the generators of the SU(3) group, while the interactions are stemmed by group SU(2), with color-index c changing to b:

$$B_{\mu\nu} = [\partial_\mu + (1g_2/2)B_\mu]B_\nu - [\partial_\nu + (1g_2/2)B_\nu]B_\mu =$$
$$B^b_{\mu\nu}\tau_b; b = 1,2,3$$

(37)

Therefore, for global states, the Hamilton principle keeps as core analytical principle in physics.

Local symmetries and gauge invariances

In core function Z=X+iY, if the functions X and Y are analytic and the end variables are space s and time t, they will match Cauchy-Riemann condition

$$\frac{\partial X}{\partial s}-\frac{\partial Y}{\partial t}=0 \tag{38}$$

$$\frac{\partial X}{\partial t}+\frac{\partial Y}{\partial s}=0 \tag{39}$$

Now we replace X and Y with unified core function Z=X+iY, a local stable system should fit equations

$$\frac{\partial Z}{\partial s}+i\frac{\partial Z}{\partial t}=0 \tag{40}$$

$$\frac{\partial^2 Z}{\partial s^2}+\frac{\partial^2 Z}{\partial t^2}=0 \tag{41}$$

where Eq.(40) is Cauchy-Riemann equation and Eq. (41) Laplace equation that describes stable states.

Generally, different initial and boundary conditions will determine different solutions of equations (40) and (41).

The local gauge invariances keep as

$$\psi \to \psi' = e^{i\omega}\psi; \overline{\psi} \to \overline{\psi}' e^{-i\omega} \tag{42}$$

$$A_\mu \to A'_\mu = A_\mu + \partial_\mu \omega ; \overline{A}_\mu \to \overline{A}'_\mu = \overline{A}_\mu - \partial_\mu \omega \tag{43}$$

When the energy distributes bias A completely, the M looks wave with fitting quantum field F matching symmetric group U(1)

$$L = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - J^\mu A_\mu \tag{44}$$

This is just Lagrangian of QED, leading to the Maxwell's equations

$$\partial_\mu F^{\mu\nu} = J^\nu \tag{45}$$

in which bivector F=**E**+i**H** includes both electrical field **E** and magnetic field **H,** and J is probability current and satisfies the continuity equation

$$\frac{\partial |\psi|^2}{\partial \mathrm{t}} + \nabla \cdot J = 0 \tag{46}$$

If there existed strong links among ψ, A and B

$$B_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu ; \quad A = \nabla \psi \tag{47}$$

it leads to a strong linked-field. When all matter-energy concentrates on ψ, the system is completely mastered by Schrödinger equation

$$H|\psi\rangle = \mathrm{i}\hbar\frac{\mathrm{d}}{\mathrm{dt}}|\psi\rangle \tag{48}$$

where H denotes quantum Hamiltonian, describing matter-energy eigenvalues.

The energy E (linking to ψ) and momentum **p** (linking to A) will construct canonical commutation relations

$$\begin{pmatrix} E \\ p \end{pmatrix} = \begin{pmatrix} \hbar & 0 \\ 0 & \hbar \end{pmatrix}\begin{pmatrix} \omega \\ k \end{pmatrix} \tag{49}$$

in which $E = \hbar\omega$ and $\mathrm{p} = \hbar k$, and they are combined.

The energy E and momentum p will be abided by relativistic relation under Lorentz invariance

$$E^2 - p^2c^2 = m^2c^4 \tag{50}$$

where c is velocity of light. The Eq. (50) links to following Dirac equation that unified matter and antimatter when operators $(E, p) \to \begin{pmatrix} i\partial/\partial t \\ -i\nabla \end{pmatrix} \sim p_\mu \to i\partial_\mu$ are applied

$$(i\gamma^\mu \partial_\mu - m)\Psi = 0 \tag{51}$$

The vortex-based quantum and unified physics contributes a new view of the world, where matter realities are discrete quantum states and space-time is continuous background. The matter existence and evolution will affect the curvature and structure of space-time, while space-time contains matter. The method can keep concordance of methodology in processing micro-particle and macro-galaxy [9].

PRACTICAL INTERPRETATIONS

Some important practical issues need to be interpreted under the framework, including wave-particle duality and uncertainty, entanglement and teleportation, as well as physical measures of quantum information, particularly energy and entropy.

Understanding wave-particle duality and uncertainty

In a linked-measure M = (ψ, A, B), ψ=φ+iθ is a complex scalar massive function (particle-bias) and A=V+iU looks a complex vector potential function (wave-bias), while B characterizes rotation (spin). Meanwhile, M is also the measure of total matter-energy.

When the matter-energy distributes bias $\psi >> A \subset M$, the M looks like particle but fitting to wave equation, i.e. Schrödinger equation or Dirac equation. Since ψ and A are particle-bias function and wave-bias function respectively, the M will look like particle if ψ >> A; while the M will look like wave if ψ << A. As M =(ψ, A, B) becomes unified mass-energy reality for both micro-particle and macro-cosmos, all things have wave-particle duality. For micro-particle, the energy changes easily between ψ and A, so that the micro-particle looks obvious wave-particle duality. For macro-things, the mass-energy concentrates and keeps mostly in ψ or A, so that there is no obviously observed wave-particle duality. When vortex becomes general methodological approach for both micro- and macro-things, the world can be naturally and unitedly interpreted. A visual image of local wave-particle duality can also be described by relation of ψ and A. When ψ is projection of matter particle to space and A is projection of wave vector to time, they look like Fourier-type transformation between ψ and A.

For any normalized vortex M in Hilbert space and for any operator X on Hilbert space, when $\langle X\rangle=\langle M|X|M\rangle$ and $(\Delta X)^2=\langle X^2\rangle-\langle X\rangle^2$, there exists uncertainty relation

$$(\Delta X)^2(\Delta Y)^2 \geq \frac{1}{2^2}(\hbar^2 + f^2) \qquad (52)$$

where $f=\langle XY+YX\rangle-2\langle X\rangle\langle Y\rangle$. If f=0, we have Heisenberg uncertainty relation

$$(\Delta X)^2(\Delta Y)^2 \geq (\frac{\hbar}{2})^2 \qquad (53)$$

In the vortex quantum and unified physics, as the quantum matter-energy is evolutional, the curvature of space-time will be also evolutional, following the matter-energy change. As discrete matter would distribute in the continuous space-time, all look both discrete and continuous entities.

Charactering quantum entanglement and teleportation

Basically, the entanglement can be the entangled quantum pair of right vortex particle and left vortex particle. More generally, when two quantum particles link to same source, such as M and $\tilde{M}$ linking M, the entanglement may happen. A typical situation looks like Figure 1.

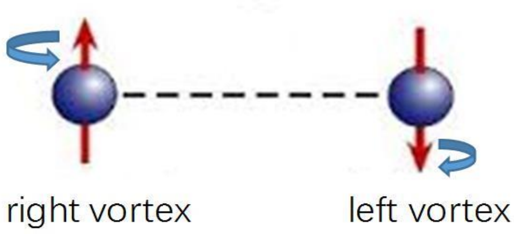

Fig.1 A typical entangled quantum pair

In teleportation, when Alice wants to send Bob quantum information via classical channel, she can send two classical items, in which one is portion of (ψ, A, B) as secret key and another is how M does entanglement based on Eq. (28), or (29), or (30), or (31) and so on. After Bob receives the information, he can recover an entangled quantum state of M and $\tilde{M}$, as shown as Figure 2.

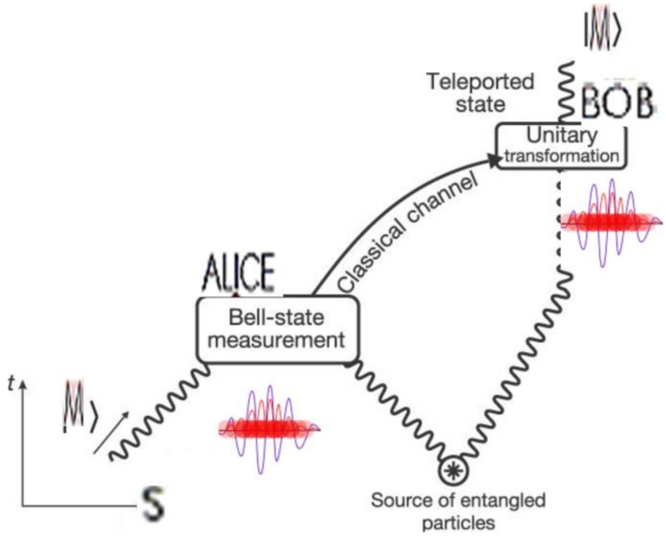

Fig.2 A mechanism of teleportation

The entanglement emerges between M and $\tilde{M}$, and teleportation happens when ones transfer quantum information via classical channel. As $\tilde{\tilde{M}} = M$, M and $\tilde{M}$ are relative. For example, we all see that there are two entangled electrons in molecule hydrogen, but we cannot differ which electron is M or $\tilde{M}$. When one is M, another is $\tilde{M}$.

Setting quantum information and computation

If a macro-system contains many micro-states M_i, its entropy S can be defined as Shannon entropy [17] for non-quantum states and von Neumann entropy for quantum states [14-15, 18] and then the information is negative entropy as

$$I = -S = \begin{cases} -k\sum_i M_i \log M_i ; non-quantum \\ -k\sum_i tr(M_i \log M_i); quantum \end{cases} \quad (54)$$

Therefore, both I and S are measures of quantum or non-quantum states, while the linked-measure M = (ψ, A, B) can be applied to measure both micro- and macro- physical objects.

For a quantum channel, it is a communication channel that can transmit both quantum information (such as the state of a qubit) and classical information (such as a bit). Both classical information and quantum information can be transmitted by quantum channel, but the capacity of the channel would follow

$$Q(t) \geq C(t) \tag{55}$$

where Q(t) is entangled quantum capacity, enhanced by entanglement, and C(t) fits to classical Shannon coding theorem.

For non-entangled quantum state $|M\rangle = \sum_j f(j)|j\rangle$, quantum Fourier transformation could help quantum computation

$$|\tilde{M}\rangle = F|M\rangle = \sum_{k=0}^{N-1} \tilde{f}(k)|k\rangle \tag{56}$$

in which $\tilde{f}(k) = \frac{1}{\sqrt{N}} \sum_{j=0}^{N-1} \exp(2\pi i \frac{jk}{N}) f(j)$ and $N=2^n$ contains n qubits.

The situation means that the non-entanglement could help computation while entanglement might enhance communication.

EXPERIMENTAL DESIGN: suggestions

The vortex-based quantum and unified physics certainly need experimental foundations, which should be shown by both macro- and micro-phenomena. So the vortex physics would be founded by two designed fundamental experiments, in which one is water vortex and another is optical vortex.

It is suggested to test water spiral vortices and light spiral vortices with double spiral split, for determining the foundations of vortex-based physics, via observing the vortices with their interactions.

In the experiment of water double vortices, it is expected to observe the phenomena of strengthened and weakened vortices, as shown as Figure 3.

Differentiating from common split flows, the experiment of water spiral vortices could contribute the physical foundations of vortex formulation, which might set up real representations of superposition states. It is suggested to verify and correct the Eqs. (18-23) of the superposition states based on the experiment.

In the experiment of light double vortices, it is expected to observe the phenomena of light vortices' interference, as shown in Figure 4, with a little difference from normal double split experiment.

Differentiating from common double split experiment, the experiment of light spiral vortices could contribute the real physical foundations of quantum formulation, via which we might find various quantum states and their interactions. Therefore, it is suggested to verify and correct the various quantum states based on the experiment.

Meanwhile, on the basis of the experimental results, the various states and physical principles will have their real foundations. Also, above vortex formulation of quantum physics can be corrected based on the experiments.

In future, more experiments can be designed for quantum entanglement and teleportation, as well as quantum information and computation.

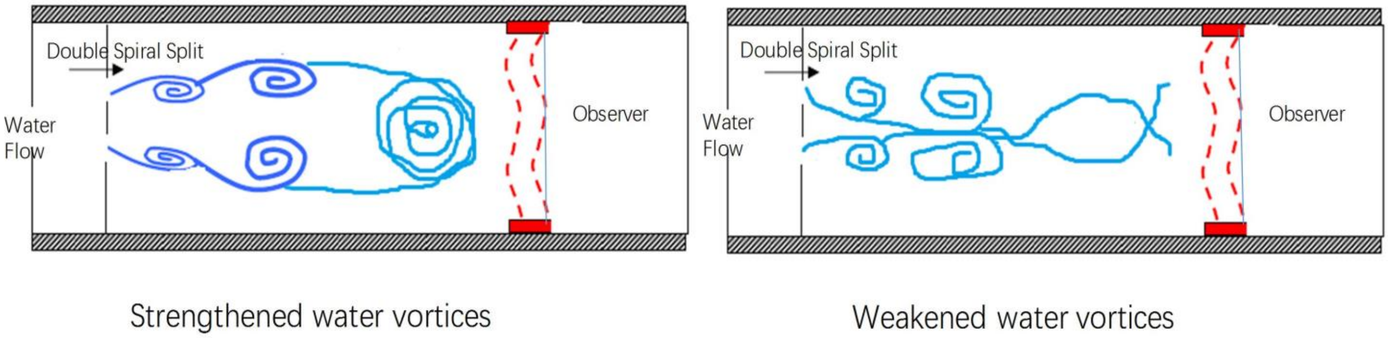

Fig.3 Designed experiment 1: water spiral vortices

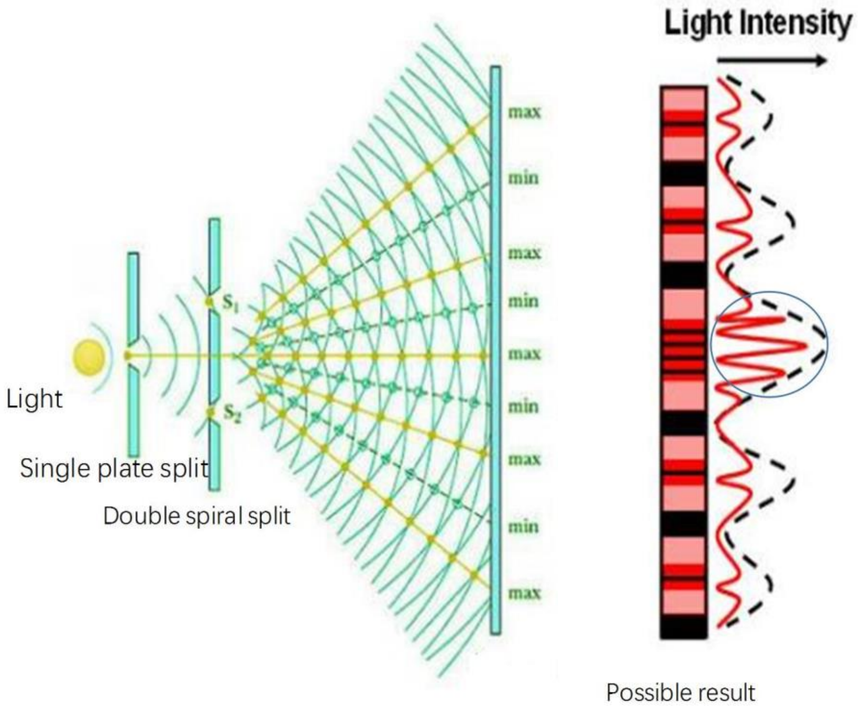

Fig.4 Designed experiment 2: light spiral vortices

DISCUSSION: predictions and limitations

According to above vortex quantum physics, following predictions are waiting for correction

1. Entangled states happen between M and $\tilde{M}$. The entanglement might enhance communication by quantum channel.
2. As antimatter is rare in the universe, $M >> \overline{M}$. So the antimatter seldom exist independently.
3. Uncertainty is a necessary result of wave-particle duality and non-commutation relation.

The vortex-based physics also gave an obvious answer to the EPR paradox about the quantum world: it is reality, but it is no-locality.

Furthermore, setting discrete quantum states into continuous space-time looks the quantum Fourier transform, as if this is a quantum analogue of the discrete Fourier transform, which may be used in several quantum algorithms and can be efficiently implemented on a quantum computer using only a polynomial number of quantum gates.

Actually, vortex looks a really universal phenomenon [19], and there are two terms related to our discussed topics in physics, one is “quantum vortex”, and another is “optical vortex”.

A quantum vortex represents a quantized flux circulation of some physical quantity. In most cases quantum vortices are a type of topological defect exhibited in superfluids and superconductors, which were observed experimentally in Type-II superconductors, liquid helium, as well as Bose–Einstein condensate and so on. In a superfluid, a quantum vortex "carries" quantized orbital angular momentum, thus allowing the superfluid to rotate. In a superconductor, the vortex carries quantized magnetic flux. The knowledge is expected to apply into above designed experiment 1.

An optical vortex, or a photonic quantum vortex, is a corkscrew of light with darkness at the center, which is just quantum vortex in photon fields. In an optical vortex, light is twisted like a corkscrew around its axis of travel. Because of the twisting, the light waves at the axis itself cancel each other out. When projected onto a flat surface, an optical vortex looks like a ring of light, with a dark hole in the center. The optical vortex can be given a number, called the topological charge, according to how many twists the light does in one wavelength. The number is always an integer, and can be positive or negative, depending on the direction of the twist. The higher the number of the twist, the faster the light is spinning around the axis. This spinning carries orbital angular momentum with the wave train, and will induce torque on an electric dipole. This orbital angular momentum of light can be observed in the orbiting motion of trapped particles. Interfering an optical vortex with a plane wave of light reveals the spiral phase as concentric spirals. The number of arms in the spiral equals the topological charge. The knowledge is expected to apply into above designed experiment 2.

The vortex formulation may contribute a unified math-physical foundation for quantum physics, on which theoretical progresses are expected. Also, since 1990s, experimental progresses had been developing, from entangled photo pair [20], five-photon entanglement [21], six-photon entanglement [22], eight-photon entanglement [23], to the experiment by quantum satellite [24], promoting new findings. It seems really true that we face the second quantum revolution. The quantum experiments and theories [25] are pushing quantum physics, quantum information and computation to quicken progresses.

At last we also discuss the limitations. As space-time is continuous and matter realities are discrete, it constructs a basic contradiction. There are two possibilities: (1) the space-time is the existed background of matter realities, so all are included in space-time. In this case, there is no space-time singularity. All realities came from original matter. (2) the space-time and matter realities generated from “big-bang”, so space-time will be evolutional with matter. In this case, there is a space-time singularity. What is truth?

This is an issue concerning the structure and evolution of space-time. The issue is a key to understand our universe. Also, it is an important topic in physics from ancient to modern age. Newton believed absolute space and time, where motion takes place against the backdrop of a rigid Euclidean reference frame that extends throughout all space and all time, and gravity is mediated by a mysterious force, acting instantaneously across a distance, without depending on the intervening space. Einstein denied that there is any background Euclidean reference frame that extends throughout space, nor is there any such thing as a force of gravitation, in his general relativity. Now it is well known that Newtonian gravitation is a theory of curved time, and general relativity is a theory of curved time and curved space where the curvature of space-time is equivalent to gravitation.

Another newfangled concept is time crystal or space-time crystal, which is a structure that repeats periodically in time, as well as in space. A time crystal is a type of non-equilibrium matter, which never reaches thermal equilibrium. Now it has been observed [26].

Totally, the issue of space-time keeps both scientific and philosophical open question. Meanwhile, another extended question concerns information and knowledge. While information is physical and objective [27]. Knowledge is psychological and subjective, as knowledge is different person by person. When we set up measurable link between information and knowledge [28], it is a non-quantum metrics, beyond the scope of discussion here.

CONCLUSION

Conclusively, above vortex formulation of quantum physics are characterized as follows:

1. Globally, Hamilton principle keep effective for linked-measure M=(ψ, A, B). The EPR paradox is solved by its reality and no-locality.
2. Locally, gauge invariances keep effective. When the mass-energy concentrates on ψ in a system, the system will be mastered by Schrödinger equation and Dirac equation.
3. Quantum entanglement happens between M and $\tilde{M}$. While entanglement might enhance communication via quantum channel, the non-entanglement could help computation.

Totally, quantum entanglement and teleportation, matter and antimatter, wave-particle duality can be united smoothly. Two experiments are suggested to correct and verify the foundations for setting discrete quantum states into continuous space-time via vortex. The view contributes a unified framework for interpreting and understanding quantum physics, on which further studies are expected.

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