Unified Cosmic Mechanics Evolution Theory (XVII) : Quantum Entanglement — Single-Particle Coordinated Evolution and Three-Layer Angular Momentum Conservation

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Abstract

[**Series Information**] This paper is one of 23 installments in the Unified Cosmic Mechanics Evolution Theory. This framework is built upon the monumental achievements of the great scientists who preceded us. Its mission is to provide a foundational explanation of physical reality through the integration of Logic, Mathematics, and Empirical Observation. By introducing the Generalized Dynamical State Evolution Logic, this framework provides a compatibility reconciliation for classical mechanics, relativity, and quantum mechanics. Driven by natural and necessary evolutionary constraints,this framework resolves long-standing systemic conflicts, addressing core issues such as ultraviolet divergence, quantum uncertainty, the dark matter problem, wave-particle duality, the nature of mass-energy conversion, and conservation anomalies. Its scope extends from microscopic particles to macroscopic matter, and into the emergence of life and intelligence. We wish to state our position clearly: this framework does not negate the brilliant work of our predecessors. On the contrary, we believe the foundational observations and laws established by them are fundamentally correct. Our work is an effort to find a unified path of interpretation that honors their exceptional contributions while advancing our collective understanding. We express our deepest gratitude for the centuries of effort and wisdom that have paved the way for this synthesis.

22.Cosmic Free-Steady-State Binary Game Evolution — Natural Evolution vs. Unnatural Evolution

23.Co-evolution of Large-Scale Topological Structures of Cosmic Matter

[**This article**] This paper is the seventeenth in the 22-paper series of the "Unified Cosmic Mechanics Evolution Theory" framework. Grounded in fundamental dynamical evolutionary principles, the framework develops a unified physical description that is consistent across mathematical formalism, logical structure, and empirical phenomena, and provides a coherent reconstruction of classical mechanics, relativity, and quantum mechanics within a single relational evolution system.

Traditional quantum mechanics interprets quantum entanglement as non-local statistical correlation, but fails to answer the underlying physical mechanism of entanglement: what "maintains" the correlation between entangled particles? Why can this correlation transcend spatial distance? Based on the framework of the *Unified Cosmic Mechanics Evolution Theory*, this paper proposes that the essence of quantum entanglement is an inline perception protocol that maintains the coordinated evolution of multiple momentum units.

The core conclusions include: (1) The core role of quantum entanglement is to support the conservation of carrier angular momentum, which is the fundamental premise for particles to realize spin and macroscopic rotation — a single momentum unit cannot rotate, and "rotatability" is an emergent property of the entanglement protocol; (2) A single elementary particle has three coordinated evolution forms (collapsed, diffused, fluid) [1], and the state transition depends on the internal structure and coordinated evolution ability endowed by the quantum entanglement protocol; (3) The multi-particle entangled state can be regarded as "single-particle coordinated evolution" at the macroscopic level, which originates from the multi-layer encapsulation characteristics of momentum units $m_0 \cdot c$ [2]; (4) The core mechanism for quantum entanglement to realize superluminal action is perceptual angle interlocking — establishing a logical correlation independent of geometric distance through an inline protocol, rather than trans-spatial propagation; (5) Both instantaneous force interaction and quantum tunneling can be reconstructed as local potential space momentum borrowing and returning state transition processes, without relying on propagator flight [3,4,5].

This paper further argues that quantum entanglement, elementary force interaction, and quantum tunneling are not isolated phenomena, but three manifestations of the same set of momentum topological coding and potential space borrowing and returning mechanisms under different boundary conditions — entanglement is a static protocol maintaining structural stability, force is a dynamic state update after protocol triggering, and tunneling is a potential space topological transition guided by the protocol. This framework reduces quantum mechanics to a deterministic information dynamics evolution process based on protocol rules, providing a new ontological support for understanding the causality of the microcosm.

Keywords: Nature of quantum entanglement; Origin of momentum entanglement; Angular momentum conservation; Momentum conservation; Origin of rotation; Origin of spin; Momentum distribution relationship; Unified mechanics

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Introduction

Quantum entanglement is one of the most counterintuitive phenomena in quantum mechanics. The traditional interpretation regards entanglement as non-local statistical correlation, holding that the measurement of one particle in an entangled pair will ”instantly” affect the state of the other particle, no matter how far apart they are. However, this interpretation does not answer the underlying physical mechanism of entanglement: what ”maintains” the correlation between two particles? Why can this correlation transcend spatial distance? Does the ”non-locality” of the entangled state mean that information transmission can exceed the speed of light?

In the framework of the *Unified Cosmic Mechanics Evolution Theory*, this paper re-examines the essence of quantum entanglement. We propose that quantum entanglement is not merely a statistical correlation, but an inline perception protocol that maintains the coordinated evolution of multiple momentum units [6]. To address the ontological problem that ”a single basic momentum unit cannot rotate”, this paper argues that ”rotatability” is an emergent property of the entanglement protocol: only by locking discrete momentum units into a topological whole through the protocol can particles possess the physical reality of spin and macroscopic rotation [7].

It should be clarified that particle carrier angular momentum, spin angular momentum, and rotational angular momentum are essentially three different concepts, and the core role of quantum entanglement is to support the conservation of carrier angular momentum, which is the fundamental premise for particles to realize spin and macroscopic rotation. On this basis, the paper clarifies that a single elementary particle has three coordinated evolution forms (collapsed, diffused, fluid), and these three forms enable particles to obtain internal structure and realize coordinated evolution and state transition through the quantum entanglement protocol; in addition, there exists a multi-particle entangled form, which can be regarded as ”single-particle coordinated evolution” at the macroscopic level — because the essence of the field is a protocol (including encapsulation protocol) [4], and the encapsulation of momentum units itself includes multi-layer encapsulation [8], so multiple atoms can be regarded as a single composite particle for coordinated evolution within the framework of this evolution theory, and such composite entanglement often occurs during the execution of the momentum distribution protocol.

At the same time, we reconstruct instantaneous force interaction and quantum tunneling as state transition processes based on potential space momentum borrowing and returning, and it should be emphasized that potential space borrowing and returning are all local potential space borrowing and returning, independent of spatial propagation. Studies have shown that quantum entanglement is an absolute premise for the universe to emerge continuous rotational symmetry and conservation laws from discrete momentum resources.

Note: The inline mentioned in this paper does not only refer to the inline protocol for the independent encapsulation and coordinated evolution of absolute elementary particles, but also refers to the possible quantum entanglement coordinated evolution from leptons to baryons, atoms, and even molecules, that is, the multi-layer encapsulated inline coordinated evolution protocol above momentum units.

The following will elaborate on the realization mechanism of quantum entanglement, the forms of coordinated evolution, the unified correlation with force/tunneling, and the emergence of rotation.

1 Realization Mechanism of Quantum Entanglement and Angular Momentum Conservation

The realization of quantum entanglement depends on the momentum unit perceptual angle complementary interlocking mechanism, namely the inline perception protocol [9]. The core key is that perceptual angle interlocking is realized through the inline entanglement protocol during the perception process, and this protocol-based logical correlation is not limited by geometric distance, which is also the fundamental reason why quantum superluminal action can be realized [10]. Under this protocol, the internal sub-unit structures of particles establish correlations through perceptual angle complementarity, and the sum of the emergent angular momenta between each pair of sub-unit structures is 0, so that the total angular momentum of the particle always remains conserved and realizes synchronous rotation during the overall rotation and spin process. Its mathematical expression can be standardized as:

$$\sum_{i=1}^{n} \vec{L}_i = 0$$

where $\vec{L}_i$ is the emergent angular momentum of the i-th pair of sub-unit structures, and n is the number of pairs of internal sub-unit structures of the particle. This formula reflects the constraint effect of the inline perception protocol on the conservation of system angular momentum, and the conservation of this carrier angular momentum is the premise for existence and stability of particle spin angular momentum and macroscopic rotational angular momentum [11,12,13,14],[15].

2 Forms of Coordinated Evolution and Their Physical Mechanisms

2.1 Origin of Wave-Particle Duality

Combining the corresponding relationship between this evolution theory and the standard model (only for logical reference), the essence of wave-particle duality is that particles have a clear internal structure — all particles encapsulate the evolutionary carrier (momentum unit) through multi-layers via field protocols, and momentum units obtain the core ability of coordinated evolution of all momentum units through the inline perception protocol (quantum entanglement), which is also the fundamental premise for particles to realize state transition. Particles do not only exist in a single form of ”wave” or ”particle”; they essentially have three mutually switchable basic states (collapsed, diffused, fluid). The triggering of state transition depends on the synergistic effect of external conditions and internal protocols, which are specifically as follows: when a fermion obtains a large momentum deviation, the internal momentum units will change from a loose coordinated state to a highly concentrated state, and the particle will enter the spherical collapsed state, at which time the particle shows obvious ”particle nature”; when the particle is in a low momentum deviation environment such as Bose-Einstein condensation (BEC) or inside an atom, the momentum units are diffusely distributed, and the particle shows a spherical diffused state, presenting a certain ”wave nature”; when the particle passes through specific scenarios such as multi-slit-like paths, it will enter the multi-path fluid state, realizing extensive weak coupling with the environment through multiple paths, at which time the ”wave nature” is more significant. In summary, wave-particle duality is not an inherent contradictory property of particles, but an external manifestation of a single elementary particle switching between three basic coordinated states through the quantum entanglement protocol. Quantum entanglement is an absolute premise for all state transitions to be smoothly realized. At the same time, the carrier angular momentum conservation maintained by quantum entanglement provides a guarantee for the stability of spin and rotation states during the state transition [16,17,18,19].

Supplementary Logic: The self-superposition phenomenon also emerges from the quantum entanglement mechanism, whose essence is the self-superposition and interference effect of momentum flow inside the particle under the constraint of quantum entanglement. The quantum entanglement protocol locks discrete momentum units into a topological whole, enabling the internal momentum flow to form multiple independent and coordinated flow trends within the same particle system. These momentum flows superimpose and interfere with each other, thereby emerging the self-superposition characteristic — this characteristic is not a simple superposition of momentum units, but a synergistic effect based on the entanglement protocol, making the particle present the appearance of ”being in multiple states at the same time”. Moreover, this self-superposition is always constrained by the conservation of carrier angular momentum, ensuring the overall balance of momentum and angular momentum during the superposition process, which is also an important internal driving force for particle state transition.

2.2 Spherical Collapsed State

When a particle obtains a high momentum deviation, it will enter the spherical collapsed state, whose characteristics correspond to the Compton wavelength. The expression of the Compton wavelength λ_c is:

$$\lambda_c = \frac{h}{mc}$$

where h is the Planck constant, m is the rest mass of the particle, and c is the speed of light. When the particle is in the spherical collapsed state, the momentum units are highly concentrated, the encapsulation structure presents a stable spherical symmetric compact form, and the momentum deviation Δp satisfies $\Delta p \gg 0$. At this time, the quantum entanglement protocol still maintains the conservation of carrier angular momentum, ensuring the stability of the particle's spin state and avoiding spin disorder caused by momentum concentration.

2.3 Spherical Diffused State

When a particle is in a Bose-Einstein condensation (BEC) or inside an atom, and the unit has a low momentum deviation, it will present a spherical diffused state, whose characteristics correspond to the de Broglie wavelength. The expression of the de Broglie wavelengthλ is:

$$\lambda = \frac{h}{p}$$

where p is the particle momentum. In the spherical diffused state, the momentum units are diffusely distributed, the encapsulation structure presents a loose spherical symmetric form, the momentum deviation$\Delta p \approx 0$, and the particle shows obvious quantum coherence [20,21]. In this state, the inline perception protocol maintains the conservation of carrier angular momentum through perceptual angle interlocking, enabling the stable existence of the particle's spin state and providing support for the potential possibility of macroscopic rotation.

2.4 Multi-Path Fluid State

When a particle passes through a multi-slit-like path, it will exist in a multi-path fluid state. Its core characteristic is that the particle distributes its own momentum flow to multiple paths, forms extensive weak coupling with the path walls, and realizes coordinated evolution through self-interference of momentum flow. This process can be described by path integral, whose mathematical form is:

$$\psi(x) \propto \int \mathcal{D}[p] e^{(i \int p \cdot dx/\hbar)}$$

where $\psi(x)$ is the particle wave function, and $\mathcal{D}[p]$ is the path integral measure of momentum flow, reflecting the entanglement correlation and interference effect of momentum flow under multiple paths. In this process, quantum entanglement ensures the coordination of momentum flow in each path through perceptual angle interlocking, maintains the conservation of carrier angular momentum, and at the same time, the momentum adjustment between paths can be realized through local potential space borrowing and returning, without trans-spatial propagation, ensuring the synchronization of the interference process.

2.5 Multi-Particle Entangled State and Momentum Distribution Principle

In addition to the three coordinated evolution forms of a single elementary particle, the multi-particle entangled state is another important form of coordinated evolution. This form can be regarded as ”single-particle coordinated evolution” at the macroscopic level — because the essence of the field is a protocol, and the encapsulation of momentum units itself includes multi-layer encapsulation, so multiple atoms can be regarded as a single composite particle for coordinated evolution within the framework of this evolution theory, and such composite entanglement often occurs before and after particle decoupling and coupling, which is essentially a momentum distribution process between multiple particles. It core follows the quantum entanglement distribution protocol, that is, multiple particles share the information momentum conservation code, and realize the sharing and balance of momentum deviation through local potential space momentum borrowing and returning, and the borrowing and returning process only occurs in the local potential space, without involving spatial propagation.

Supplementary Explanation: The multi-particle entangled state and the multi-path fluid state are essentially homologous, and both can be understood as ”the distribution and coordinated evolution of the same overall momentum package” — the multi-path fluid state is that a single particle distributes its own overall momentum package to multiple spatial paths, and realizes coordinated evolution through entanglement and interference of momentum flow between paths; the multi-particle entangled state is that an overall momentum package is distributed to multiple spatially independent particles (i.e., multi-spatial carriers), and each particle, as a ”sub-carrier” of the momentum package, establishes an entanglement correlation through the inline perception protocol to realize the coordinated evolution and conservation of the overall momentum. The core commonality of the two is that they both maintain the conservation of the overall momentum package based on the quantum entanglement protocol and realize the coordination effect through momentum distribution. The only difference lies in the carrier form of momentum package distribution (multi-paths of a single particle vs. multi-spatial carriers of multiple particles), and in both forms, the adjustment and balance of momentum are completed through local potential space momentum borrowing and returning, independent of trans-spatial propagation.

For a multi-particle system (particles A, B, C, etc.), let the momentum of each particle be p_A, p_B, p_C, and the total momentum of the system satisfies the conservation law:

$$p_A + p_B + p_C + \cdots = 0$$

The specific distribution process is as follows: Particle A ($p_A = P+1$) and Particle B ($p_B = P-1$) are initially in a momentum equilibrium state ($(P+1)+(P-1) = 0$); when Particle A is coupled with Particle C ($p_C = P - 0.8$) to form a new particle (with momenta P-0.8 and P+1), a momentum deviation $\Delta p = -0.2$ is generated. At this time, Particle A transmits the excess momentum -0.2 to Particle B through the inline perception protocol, so that the system reaches equilibrium again ($(P-0.8)+(P+1)+(-0.2) = 0$).

In this process, the multi-particle entangled state will centrally distribute the remaining momentum deviation to the last associated particle, which completes the deviation processing. Essentially, it is a widespread out-of-box momentum sharing protocol during particle decoupling and coupling; during the interaction process, all borrowed and returned momenta are completed through the local potential space, and the return is manifested as quantum fluctuations, corresponding to the potential space momentum pair of the propagator $(\vec{p}_{\mathrm{m}}, -\vec{p})$. At the same time, quantum entanglement always maintains the conservation of carrier angular momentum of the entire multi-particle system, providing stable support for the spin and potential rotation states of each particle.

Therefore, quantum entanglement is not only an inline protocol for elementary particles, but also a possible inline protocol for multi-scale coordinated evolution from leptons to baryons, atoms, and molecules [19,20,21,22,23,24].

3 Unified Correlation between Quantum Entanglement, Force Interaction, and Quantum Tunneling

3.1 Core Axiom: Instantaneous Interaction Protocol Driven by Perceptual Cross-Section

Based on the core viewpoint of "field is protocol" in the *Unified Cosmic Mechanics Evolution Theory*, the essence of force is momentum toggle after protocol matching, rather than the interaction that decays with distance $(1/r^2)$ in traditional theory. As long as the momentum topological codes (charge, color charge, spin, etc.) of two particles meet the matching conditions, the interaction can occur instantaneously, independent of the geometric distance r, and the distance only affects the effective coupling probability under macroscopic statistics. The realization of this instantaneous interaction lies in the fact that perceptual angle interlocking is realized through the inline entanglement protocol during the perception process, establishing a cross-distance logical correlation. At the same time, the momentum adjustment during the interaction is completed through local potential space borrowing and returning, without propagator flight, further ensuring the instantaneousness of the interaction.

The code matching degree between particles can be expressed by inner product:

$$\langle \mathrm{Code}_A | \mathrm{Code}_B \rangle$$

where Code_A and Code_B are the momentum topological codes of particles A and B, respectively. The instantaneousness of the interaction can be characterized by the delay time $t_{\mathrm{delay}} = 0$, which is essentially the synchronous update of the local encapsulation state of the particle, without the flight time of the propagator. At the same time, the conservation of carrier angular momentum is always followed during the interaction process, and this conservation is maintained by the quantum entanglement protocol, providing a guarantee for the stability of spin and rotation states.

3.2 Reconstruction of Quantum Tunneling: Potential Space Momentum Borrowing and Returning and State Transition

The concept of "potential barrier penetration" in traditional theory is reconstructed as "potential space momentum redistribution and state transition triggered by protocol" in this framework. The essence of quantum tunneling is not the physical penetration of the potential barrier by particles, but when particles encounter a high potential energy encapsulation layer (potential barrier), they borrow a pair of virtual momenta $(\vec{p}_{\mathrm{virt}}, -\vec{p}_{\mathrm{virt}})$ from the local potential space through the inline entanglement protocol. The borrowing and returning process only occurs in the local potential space, without involving trans-spatial propagation, so that the total momentum state instantly meets the coding requirements for crossing the potential barrier, realizing topological transition of position/state.

The modified expression of tunneling probability is:

$$P \propto e^{(-\frac{2}{\hbar}\int\sqrt{2m(V(x)-E)}dx)}$$

where$V(x)$ is the potential barrier potential energy, E is the particle energy, and m is the particle mass. The physical meaning of the exponential term is modified as: the scarcity of "borrowing a sufficiently large momentum pair from the local potential space to unlock the target position encapsulation protocol". The wider and higher the potential barrier, the larger the momentum required for borrowing and returning, and the lower the tunneling probability.

The core process of quantum tunneling is "disappearance-reappearance": the particle is directly excited and generated behind the potential barrier through protocol judgment in front of the potential barrier, and the momentum unit at the original position returns to the equilibrium state, without time to cross the potential barrier. Its essence is a spatial transition realized through the inline entanglement protocol. At the same time, during the tunneling process, quantum entanglement still maintains the conservation of carrier angular momentum, ensuring that the spin state of the particle remains stable before and after the transition, and providing support for the possibility of rotation after the transition.

3.3 Unified Mathematical Description of Force Interaction and Quantum Entanglement

All force interactions are driven by perceptual cross-sections. As an inline perception protocol, quantum entanglement and the external perception protocol (corresponding to the four fundamental forces) together constitute the underlying mechanism of particle interaction. Based on the principle of momentum flow distribution, a unified mathematical equation is established:

$$\vec{F} = \frac{d}{dt}\sum_i \vec{p}_i + \delta(\vec{r})\langle \text{Code}_A|\text{Code}_B\rangle(\vec{p}_{\text{virt}} - \vec{p}'_{\text{virt}})$$

where the first term is the time change rate of momentum flow, representing the effect of macroscopic force; the $\delta(\vec{r})$ in the second term reflects the instantaneousness of the interaction (independent of distance), which originates from the perceptual angle interlocking effect of the inline entanglement protocol, and $\vec{p}_{\text{virt}}$ and $\vec{p}'_{\text{virt}}$ are the borrowed and returned virtual momenta, respectively, reflecting the local potential space momentum borrowing and returning mechanism.

A photon is a "goose-flock-like unidirectional momentum flow", and its interaction essence is the injection and interception of momentum flow: the process of a fermion absorbing/emitting a photon is not that the particle "eats" the photon, but adjusts its own spherical symmetric momentum encapsulation state to a new topological excited state containing the photon momentum flow through the protocol, and its energy change satisfies $\Delta E = h\nu$ (where ν is the photon frequency). In this process, quantum entanglement maintains the conservation of carrier angular momentum, ensuring that the spin state of the fermion can transition stably after absorbing/emitting the photon without disorder.

4 Emergence of Rotation and the Constraining Effect of Quantum Entanglement

4.1 Core Concept Reconstruction: Topological Structure Coordinated Precession

As the underlying non-decayable evolutionary resource of the universe, a single momentum unit only has evolutionary amplitude c, evolutionary frequency c, and evolvable direction, without internal structure, so "rotation" cannot be defined — attempting to rotate a single momentum unit will only change its direction, not generate spin attributes. The "intrinsic spin" in traditional quantum mechanics is essentially the overall precession characteristic of the topological structure formed by momentum units through the entanglement protocol. It is necessary to clearly distinguish three core concepts: particle carrier angular momentum is the collective angular momentum of the topological whole formed by momentum units through the entanglement protocol, spin angular momentum is the intrinsic precession characteristic of the topological whole, and rotational angular momentum is the macroscopic rotational characteristic of the topological whole. The three are essentially different, but quantum entanglement provides the fundamental premise for the existence of spin angular momentum and the realization of rotational angular momentum by maintaining the conservation of carrier angular momentum.

As a collective attribute of the "evolutionary carrier" (the particle structure formed by encapsulating momentum units through protocols), angular momentum is defined at the carrier level as:

$$\vec{L} = \sum_i \vec{r}_i \times \vec{p}_i$$

where $\vec{r}_i$ is the position vector of the i-th momentum unit, and $\vec{p}_i$ is its momentum vector, reflecting the collective topological winding characteristic of momentum units, which is also the core source of carrier angular momentum, and quantum entanglement is the key to maintaining this collective winding and the conservation of carrier angular momentum.

4.2 Mechanism and Mathematical Expression of "Coordinated Rotation"

The core constraining effect of quantum entanglement is reflected as "if one rotates, all rotate together": when an external torque or measurement attempts to change the spin state of the particle, the local operation acting on a certain momentum unit$\vec{p}_k$ will instantly break the original angular momentum equilibrium state $\sum \vec{L}_i = 0$ of the system; the inline perception protocol will force all associated momentum units to make compensatory adjustments through the perceptual angle interlocking mechanism, and finally realize the overall precession of the entire topological structure, which is manifested as the overall rotation or spin flip of the particle. The core of this process is that quantum entanglement maintains the conservation of carrier angular momentum, ensuring the coordinated change of spin angular momentum and rotational angular momentum, and avoiding state disorder caused by local operations.

Define the global coordinated rotation operator $\hat{R}_{\text{global}}(\theta)$, which acts on the entire entangled state:

$$\hat{R}_{\text{global}}(\theta)|\psi_{\text{entangle}}\rangle = e^{-i\theta\sum\hat{\sigma}_i}|\psi_{\text{entangle}}\rangle$$

where $|\psi_{\text{entangle}}\rangle$ is the entangled state wave function, and $\hat{\sigma}_i$ is the spin operator of the i-th momentum unit. If an attempt is made to apply the local rotation operator $\hat{R}_{\text{local}} = e^{-i\theta\hat{\sigma}_k}$, due to the strong entanglement term $\hat{H}_{\text{entangle}} \propto \sum \vec{\sigma}_i \cdot \vec{\sigma}_j$ in the Hamiltonian, a very high energy cost will be generated, and the system will instantly evolve back to the eigenstate of global coordinated rotation, proving that local rotation cannot occur alone. This further confirms that only under the premise of carrier angular momentum conservation maintained by quantum entanglement can the spin and macroscopic rotation of particles be realized synergistically.

4.3 Topological Explanation of 720° Rotation: Helical Precession and Phase Locking

Fermions need to rotate 720° to return to their original state. Its essence is not simple topological winding, but a "helical precession" dynamic structure formed by momentum units under the constraint of the entanglement protocol. In this structure, there is a strict 2:1 gear coupling between the spatial revolution of the carrier and the internal spin axis:

Rotation by 360° (half period): The carrier completes a closed "S-shaped winding" on the spatial trajectory, but due to the helical coupling, the internal spin axis only rotates by 180°, leading to the inversion of the winding phase of the momentum unit (psi to -psi), and the topological structure is in a "mirror antisymmetric" state, which is not fully restored;

Rotation by 720° (full period): The carrier completes the second "S-shaped winding", the internal spin axis rotates by 360° cumulatively, and the winding phase is inverted again (-psi to psi), and the system finally returns to the original symmetric state.

Conclusion: This characteristic confirms that spin is a collective emergent property of the entangled topological structure (i.e., spin angular momentum), rather than the mechanical rotation of a single momentum unit. The stability of this collective property completely depends on the carrier angular momentum conservation maintained by the quantum entanglement protocol — once the entanglement is lifted, the helical structure collapses, and the spin attribute disappears immediately [25,26,27].

4.4 Angular Momentum Distribution in EPR Pairs

For an EPR entangled pair (particles A and B), the two share the same "angular momentum account" through the inline perception protocol, satisfying the conservation of total angular momentum:

$$\vec{L}_A + \vec{L}_B = 0$$

If the collective precession of the momentum unit group of particle A is manifested as the spin state $|\uparrow\rangle$ (angular momentum $+\hbar/2$), the protocol forces the collective precession of the momentum unit group of particle B to be the spin state $|\downarrow\rangle$ (angular momentum $-\hbar/2$). This constraint is not limited by geometric distance, and its essence is a logical correlation realized by the inline protocol through perceptual angle interlocking, rather than spatial propagation, reflecting the non-locality of quantum entanglement, and it is this non-local protocol correlation that enables superluminal action. At the same time, this angular momentum distribution process always takes the conservation of carrier angular momentum as the core, ensuring that the spin angular momenta of the two particles match each other, providing support for their potential macroscopic rotation [28,29,30,31],[32].

5 Summary

1. As the underlying inline perception protocol of the universe, the core of quantum entanglement is to maintain the global conservation constraints of angular momentum, momentum, and charge,

among which the most critical is to maintain the conservation of carrier angular momentum — particle carrier angular momentum, spin angular momentum, and rotational angular momentum are essentially three different concepts, and quantum entanglement can realize the spin and macroscopic rotation of particles only on the premise of supporting the conservation of carrier angular momentum. It solves the logical paradox that a single-point momentum unit cannot define "rotation", and further emerges the spin attribute and rigid structure of particles through the strong coordination mechanism of "if one rotates, all rotate together".

2. The coordinated evolution of a single elementary particle only has three forms: collapsed, diffused, and fluid. The realization and state transition of these three forms completely depend on the internal structure and coordinated evolution ability endowed by the quantum entanglement protocol; multi-particle entanglement can be regarded as "single-particle coordinated evolution" at the macroscopic level, which is derived from the protocol essence of the field and the multi-layer encapsulation characteristics of momentum units, and such composite entanglement mostly occurs during the execution of the momentum distribution protocol. In addition, the core mechanism for quantum entanglement to realize superluminal action is: perceptual angle interlocking is realized through the inline entanglement protocol during the perception process, establishing a logical correlation independent of geometric distance, rather than the traditional trans-spatial action; the potential space momentum borrowing and returning involved in quantum tunneling and force interaction are all local potential space borrowing and returning, without involving trans-spatial propagation, which further eliminates the mystery of "superluminal action".

3. Self-superposition is an important emergent property of quantum entanglement, which originates from the self-superposition and interference of momentum flow inside the particle under the constraint of the entanglement protocol, providing internal motivation for particle state transition; multi-particle entangled state and multi-path fluid state are homologous, both being the coordinated evolution after the overall momentum package is distributed to different carriers (multi-paths or multi-particles), and both together confirm the core role of quantum entanglement in momentum distribution and coordinated evolution.

4. From the perspective of evolution theory, quantum entanglement, elementary force interaction, and quantum tunneling are no longer isolated phenomena, but three manifestations of the same set of momentum topological coding and potential space borrowing and returning mechanisms under different boundary conditions: entanglement is a static protocol maintaining structural stability; force is a dynamic state update after protocol triggering; tunneling is a potential space topological transition guided by the protocol. This theoretical framework reduces quantum mechanics to a deterministic information dynamics evolution process based on protocol rules, providing a new ontological support for understanding the causality of the microcosm.

5. The conservation of carrier angular momentum (the sum of angular momenta is 0) is the fundamental requirement for realizing non-integer spin. A unidirectional momentum unit cannot independently evolve $-\vec{p}$ into $\vec{p}$, which will lead to the non-conservation of its space-time state. It can only realize the distribution of momentum state by forming a new inertial direction through causal interaction. However, the angular momentum of almost all basic particles is not zero, because protocols such as gravity and electromagnetic force are action-reaction forces, and interactions will toggle their own momentum evolution state through external interaction protocols, resulting in conservation only with the outside. Therefore, almost all particles in the universe have no absolute static state, and the motion of all particles originates from the momentum breaking or combined velocity carried by interaction/self.

6. Predictive Conjecture: The reason why spin is perpendicular to the direction of motion to form an independent evolution degree of freedom may be that spin does not affect the conservation of carrier angular momentum.

Additional Logic

In a relational state evolution system, superluminal action does not necessarily require much energy or cost, because any system can perform synchronous scaling of evolutionary resources and evolutionary rules compared with the external system, and the system has no internal perception ability, nor does it affect the evolution of any internal relations. Therefore, distance is a relative concept in the system, and only the relational distance that crosses or dominates countless causal chains and countless evolutionary carriers is the real superluminal distance.

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[12] Belinfante, F. J. (1939). On the spin angular momentum of mesons. *Physica*, 6(1), 887–898. (DOI: 10.1016/S0031-8914(39)90058-2). — Proved that spin angular momentum can be equivalently expressed as intrinsic orbital angular momentum flow, supporting the view in this paper that "spin is the collective precession of internal units".

[13] Hofstadter, R. (1956). Electron scattering and nuclear structure. *Reviews of Modern Physics*, 28(3), 214–254. (DOI: 10.1103/RevModPhys.28.214). — Scattering experiments confirmed that protons have an internal charge distribution structure, by analogy supporting that elementary particles such as leptons also have a "momentum unit encapsulation" structure at a more microscopic scale.

[14] Harari, H. (1979). A schematic model of quarks and leptons. *Physics Letters B*, 86(1), 83–86. (DOI: 10.1016/0370-2693(79)90623-9). — Proposed the Preon model attempt, and this paper deepens this idea into an "evolutionary carrier encapsulation" model based on information protocols rather than traditional material fields.

[15] Zurek, W. H. (2009). Quantum Darwinism. *Nature Physics*, 5(3), 181–188. (DOI: 10.1038/nphys1202). — Proposed that physical reality is an emergent property of environmental coding, supporting the view in this paper that "field is an information interaction protocol".

[16] Nayak, C., Simon, S. H., Stern, A., Freedman, M., & Das Sarma, S. (2008). Non-Abelian anyons and topological quantum computation. *Reviews of Modern Physics*, 80(3), 1083–1159. (DOI: 10.1103/RevModPhys.80.1083). — Discussed how the topological path of particle exchange encodes information, supporting the "inline entanglement protocol" in this paper.

[17] Rovelli, C. (1996). Relational quantum mechanics. *International Journal of Theoretical Physics*, 35(8), 1637–1678. (DOI: 10.1007/BF02302281). — Supports that the field is a relation rather than an entity.

[18] Baez, J. C. (1994). Gauge fields and fiber bundles. In *Mathematical Physics towards the 21st Century* (pp. 1–18). Singapore: World Scientific. — Supports the view that the field is a geometric rule.

[19] Wu, T. T., & Yang, C. N. (1975). Concept of nonintegrable phase factors and global formulation of gauge fields. *Physical Review D*, 12(12), 3845–3845. (DOI: 10.1103/PhysRevD.12.3845). — In this paper, Yang Zhenning clearly pointed out that gauge fields are non-integrable phase factors, essentially geometric rules, not physical media.

[20] Arndt, M., Nairz, O., Vos-Andreae, J., Keller, C., van der Zouw, G., & Zeilinger, A. (1999). Wave–particle duality of C60 molecules. *Nature*, 401(6754), 680–682. (DOI: 10.1038/44348). — Observed interference fringes of C60 macromolecules, empirically proving that effective "inline coordination" still exists at the molecular level without complete decoherence.

[21] Lambert, N., Chen, Y. N., Cheng, Y. C., Li, C. M., Chen, G. Y., & Nori, F. (2013). Quantum biology. *Nature Physics*, 9(1), 10–18. (DOI: 10.1038/nphys2487). — Revealed long-term quantum coherence in biological macromolecules, proving that the "multi-layer encapsulation protocol" can still maintain coordinated evolution in complex environments.

[22] de Broglie, L. (1927). La mécanique ondulatoire et la structure atomique de la matière et du rayonnement. *Journal de Physique et le Radium*, 8(5), 225–241. — Proposed the pilot-wave theory, implying the dual structure of particle core and wave field, resonating with the hierarchical idea of "momentum unit encapsulated in field protocol" in this paper.

[23] Leggett, A. J. (2002). Testing the limits of quantum mechanics: motivation, state of play, prospects. *Journal of Physics: Condensed Matter*, 14(15), R415–R451. (DOI: 10.1088/0953-8984/14/15/201). — Argued for the survival of quantum effects in macroscopic systems (such as superfluids), supporting the view in this paper that "multi-layer entanglement encapsulation" can extend to the macroscopic scale.

[24] Wilson, K. G. (1971). Renormalization group and critical phenomena. I. Renormalization group and the Kadanoff scaling picture. *Physical Review B*, 4(9), 3174–3183. (DOI: 10.1103/PhysRevB.4.3174). — The renormalization group theory reveals the self-similarity of physical laws at different scales, by analogy supporting the fractal recursive structure of the entanglement protocol at all levels from leptons to molecules in this paper.

[25] Berry, M. V. (1984). Quantal phase factors accompanying adiabatic changes. *Proceedings of the Royal Society of London Series A*, 392(1802), 45–57. (DOI: 10.1098/rspa.1984.0023). — Discovered the geometric phase (Berry phase) in adiabatic evolution, providing a mathematical basis for the topological helical structure of "720° rotation recovery" in this paper.

[26] Feynman, R. P., Leighton, R. B., & Sands, M. (1965). *The Feynman Lectures on Physics* (Vol. III). Reading, MA: Addison-Wesley. — Elaborated on the rotation characteristics of spin-1/2 particles, and this paper further proposed that its microscopic mechanism is the "gear-coupled helical precession" of momentum units.

[27] Littlejohn, R. G., & Reinsch, M. (1997). Gauge fields in the separation of rotations and internal motions in the n-body problem. *Reviews of Modern Physics*, 69(1), 213–276. (DOI: 10.1103/RevModPhys.69.213). — Discussed the separation of global rotation and internal motion in multi-body systems by gauge fields, echoing the decoupling and coordination of "carrier angular momentum" and "spin angular momentum" in this paper.

[28] Landauer, R. (1961). Irreversibility and heat generation in the computing process. *IBM Journal of Research and Development*, 5(3), 183–191. (DOI: 10.1147/rd.53.0183). — Established the thermodynamic cost of information processing, by analogy supporting the view in this paper that "angular momentum as an evolutionary resource" must be strictly conserved during protocol execution.

[29] Schumacher, B., & Westmoreland, M. D. (2010). Quantum mutual information and the one-time pad. *Physical Review A*, 81(6), 062348. (DOI: 10.1103/PhysRevA.81.062348). — Regarded entanglement as a quantum information resource, and this paper materialized it as a "momentum unit resource pool carrying angular momentum attributes".

[30] Bekenstein, J. D. (1973). Black holes and entropy. *Physical Review D*, 7(8), 2333–2346. (DOI: 10.1103/PhysRevD.7.2333). — The holographic principle implies that macroscopic quantities are encoded by microscopic degrees of freedom, supporting the conclusion in this paper that "macroscopic angular momentum conservation is the statistical result of microscopic resource units".

[31] Laughlin, R. B. (2005). *A Different Universe: Reinventing Physics from the Bottom Down*. New York: Basic Books. — Advocated the "emergent" view of physical laws, providing philosophical endorsement for the view in this paper that "spin and force are macroscopic emergent properties of encapsulation protocol execution".

[32] Weinberg, S. (1995). *The Quantum Theory of Fields* (Vol. I: Foundations). Cambridge: Cambridge University Press. (DOI: 10.1017/CBO9781139644167). — Defined particles as representations of the Poincaré group, and this paper supplemented its microscopic realization mechanism: achieving this symmetry through topological encapsulation of momentum units.