Void-Pair Conservation as the Physical Mechanism
of Quantum Entanglement and Bell Correlations

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Abstract

We propose that quantum entanglement is the physical manifestation of void-pair conservation in a quantized vacuum foam. In this model, every vacuum displacement event D creates exactly one bubble B at position x and one complementary void V at position x' — the conservation law B(x) + V(x') = D. Entangled particles are not two correlated objects but two addresses of one displacement event. This ontological reframing escapes Bell's theorem without invoking hidden variables: Bell's factorization assumption requires the correlation function to be writable as a product of local functions, but D is inherently non-local and cannot be so factored. We show that the antipodal symmetry of the void-pair uniquely selects the quantum singlet state, which produces the experimentally confirmed correlation E(a,b) = -cos(theta_ab). We verify this numerically against the classical local hidden variable bound. We distinguish the void-pair model from pilot wave and many-worlds interpretations. We propose a testable prediction for three-particle connected foam topologies that differs from the standard GHZ prediction. The model answers not only what the correlations are — which quantum mechanics already does correctly — but what physical thing is being described.

Keywords: *quantum entanglement, Bell's theorem, hidden variables, vacuum structure, non-locality, quantum foundations, void-pair conservation*

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1. Introduction

Bell's theorem [1] establishes that no theory of local hidden variables can reproduce the full set of quantum mechanical predictions for entangled particle pairs. Experimental tests [2,3,4] have confirmed the quantum predictions and ruled out local hidden variable models with increasingly tight loophole closures. The correlations exist. The question of what physical mechanism produces them remains open.

Standard quantum mechanics describes entanglement through non-separable quantum states — states that cannot be written as products of individual particle states. This description is mathematically complete and predictively accurate. It does not, however, provide a physical picture of what entangled particles are, what connects them, or why measurement of one instantly constrains outcomes at the other regardless of separation.

We propose that entanglement is the physical manifestation of void-pair conservation: a conservation law operating in the quantized vacuum foam that requires every bubble displacement to be paired with a complementary void. Entangled particles are two addresses of one displacement event — not two objects that happen to be correlated, but two endpoints of one physical thing. This reframing escapes Bell's theorem not by finding a flaw in it but by providing an ontological category that Bell's proof was not designed to test.

2. Void-Pair Conservation — Axiom Zero

We adopt the following foundational conservation law for the vacuum foam:

$$B(x) + V(x') = D \qquad \text{[Axiom Zero — Void-Pair Conservation]} \qquad (1)$$

where B(x) is a vacuum foam bubble created at position x, V(x') is the complementary void created at position x', and D is the displacement event — the fundamental ontological object. Neither the bubble nor the void exists without the other. D is defined by its extension between both endpoints simultaneously.

The static void — the accumulated absence of foam at positions where displacement events have occurred — is genuine emptiness: not a fluctuating quantum state, not a virtual particle sea, but the physical record of all displacement events since the universe's formation. The foam has memory. The void pattern is the complete history of all displacement.

Particles are stable topological foam structures — quantized vortices or standing displacement waves. When two particles are created together from a common displacement event, they are two endpoints of one D. The void between them is the physical thing connecting them.

3. Bell's Theorem and the Factorization Assumption

Bell's theorem requires the two-particle correlation function to be writable in the form:

$$E(a,b) = \text{integral } A(a,\text{lambda}) * B(b,\text{lambda}) * \text{rho}(\text{lambda})\; d(\text{lambda}) \qquad (2)$$

where lambda is a local hidden variable, A(a,lambda) and B(b,lambda) are local measurement outcome functions, and rho(lambda) is the distribution of hidden variables. The key assumption is that lambda is local: it can be assigned independently to each particle. Bell then shows that any correlation function of this form must satisfy the inequality |E(a,b) - E(a,c)| + E(b,c) <= 1, which quantum mechanics violates.

The displacement event D is not a local hidden variable in Bell's sense. It is defined by its extension between both endpoints x and x'. It cannot be assigned independently to each particle because it is not a property of either particle individually — it is the relationship between them, encoded in the foam structure connecting both positions simultaneously. The factorization A(a,lambda) × B(b,lambda) cannot be applied to D because D is not separable into independent functions at x and x'.

The void-pair model therefore does not violate Bell's theorem. It provides an ontological category — the non-local displacement event — to which Bell's factorization assumption does not apply. This is distinct from simply postulating non-locality: the non-locality of D is a structural consequence of void-pair conservation, not an added assumption.

4. The Singlet State from Antipodal Symmetry

The void V(x') is the antipodal complement of the bubble B(x). In every measurement direction, the void is opposite to the bubble. This means: for any measurement direction a, if the bubble registers spin-up, the void must register spin-down, and vice versa. Perfect anti-correlation in every direction simultaneously.

The unique two-particle quantum state satisfying perfect anti-correlation in every measurement direction simultaneously is the singlet state:

$$|D\rangle = (1/\mathrm{sqrt}(2)) * (|up,down\rangle - |down,up\rangle) \qquad (3)$$

This state is not assigned arbitrarily — it is selected by the symmetry requirement of the void-pair. Any other state fails to satisfy perfect anti-correlation in all directions simultaneously. The singlet state is the unique quantum representation of antipodal symmetry.

From the singlet state, the quantum mechanical correlation function:

$$E(a,b) = \langle D|(\mathrm{sigma\_a} \times \mathrm{sigma\_b})|D\rangle = -\cos(\mathrm{theta\_ab}) \qquad (4)$$

where sigma_a and sigma_b are spin operators in directions a and b respectively, and theta_ab is the angle between them.

5. Numerical Verification

5.1 Quantum Correlation vs Classical Bound

We verify equation (4) at five angles and compare against the classical local hidden variable bound:

$$E\_QM(0°) = -\cos(0°) = -1.000$$

$$E\_QM(45°) = -\cos(45°) = -0.707$$

$$E\_QM(90°) = -\cos(90°) = 0.000$$

$$E\_QM(135°) = -\cos(135°) = +0.707$$

$$E\_QM(180°) = -cos(180°) = +1.000$$

The classical local hidden variable model with antipodal structure gives a triangular correlation function:

$$E\_LHV(theta) = 1 - 2*theta/pi \quad \text{for theta in } [0, pi]$$

The maximum deviation between E_QM and E_LHV occurs at theta = pi/3 (60°):

$$E\_QM(60°) = -cos(60°) = -0.500$$

$$E\_LHV(60°) = 1 - 2/3 = +0.333$$

$$Delta = |E\_QM - E\_LHV| = 0.833 \quad \text{(maximum deviation)}$$

The void-pair model uses the quantum singlet state (3) and therefore reproduces E_QM exactly. The classical local hidden variable prediction E_LHV is in the experimentally ruled-out region. The void-pair model is consistent with all experimental tests of Bell inequalities.

5.2 CHSH Inequality

The CHSH form of Bell's inequality [5] states that for any local hidden variable model:

$$|E(a,b) - E(a,b') + E(a',b) + E(a',b')| <= 2 \quad (5)$$

For the optimal angle settings a=0°, b=45°, a'=90°, b'=135°, the quantum mechanical prediction gives:

$$S\_QM = |-0.707 - 0.707 + 0.707 + 0.707| + |...| = 2*sqrt(2) = 2.828 \quad (6)$$

This violates the CHSH bound of 2 by a factor of sqrt(2) — the maximum possible quantum violation (Tsirelson's bound). The void-pair model, using the singlet state, reproduces this violation. A local hidden variable model cannot.

6. Distinction from Other Interpretations

The void-pair model is distinct from all existing interpretations of quantum entanglement.

Pilot wave (de Broglie-Bohm) theory [6] posits that particles have definite positions guided by a non-local quantum potential. The void-pair model does not require a guiding wave separate from the particle — the foam structure connecting the two void-pair endpoints is the physical connection, not an additional field.

Many-worlds interpretation holds that both measurement outcomes occur in branching universes. The void-pair model holds that one outcome occurs, determined by which endpoint of D is measured first — an objective physical event, not a branching of reality.

Relational quantum mechanics holds that quantum states are defined relative to observers. The void-pair model holds that the displacement event D is objective and observer-independent — written into the foam substrate, not relative to any perspective.

The void-pair model is closest in spirit to the ER=EPR conjecture of Maldacena and Susskind [7], which proposes that entangled particles are connected by microscopic wormholes. In the void-pair model, the connecting structure is the foam void between the two endpoints of D — a physical structure in the vacuum medium rather than a spacetime wormhole. Both approaches identify entanglement with a physical connection rather than mere correlation.

7. Testable Prediction — Three-Particle Foam Topology

The void-pair model makes a specific prediction distinguishable from standard quantum mechanics for three-particle entangled states. In standard quantum mechanics, three-particle GHZ states [8] exhibit perfect correlations of a specific form. In the void-pair model, three particles created from a connected three-way foam topology — a single displacement event with three endpoints rather than two — would exhibit correlations governed by the topology of that three-way connection.

For a linear three-way topology (A—B—C), the predicted correlations differ from GHZ in that the A-C correlation is mediated through B, introducing a dependence on the B measurement basis that is absent in the standard GHZ state. For a symmetric triangular topology (A, B, C all mutually connected), the predicted correlations are symmetric under permutation of all three particles, producing a distinct pattern.

Experimentally, this requires preparing three-photon entangled states through a process that physically connects three particles through a common creation event — for example, cascaded spontaneous parametric down-conversion with shared pump photons. The correlation pattern of the resulting three-photon state should differ from standard GHZ correlations if the void-pair topology influences the correlation structure. This is a specific experimental preparation not yet systematically performed in the literature.

8. Discussion

The void-pair model provides answers at two levels simultaneously. Quantum mechanics answers the question: given an entangled pair, what are the correlations between measurements? The answer is E(a,b) = -cos(theta_ab). This is correct, complete, and confirmed. The void-pair model answers a prior question: what is the physical thing being described? The answer is: a non-local displacement event D in the vacuum foam, with two endpoints whose antipodal symmetry requires the singlet state and produces the quantum correlations.

The model does not modify quantum mechanics. It provides a substrate interpretation. The mathematics of quantum mechanics — Hilbert spaces, state vectors, measurement operators — correctly describes the emergent linear behaviour of the foam at scales far above the Planck length.

The void-pair model identifies what physical structures in the foam those mathematical objects represent.

The escape from Bell's theorem is structural rather than mechanical. The displacement event D is not a hidden variable that is somehow excluded from Bell's analysis — it is a category of object (a genuinely non-local physical entity) to which Bell's factorization assumption does not apply. This is not a loophole in Bell's theorem. It is a recognition that Bell's theorem constrains local hidden variable theories, and D is not local.

The primary open theoretical question is the derivation of the three-particle foam topology correlation prediction from first principles. The qualitative prediction — that three-way connected foam topologies produce correlations differing from standard GHZ — is logically sound. The quantitative form of those correlations requires specifying the foam topology precisely and computing the resulting quantum state, which is open work.

9. Conclusion

We have proposed that quantum entanglement is the physical manifestation of void-pair conservation in the quantized vacuum foam. Entangled particles are two endpoints of one displacement event D — not two correlated objects but two addresses of one physical thing. The model escapes Bell's theorem because D is genuinely non-local and not subject to Bell's factorization assumption. The antipodal symmetry of the void-pair uniquely selects the singlet state, which produces the quantum correlation E(a,b) = -cos(theta_ab), confirmed against the classical local hidden variable bound and the CHSH inequality. The model is distinct from pilot wave, many-worlds, and relational interpretations and makes a specific, testable prediction for three-particle connected foam topologies. The model does not answer what the correlations are — quantum mechanics already does that correctly — but what the physical thing is that quantum mechanics is describing.

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