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Temporal Duality of Matter and Antimatter

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Abstract

This paper proposes a conditional history-space interpretation of the matter–antimatter distinction as a duality of marked physical excitations embedded in complete four-dimensional histories. The starting point is the Complete-Timeline Configuration Space framework and its Bhaskar Complete-Timeline Equation (BCTE) [1]. Because ordinary matter and antimatter coexist within one observed spacetime, the proposed reversal does not classify entire universes as matter or antimatter; instead, it acts on a gauge-consistent bundle of locally marked excitation histories. An orientation grading Ω and a pairing involution J are introduced, yielding the compact Bhaskar Temporal Duality Equation, $J\Omega + \Omega J = 0$. The identity is derived exactly from a reversible pairing construction, but its physical identification with antiparticle structure remains a hypothesis rather than a consequence of the standard model or of BCTE alone. When the regulated BCTE operator commutes with J, an orientation-balance theorem follows: any J-invariant density operator has vanishing orientation-odd expectation value. A two-history graph model then gives a solvable eigenvalue splitting and shows explicitly how geometric or boundary asymmetry could bias the two orientations. Compatibility with quantum field theory, charge superselection, CPT, CP violation, thermodynamic time, gravitational covariance, and baryogenesis is analyzed without identifying an antiparticle with a literal backward-aging observer. The paper isolates a

possible bridge to quantum gravity while specifying what would be required for a genuine, testable advance. Its results are exact within the stated finite-dimensional assumptions, not an experimentally confirmed theory of antimatter.

Keywords: antimatter; temporal orientation; charge conjugation; CPT symmetry; complete-history configuration space; relational time; quantum gravity; BCTE; graph Laplacian; baryogenesis

1. Introduction

Antimatter is established experimentally and described quantitatively by relativistic quantum field theory. Positrons were observed long before current attempts to quantize spacetime, and modern field theory accounts for antiparticle production, propagation, and annihilation through states and operators with the appropriate conserved charges [2–5]. The Feynman–Stueckelberg picture permits a useful backward-time representation of certain propagator contributions; it is not a demonstration that antiparticles possess clocks which literally run backward [4]. The physical challenge is therefore not to redescribe a positron as a time-reversed electron. It is to determine whether the symmetry underlying paired particle and antiparticle descriptions admits a covariant formulation when spacetime itself is emergent.

The earlier Complete-Timeline Configuration Space proposal [1] takes entire geometrical and matter histories, rather than instantaneous configurations, as arguments of a timeless state functional. Its BCTE is derived from a real phase-covariant quadratic effective functional, with a local history-space operator and a nonlocal kernel of phase-transported amplitude differences. The framework admits relational clock descriptions only within appropriate decoherent semiclassical sectors. Its continuum measure, microscopic dynamics, and empirical distinction from established quantum gravity proposals remain unresolved. Those limitations are inherited here and are not concealed by the introduction of a new symmetry label.

The present work asks whether matter and antimatter could be regarded as two relative orientations of marked excitations within the same complete-history geometry. The term orientation will not mean global cosmic time reversal, the sign of entropy production, or particle speed along a worldline. It means a discrete grading on a precisely defined auxiliary space of history records. A map that exchanges the grading is proposed as a candidate structural predecessor of an emergent particle–antiparticle comparison. Distinguishing this abstract map from the physical C, P, T, and CPT transformations is essential. The analysis gives a concise equation, a symmetry theorem, a finite-graph realization, and a list of correspondence tests; it does not supply a derivation of standard-model antiparticles from an already completed quantum-gravity theory.

2. Relation to Established Physics

2.1 Dirac theory and the particle–antiparticle interpretation

The relativistic wave equation and its field-theoretic quantization led to excitations with positive energy and opposite internal charges, not necessarily opposite proper-time evolution [2]. Anderson's positron observation established the existence of the electron antiparticle [3]. Feynman's positron formalism reorganizes boundary-condition and propagator contributions into an elegant spacetime interpretation [4]. This paper accepts these results as fixed low-energy constraints. Its proposed additional structure is placed on complete, record-bearing histories and cannot modify measured pair-production or annihilation amplitudes without explicit, testable corrections.

2.2 C, P, T, and CPT are different transformations

Charge conjugation C exchanges particles with their antiparticles at the level of charge-conjugate field content; it does not, by itself, reverse physical time. Parity P reverses spatial orientation: time reversal T has a distinct antiunitary implementation in ordinary quantum mechanics. CPT relates all three operations under standard axioms of local Lorentz-invariant quantum field theory [6]. An auxiliary orientation exchange must not be silently equated with any of these transformations. If a physical map to CPT exists, its antiunitary character, action on spinors, and behavior on curved, oriented backgrounds must be reproduced. Curved-spacetime generalizations formulate such comparisons between appropriately reoriented geometries [7].

2.3 Closed-system quantum theory and relational clocks

Quantum gravity faces the problem that the geometry supplying classical clock time is itself dynamical. DeWitt's canonical formulation and subsequent relational-time analyses represent significant approaches to this difficulty [8,9]. Page and Wootters showed how effective evolution can be recovered through conditioning on an internal clock even when the overall description is stationary [9]. In the present proposal, orientation labels are not clock readings. They remain distinct from relational temporal order and from thermodynamic irreversibility.

2.4 Matter–antimatter asymmetry is not the same as duality

The observed preference for matter in the visible universe cannot be deduced merely by pairing two labels. Weak interactions violate CP, as shown in neutral-kaon decays [10]. Sakharov identified the conditions required for a dynamical baryon asymmetry in the standard cosmological setting, including baryon-number violation, C and CP violation, and departure from thermal equilibrium [11]. Any deeper complete-history proposal must either recover such mechanisms or supply an explicit

alternative with demonstrably equivalent empirical consequences. Exact orientation pairing alone produces no baryogenesis.

3. Postulates and Scope

1. Complete-history postulate. The starting domain is the gauge-quotiented configuration space of complete geometrical, matter-field, and physical-record histories defined in BCTE [1].
2. Marked-excitation postulate. Particle comparisons are made on histories with a localized, gauge-consistent excitation mark; globally distinct matter and antimatter universes are not required.
3. Orientation-grading postulate. A chosen sector of marked histories admits a binary label $\sigma = +1$ or -1. The label is not a fundamental coordinate time and is not assumed universal for self-conjugate excitations.
4. Pairing postulate. On the chosen sector, an invertible map j exchanges marks of opposite grading, preserves the operational pairing measure, and acts twice as identity.
5. Correspondence postulate. Electric charge, field content, locality, spin statistics, CPT, and ordinary laboratory forward-time measurements must agree with quantum field theory.
6. Dynamical modesty postulate. The abstract pairing need not be a symmetry of the full dynamics; CP-violating interactions, boundary conditions, and background geometry can restrict or break the effective comparison.
7. Empirical postulate. A proposed physical departure becomes predictive only after its kernels, couplings, physical observables, and controlled standard-model limit are specified independently of observation.

4. Kinematics of Marked Complete Histories

4.1 The BCTE base space

Let $\mathscr{H}$ denote admissible complete field-and-geometry histories and $\mathscr{G}$ the relevant diffeomorphism and internal-gauge redundancies. The original theory uses the physical quotient $\mathscr{T} = \mathscr{H}/\mathscr{G}$. Each point $T \in \mathscr{T}$ contains an entire candidate history, including correlations or records used to define an emergent quasiclassical spacetime [1]. The timeless functional $\Psi[T]$ obeys an effective constraint $H_B \Psi = 0$; in a regulated graph realization the operator contains a potential V and phase-twisted weighted Laplacian. No preferred global coordinate time is postulated.

$$\mathscr{T} = \mathscr{H} / \mathscr{G}, \qquad H_B \Psi = 0. \quad (1)$$

4.2 Why a mark is necessary

A single history can contain electrons, positrons, photons, antiparticles of multiple species, and interactions between them. Therefore, assigning $\sigma = +1$ to an entire matter history and $\sigma = -1$ to an entire antimatter history would misrepresent even the simplest annihilation event. Instead define an auxiliary set $\mathfrak{M}$ of pairs $h = (T, m)$, where m is a selected physical excitation record or gauge-invariant marked correlation within T. Admissible marks must specify a localized field excitation, its species, and sufficient relational data to identify it without a chosen coordinate origin. This auxiliary construction does not enlarge physical spacetime; it organizes questions asked of a complete history.

$$\mathfrak{M} = \{(T, m) : T \in \mathscr{T}, \text{ m an admissible marked excitation}\}. \quad (2)$$

4.3 Charge and the orientation grading

For a non-self-conjugate charged species, assign a grading $\sigma(h) \in \{+1, -1\}$ relative to a specified reference convention. Let $q_a(h)$ denote the additive gauge charges of the marked excitation. The core physical hypothesis is that the sign exchange in a suitable pair map may correlate with reversal of appropriate charge labels in the standard field-theoretic limit. Such a correlation is not the identity "negative charge equals backward time"; a positively charged proton is matter, and neutral particles may have distinct antiparticles. The full set of particle quantum numbers, rather than one electric-charge sign, must determine whether a physical particle–antiparticle pairing is possible.

$$\sigma(jh) = -\sigma(h), \qquad q_a(jh) = -q_a(h) \text{ (where applicable).} \quad (3)$$

The charge relation in Eq. (3) is a required matching condition for an admissible charged pair, not a theorem from BCTE. Species that are their own antiparticles, or neutral sectors where charge conjugation acts nontrivially without a simple binary charge, require a different representation. The label is consequently sector-relative and cannot be declared a universal property of every field degree of freedom.

4.4 Measure and Hilbert space

To make the duality algebra definite, consider first a finite or countable regulated set of marked histories with positive weights, and later a measurable space $(\mathfrak{M}, \nu)$. Define the auxiliary Hilbert space $\mathbb{K} = L^2(\mathfrak{M}, d\nu)$. An admissible pairing $j: \mathfrak{M} \to \mathfrak{M}$ satisfies $j^2 = \text{identity}$ and $\nu(jE) = \nu(E)$ for all measurable E. These assumptions guarantee that relabeling marked histories does not change their inner product. Physical amplitudes and observable probabilities still require the BCTE physical inner product, decoherence, and constraints; the auxiliary $\mathbb{K}$ is not yet the Hilbert space of the universe.

$$\mathbb{K} = L^2(\mathfrak{M}, d\nu), \qquad j^2 = \mathrm{id}, \qquad j_*\nu = \nu. \quad (4)$$

5. The Bhaskar Temporal Duality Equation

5.1 Definition of the operators

Define an orientation operator Ω by multiplication with the grading and a pairing operator J by pullback along j. In the real-permutation sector used here, J is a linear unitary involution, not the physical antiunitary time-reversal operator. It is introduced to isolate a simple kinematic structure without assuming more than the selected marked sector supports.

$$(\Omega\psi)(h) = \sigma(h)\psi(h), \qquad (J\psi)(h) = \psi(jh). \quad (5)$$

From $j^2 = \mathrm{id}$ and $\sigma(jh) = -\sigma(h)$, one has $\Omega^2 = I$, $J^2 = I$, and, for every ψ in the common operator domain, $(J\Omega\psi)(h) = \sigma(jh)\psi(jh) = -\sigma(h)\psi(jh) = -(\Omega J\psi)(h)$. Hence the operators anticommute. The relation is the distinctive compact expression chosen to summarize the proposed history-orientation architecture.

5.2 Bhaskar Temporal Duality Equation (BTDE)

$$\mathbf{J\Omega + \Omega J = 0} \quad \mathbf{(6)}$$

Equation (6) is designated the Bhaskar Temporal Duality Equation (BTDE) within this manuscript. In plain language: exchanging a paired excitation reverses its orientation label. The equation is an exact algebraic consequence of Eqs. (3)–(5), not an experimental discovery, a new form of the Heisenberg uncertainty relation, or a dynamical law derived from microscopic quantum gravity. Algebraically it is an anticommutation relation familiar from two-state systems; the proposed novelty is its carefully limited application to marked complete histories and the dynamical constraints this application exposes.

5.3 Immediate consequences

The pair map intertwines the two orientation eigenspaces. With $\Pi_\pm = (I \pm \Omega)/2$, the BTDE implies $J\Pi_\pm = \Pi_\mp J$. Therefore, the two auxiliary sectors have equal dimension in a finite paired construction, and J maps any + orientation vector into a − orientation vector of the same norm. These are exact kinematic consequences. Equal auxiliary dimension does not mean equal population, equal decay rates, or exact charge-conjugation symmetry of the weak interactions.

$$\Pi_\pm = (I \pm \Omega)/2, \qquad J\Pi_\pm = \Pi_\mp J. \quad (7)$$

6. Compatibility with the Bhaskar Complete-Timeline Equation

6.1 Regulated BCTE operator

The earlier effective functional yields a continuum operator involving a local history-space Laplace–Beltrami term, curvature coupling, a consistency potential, and a phase-twisted nonlocal kernel [1]. Because the continuum operator is formal, symmetry statements are cleanest on the finite graph regulator already employed in BCTE. Give each marked node i a phase S_i, potential V_i, amplitude ψ_i, and pairwise nonnegative symmetric kernel K_ij. The regulated operator is

$$(H_B\,\psi)_i = V_i\,\psi_i + \kappa\,\Sigma_j\,K_{ij}\,[\psi_i - \exp\{i(S_i - S_j)/\hbar\}\,\psi_j]. \quad (8)$$

This is a Hermitian phase-twisted graph Laplacian plus a real potential when κ and V_i are real, K_ij = K_ji ≥ 0, and suitable graph boundary conditions hold. The action-phase factor is required for the same relative-phase covariance as in the original paper [1]. The orientation mark can enter K through gauge-invariant record comparisons; it must not be used to evade locality, charge conservation, or superselection.

6.2 When the pairing is a dynamical symmetry

Let π be the node permutation implementing j and let $J\psi_i = \psi_{\pi(i)}$. The additional conditions $V_{\pi(i)} = V_i$, $K_{\pi(i)\pi(j)} = K_{ij}$, and $S_{\pi(i)} - S_{\pi(j)} = S_i - S_j \pmod{2\pi\hbar}$ are sufficient for JH_B = H_BJ. These conditions are stronger than the BTDE and are not automatically true for realistic interactions. In particular, the time orientation and charge content transformed by physical CPT require a different implementation in spinor and curved-spacetime sectors [6,7].

$$JH_B = H_BJ \quad \text{(only if paired potentials, kernels, and phases agree).} \quad (9)$$

6.3 Orientation-balance theorem

Proposition. Suppose that ρ is a normalized trace-class density operator on a regulated marked-history sector, J is a unitary involution, $\{J,\Omega\} = 0$, and $J\rho J = \rho$. Then the orientation-odd order parameter $A = \mathrm{Tr}(\rho\Omega)$ vanishes. The proof is immediate: by cyclicity of trace, $\mathrm{Tr}(\rho\Omega) = \mathrm{Tr}(J\rho J\Omega) = \mathrm{Tr}(\rho J\Omega J) = -\mathrm{Tr}(\rho\Omega)$. Thus A = 0. For a normalized pure state satisfying $J\psi = \pm\psi$, the same conclusion follows from its expectation value of Ω.

$$J\rho J = \rho \quad \Rightarrow \quad A \equiv \mathrm{Tr}(\rho\Omega) = 0. \quad (10)$$

This theorem is more informative than the algebraic naming alone: exact duality symmetry forbids a nonzero orientation-odd average in a symmetry-invariant ensemble. Consequently, any physical explanation of a preference for one orientation must specify which assumption fails, whether through boundary-state selection, asymmetric effective dynamics, a degenerate sector, or different conditioning

on records. A ≠ 0 does not by itself equal a measured cosmic baryon excess; connecting the two requires a separately defined physical baryon-number observable and a valid low-energy mapping.

6.4 A necessary restriction from gauge superselection

Physical states of different total gauge charge generally cannot be treated as freely coherently mixing alternatives. A proposed pair comparison across charged sectors must respect the associated superselection structure. In a controlled charged theory, J may act as an isomorphism between distinct charge sectors rather than as an observable operator that converts one charged particle into another. The positive mismatch construction below is therefore applied to neutral, gauge-matched process records, or to an explicitly doubled auxiliary comparison space. It is not an electric-charge-violating transition Hamiltonian.

7. Exactly Solvable Paired-History Model

7.1 A two-record regulator

Consider two gauge-matched marked histories h+ and h− related by j, representing two alternative records of an admissible charge-neutral comparison process. Let their effective consistency potentials be V+ = v + δ and V− = v − δ. Introduce a positive symmetric kernel weight K and λ = κK ≥ 0, with phase difference θ = (S+ − S−)/ℏ. The finite BCTE constraint is represented by the Hermitian matrix

$$H_{pair} = \begin{bmatrix} v+\delta+\lambda & -\lambda \exp(i\theta) \\ -\lambda \exp(-i\theta) & v-\delta+\lambda \end{bmatrix}. \quad (11)$$

An overall phase redefinition of the second basis vector removes θ, so the two eigenvalues depend only on λ and δ. Diagonalization gives

$$E\pm = v + \lambda \pm \sqrt{(\delta^2 + \lambda^2)}. \quad (12)$$

Writing Ω = diag(1, −1), the normalized eigenvectors have orientation expectations, with signs chosen consistently with the upper and lower eigenvalues,

$$\langle \Omega \rangle \pm = \pm \delta / \sqrt{(\delta^2 + \lambda^2)}. \quad (13)$$

For λ > 0 and δ = 0, both energy eigenvectors have vanished orientation expectation and the pairing-exchange symmetry is unbroken. For δ ≠ 0, the eigenvectors are biased: the relative consistency mismatch competes with phase-covariant history coupling. For λ → 0 at fixed nonzero δ, the limiting eigenvectors localize on one of the two orientations. These results are exact statements about the specified 2 × 2 matrix. The zero-constraint condition $H_{pair}\,\psi = 0$ requires a suitable value of v; its existence is not automatic.

7.2 Relation to history-space geometry

An illustrative BCTE kernel reads $K_{ij} = N_{ij} \exp[-d_T^2(i,j)/(2\ell_T^2)]$, where d_T is a positive operational separation and ℓ_T a coherence scale [1]. If geometry or persistent records alter the consistency costs, $\delta = (V+ - V-)/2$ can formally depend on those differences. In that restricted sense Eq. (13) connects an orientation-odd expectation with data drawn from the geometry and consistency structure of entire histories. The step from such a graph to an observable gravitational effect is unproved: it requires a physical map from the mark to quantum-field excitations and independent determination of λ, δ, and the history-space regulator.

$$\lambda = \kappa N \exp[-d_T^2/(2\ell_T^2)], \qquad \delta = (V+ - V-)/2. \quad (14)$$

7.3 No double counting of physical amplitudes

The pair graph is an auxiliary regulator, not a new duplication of physical electrons. When a branch or a detector record identifies one excitation, the corresponding conditional probabilities must be calculated using the physical decoherence functional rather than by assigning equal objective existence to both labels. In particular, the graph eigenvalue splitting alone cannot predict laboratory masses, magnetic moments, production cross sections, or cosmic abundances. It is a mathematical proof of principle for the claimed orientation algebra and its possible dynamical breaking, and nothing more.

8. Recovery of Relativistic Quantum Field Theory

8.1 Charge-conjugate field content

For a Dirac field on a sufficiently regular semiclassical background, the low-energy interpretation of the marked excitations must reduce to ordinary charged particle and antiparticle modes. In conventional notation the charge-conjugated spinor is built from the original spinor with the appropriate charge-conjugation matrix and complex conjugation. This operation changes charged field content without introducing a new observable proper-time direction. The map j may be called physically interpretable only if the induced transformation of relevant gauge-invariant amplitudes reproduces this field-theory correspondence. If it fails to do so, the proposed grading is at most an auxiliary mathematical classification.

8.2 Particle and antiparticle share ordinary laboratory time

In a quasiclassical branch with physical clock C, both a particle and its antiparticle are described using correlations with the same monotonically ordered laboratory clock readings. This prevents a misleading claim that an antiparticle must age in the opposite temporal direction. The backward-in-

time line in a Feynman diagram is a representation of an amplitude, not a literal instruction to the antiparticle's internal clock [4,9]. A candidate orientation variable that changes those predictions would contradict the low-energy correspondence requirement and would need direct experimental support.

8.3 CPT, not an unqualified C symmetry

The weak interaction does not preserve C or CP separately. Consequently demanding [H_B,J] = 0 with J identified globally as C would be wrong for a realistic standard-model reduction. A more defensible approach asks whether a corrected, possibly antiunitary pairing across reversed spacetime orientations can reduce to the familiar CPT correspondence. That problem requires spin structures, an orientation prescription for the curved background, and the correct action on local field algebras; the simple two-state J considered here is not that full operator [6,7]. CPT tests place strong limits on any proposed departure, and CPT violation cannot be invoked casually within the assumptions of ordinary local Lorentz-covariant quantum field theory [12,13].

8.4 Annihilation and pair creation

Processes such as electron–positron annihilation and charged pair production are encoded by local field interactions and conserved four-momentum, angular momentum, and charges. Neither Eq. (6) nor Eq. (13) provides a new decay rate or energy budget. A completed embedding must reproduce quantum electrodynamics amplitudes in a fixed-background limit. It must also accommodate histories containing simultaneous matter and antimatter; this requirement is one reason for introducing local marks rather than classifying complete universes by a single sign.

9. Relational Time, Entropy, and the Meaning of Reversal

9.1 Three notions that must not be conflated

A spacetime manifold may carry an orientation or a time orientation; a physical subsystem may register an ordering of clock correlations; and a thermodynamic macrostate may exhibit an entropy gradient. None is automatically identical with the sign of the auxiliary operator Ω. In particular, opposite eigenvalues of Ω do not imply opposite local entropy increase. An observer made of antimatter would not be forced by the BTDE to see memory forming backward or measurement records spontaneously erasing. Such statements would require a precise microscopic theory of records and boundary conditions.

9.2 Conditioning on a physical clock

Within a decoherent BCTE branch, split correlations into clock C and system X. A normalized conditional wave function has the schematic Page–Wootters form $\psi_X(x|t) \propto \langle C{=}t|\Psi\rangle$ [9]. A proper orientation pairing must map admissible physical records into admissible physical records without reversing experimentally observed causality. If the two marked excitations share a branch and a clock, both are conditioned on the same relational parameter t. The sign σ describes a relation between marked configurations and does not itself replace the clock.

$$\psi_X(x|t) = \langle C{=}t|\Psi\rangle \,/\, \|\langle C{=}t|\Psi\rangle\|. \qquad (15)$$

9.3 Thermodynamic consistency condition

Let ΔS_rec be the entropy change in a coarse-grained environmental record sector of a branch. A physical implementation must permit $\Delta S_rec \geq 0$ for ordinary irreversible processes involving either charge orientation under the same relevant macroscopic preparation. The orientation map is not, by definition, the transformation $\Delta S_rec \rightarrow -\Delta S_rec$. This avoids building a false claim about antimatter thermodynamics into the axioms. A distinct gravity-dependent modification to record formation would require a microscopic coupling and a calculation beyond the present framework.

10. Emergent Gravity and Curved Spacetime

10.1 The possible quantum-gravity bridge

The distinctive possible contribution is not the anticommutator alone. Anticommuting two-state operators are standard mathematical objects. The potentially interesting step is to ask whether the pairing involution can be defined over complete histories whose metric, topology, gauge fields, and record structures vary, rather than over particle states on a fixed background. BCTE already treats whole histories as points in a quotient configuration space [1]. If a consistent marked-history bundle exists over that space, its pairing properties could constrain which discrete matter symmetries survive the emergence of geometry.

10.2 Covariance and gravitational dressing

A marked excitation on a dynamical geometry cannot be specified by a coordinate location alone. Relational localization might use matter reference fields, asymptotic charges, detector correlations, or appropriately gravitationally dressed observables. The pairing map must act on such gauge-invariant data, preserve the relevant boundary conditions, and coexist with diffeomorphism constraints. The quantum-gravity construction may also require mapping a spacetime with one time and spatial

orientation to a geometry with the reversed orientation, as suggested by rigorous curved-spacetime PCT analysis [7]. No continuous map meeting all these requirements is constructed here.

10.3 Black holes as a correspondence test, not a proof

Particle creation in curved spacetime, including Hawking radiation, demonstrates that the particle concept can depend on global geometry and observer-dependent mode decompositions [14]. That makes curved backgrounds a stringent setting for any theory of emergent particle–antiparticle orientation. Nevertheless, neither event horizons nor singularities provide evidence that antimatter runs backward in time. A concrete test would compare paired, gauge-invariant detector responses or quantum-field correlation functions on the same controlled background and require agreement with established semiclassical results. The present paper does not predict black-hole portals, information retrieval from antimatter, or observable deviations in Hawking spectra.

10.4 Existing antimatter gravity measurements

The ALPHA collaboration observed the gravitational response of trapped neutral antihydrogen, finding behavior consistent with gravitational attraction toward Earth within experimental uncertainties [16]. Any physical orientation-gravity mechanism proposed from complete-history geometry must recover this result and the well-tested ordinary gravitational behavior of matter. The auxiliary two-history energy splitting in Section 7 provides no prediction for antihydrogen free fall; it should not be interpreted as evidence for reversed antimatter gravity.

11. Matter–Antimatter Asymmetry and Baryogenesis

The orientation-balance theorem shows that a J-symmetric ensemble carries no net Ω-odd order parameter. To represent an asymmetric ensemble, an initial state can fail to be J invariant, the effective paired dynamics can contain a J-odd bias, or the recorded branch can be conditioned asymmetrically. These possibilities do not determine the observed baryon-to-photon ratio. In particular, geometric bias δ in Eq. (13) describes a toy spectral orientation, not baryon-number-generating reactions.

A cosmological application must construct a baryon-number current and derive its divergence from the low-energy effective action. The calculation must then identify any baryon-number violation, CP-violating amplitudes, and nonequilibrium epoch or else explain a consistently specified alternative to the standard assumptions [10,11]. An exact CPT-consistent underlying theory can coexist with CP violation and cosmological matter dominance. The BTDE by itself neither violates CPT nor avoids Sakharov's logic. A future claim that cosmic asymmetry follows from history geometry would need an explicit source term, thermal or kinetic evolution, and parameter-independent predictions.

$$\nabla_\mu J_B{}^\mu = \mathscr{S}_B[g, \Phi, \text{records}] \quad \text{(source to be derived, not postulated).} \qquad (16)$$

12. Conditional Phenomenology and Falsifiability

12.1 A null hypothesis

The primary null hypothesis is that complete-history pairing is merely a non-observable redescription of standard CPT-compatible quantum field theory. Under this possibility, the BTDE remains a consistent mathematical bookkeeping identity and produces no novel laboratory signal. The proposal can claim explanatory success only if a physical map from marked histories to observables is constructed and it yields either a nontrivial derivation of known principles from fewer assumptions or a controlled deviation not already excluded by experiment.

12.2 Potential tests, each conditional on a completed model

First, a well-defined curved-background reduction could compare charge-conjugate detector correlation functions on geometries with carefully matched boundary conditions. Second, a laboratory implementation might search for tiny geometry-dependent differences in neutral, charge-balanced process correlations after standard quantum-field and environmental effects are accounted for. Third, a cosmological implementation could calculate a baryon source and compare its predictions with standard baryogenesis constraints. These are categories of possible tests, not predictions of the present equations. No detection threshold, signal amplitude, or parameter-free ratio follows from Eqs. (6)–(16).

12.3 Constraints against spurious novelty

A correction that generates a mass difference between a particle and its antiparticle must confront stringent CPT tests [12], and in a conventional interacting quantum field theory it cannot simply be declared independent of Lorentz structure [13]. A putative difference in electromagnetic pair creation must respect energy–momentum and gauge conservation. Any history-space nonlocality must be shown not to permit spacetime superluminal signalling. Distinguishing orientation effects from standard CP violation and instrumental systematics is indispensable before an experimental claim could be made.

13. Mathematical and Physical Consistency Requirements

13.1 Existence and uniqueness of the pairing

The map j must be defined on a genuine quotient of marked histories and shown to respect gauge equivalence, species data, topology, and physical records. A globally defined pairing might not exist

when defects, horizons, spin structures, or chiral anomalies are present. In such cases the appropriate object may be a local bundle isomorphism rather than a globally defined involution. The paper proves no general existence theorem; its exact statements apply only after j and ν have been supplied.

13.2 Antiunitarity, fermion signs, and projective effects

The simple assumptions $J^2 = I$ and linear unitary J are appropriate to the permutation regulator but cannot be imposed universally on physical time reversal or CPT. Fermionic and spinorial symmetries may carry phase conventions, antiunitary actions, or nontrivial squares on sectors of fixed fermion parity. A rigorous theory would replace the toy J with the correct real-linear or antiunitary structure and re-derive the grading identity at the level of local field algebras or an appropriate Hilbert-space bundle. This is a crucial limitation rather than a technical footnote.

13.3 Charge superselection and Hilbert-space interpretation

The orientation sectors are first mathematical fibers of an auxiliary comparison construction. They cannot be naively superposed when their physical states have inequivalent total gauge charges. If a coherent paired functional is desired, it should be restricted to gauge-neutral composite records or formulated using maps between separate charge sectors, with observable quantities acting within the physically allowed algebra. Otherwise, the pair mismatch energy would introduce an unphysical charged-particle conversion process.

13.4 Dynamics, positivity, and branch conditioning

The finite weighted graph model guarantees self-adjointness and nonnegative graph mismatch for $\kappa K \geq 0$; the full BCTE continuum measure and indefinite gravitational supermetric remain problematic [1]. The orientation-balance theorem assumes a trace-class ρ and a unitary symmetry J. Physical cosmological state may instead be constrained, non-normalizable, or subject to boundary-state selection. Each conclusion must be reconstructed after solving these measure, domain, and decoherence issues.

13.5 A genuine correspondence limit

To become more than nomenclature, the model must produce a low-energy spinor theory with the correct propagators, charge-conjugation matrix, Fermi statistics, scattering amplitudes, CP violation, and physical CPT relations. It must preserve the equivalence principle and semiclassical Einstein equations when metric fluctuations are small. Without these steps the proposed formal analogy is mathematically tidy but physically underdetermined. No theorem of emergent standard-model quantum field theory is established in this manuscript.

14. Distinction from Nearby Interpretations

The Feynman–Stueckelberg representation concerns the analytic and diagrammatic description of antiparticle propagation on a spacetime background [4]; the present construction introduces a grading of marked complete-history data and asks whether a compatible low-energy representation exists. CPT theorems concern transformation laws of local quantum fields under precise assumptions [6,7]; BTDE is a separate auxiliary pairing relation and must not be used as a substitute for those theorems. Decoherent-histories theory explains probabilities for suitable alternative histories [15]; BTDE adds a proposed structure on marked alternatives but does not itself derive probabilities. BCTE supplies the history-space effective operator and the unresolved gravitational substrate [1]; the new paper identifies a possible symmetry constraint on an extension of that substrate. A two-state Pauli-matrix identity is algebraically equivalent to Eq. (6), so the equation's shortness does not independently establish new physics.

15. Research Program

1. Construct a gauge-invariant marked-history bundle over a well-defined BCTE regulator, including charged and self-conjugate field species.
2. Define a physically valid pairing that reproduces charge conjugation or CPT as appropriate, including antiunitary and spinorial structure.
3. Derive the pairing from an action or microscopic principle rather than selecting an involution by definition.
4. Determine the modified BCTE kernel and prove covariance, self-adjointness, and positivity in the required sectors.
5. Recover quantum electrodynamics and standard-model particle–antiparticle amplitudes on a fixed semiclassical background.
6. Specify invariant relational observables and examine pairing on curved or topology-changing history backgrounds.
7. Formulate a physical baryon-number observable and calculate whether any gravity-linked source survives standard CP and CPT constraints.
8. Identify at least one numerically definite, independently parameterized observable that differs from standard quantum field theory and survives existing limits.

16. Discussion

The intuitive motivation is that a deeper theory might organize particle and antiparticle descriptions through a symmetry of complete physical histories rather than through an external universal time parameter. The construction answers a narrow mathematical question: if a reversible exchange of marked excitations flips a binary grading, which operator relation is enforced and what follows when the history-space dynamics respects that exchange? It answers this by Eqs. (6), (7), and (10), and by the explicit eigenvalues and orientation expectations in Eqs. (12) and (13). The exact finite-dimensional statements are internally coherent, but their physical relevance is conditional.

There are two distinct risks. First, the auxiliary grading may prove to be no more than a reparameterization of ordinary particle–antiparticle labels; then it gives no improved explanation of antimatter. Second, making the pairing physical without respecting CP violation, charge superselection, and curved-spacetime covariance could directly conflict with tested results. Accordingly, the BTDE is best treated as an architectural constraint for a research program. The candidate connection to quantum gravity lies in the domain on which the operator is represented, not in claiming that a familiar anticommutator has independently solved either antimatter physics or the problem of time.

The two-sector model nevertheless clarifies a route for future work: geometry and record structure enter the same effective operator that controls the conditional amplitudes, and a symmetry-preserving operator forces a vanishing orientation-odd expectation for symmetric states. In a completed physical theory, the interplay of boundary conditions, history-space geometry, and the low-energy particle algebra might decide whether such a grading offers any real explanatory compression. This route is worthwhile to test precisely because the toy model makes failures of correspondence observable as mathematical inconsistencies rather than burying them in a suggestive interpretation.

17. Conclusion

This work formulates a speculative but bounded extension of Complete-Timeline Configuration Space [1] to locally marked matter and antimatter excitations. A measure-preserving involution J and an orientation grading Ω yield the short Bhaskar Temporal Duality Equation, $J\Omega + \Omega J = 0$. The equation is proved from the specified pairing axioms. Under additional dynamical symmetry conditions, a regulated orientation-balance theorem follows; an exactly solvable two-history model demonstrates the competition between pair coupling and an effective orientation bias. Those are the mathematical results of the paper.

Neither the existence of a physical antimatter–orientation map nor a unique microscopic quantum-gravity origin has been derived. The proposal does not demonstrate literal backward-time motion, solve baryogenesis, supersede CPT, or make a parameter-free prediction. The central research hypothesis is that a physically valid particle–antiparticle correspondence might eventually be expressible as a symmetry of gauge-invariant complete-history data in a setting where geometry and clock time themselves emerge. Establishing that hypothesis requires a full standard-model correspondence, a gravitational construction, and a distinguishing quantitative test.

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Declaration of Status and Originality

The term “Bhaskar Temporal Duality Equation” is introduced by the author in this manuscript for the application of an anticommutation identity to a proposed marked complete-history orientation framework. The operator algebra itself is standard and is not claimed to be an original mathematical discovery. The finite-model results follow from explicitly stated assumptions. The putative connection between this algebra, the actual physical origin of antimatter, and quantum gravity is conjectural and unverified. Prior literature on antiparticles, CPT, relational time, and quantum gravity is acknowledged and cited. Publication, novelty, and priority are subject to independent scholarly evaluation; no experimental confirmation is claimed.

Appendix A. Symbol Summary

Symbol	Meaning
$\mathcal{T}$	Gauge-quotiented complete-timeline configuration space of BCTE
T	One admissible complete physical history
$\mathfrak{M}$	Space of locally marked complete histories

$h = (T,m)$	One marked physical excitation record within a history
$\sigma(h)$	Binary auxiliary orientation grading of a selected marked sector
j	Measure-preserving involution pairing marked histories
$\mathbb{K}$	Auxiliary regulated Hilbert space $L^2(\mathfrak{M},dv)$
Ω	Self-adjoint orientation operator, $\Omega^2 = I$
J	Linear unitary pullback pairing operator in the toy model, $J^2 = I$
$\Pi\pm$	Projectors onto positive and negative grading sectors
H_B	Regulated BCTE phase-twisted history-space constraint
K_{ij}	Nonnegative pairwise kernel on the regulated history graph
λ	Effective nonnegative strength κK of paired history coupling
δ	Half-difference of paired consistency potentials
ρ	Normalized density operator on the regulated marked sector
A	Orientation-odd expectation $\mathrm{Tr}(\rho\Omega)$; not automatically baryon number

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