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David Sigtermans *

Posted Date: 5 June 2025

doi: 10.20944/preprints202504.2263.v3

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Wave Behavior as Emergent Resolution Stability: Deriving Quantum Structure from Entropy Geometry

David Sigtermans

david.sigtermans@protonmail.com

Abstract: We show that wave-like behavior, interference, and quantization emerge necessarily from two axioms: (1) entropy geometry as the generator of physically distinguishable structure, and (2) a minimal principle selecting trajectories stable under entropy flow. Within the Total Entropic Quantity (TEQ) framework, entropy curvature defines the geometry of resolution, and the stability condition selects log-periodic modes as the only entropy-resilient solutions. From this structure, we derive the entropy-weighted path integral, the Born rule as an asymptotic stability condition, the emergence of discrete spectral modes, and the Schrödinger equation as the limiting case of entropy-flat evolution. Quantum wave behavior is thus not postulated, but structurally selected by entropy geometry. The TEQ framework reinterprets quantum theory as a special case of entropy-stabilized dynamics, where physical law arises not from imposed kinematics, but from the geometry of what can stably be resolved under finite informational precision. In this view, precision is not a matter of external control, but a structural limit: resolution is bounded by entropy curvature, which determines what distinctions can persist.

Keywords: entropy geometry; quantum foundations; wave-particle duality; entropy curvature; resolution stability; log-periodic modes; structural realism; quantum measurement; arrow of time; Total Entropic Quantity (TEQ) framework

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Meta-Abstract

This section summarizes the logical structure, assumptions, and derivational flow of this work, pre-empting the common critique that quantum wave behavior is merely postulated rather than derived.

1. **Axioms and Foundational Principles:**
   - **Axiom 0: Entropy Geometry as Structural Generator** (§2, §2.2).
     Physical structure arises from a pre-geometric entropy landscape, not a fixed spacetime; the geometry of entropy curvature determines which distinctions are resolvable and how long they persist.
   - **Axiom 1: The Minimal Principle of Resolution Stability** (§2.3, §3).
     Among all entropy-resolvable configurations, only those that minimize instability under entropy flow (i.e., are maximally stable under entropy curvature) are physically realized.
2. **Derivation Pathway:**
   - **Entropy-Weighted Action:** Starting from constrained entropy maximization over paths (§2.1), the entropy-weighted action is derived as the effective variational principle:

     $$S_{\text{eff}}[\phi] = \int dt \big(L(\phi,\dot{\phi}) - i\hbar\beta\, g(\phi,\dot{\phi})\big)$$

     where $g(\phi,\dot{\phi})$ encodes entropy flux and resolution stability. No standard quantum structures (wavefunctions, Hilbert space, operator algebra) are assumed.
   - **Stability and Spectral Structure:** Variational analysis of the entropy-weighted action (§3) leads to a second variation operator (the entropy curvature operator), whose eigenmodes

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correspond to resolution-stable (log-periodic) solutions. The Hilbert space structure and discrete spectra emerge naturally from this entropy geometry, not as axioms.
- **Wave Behavior and Interference:** The only structurally stable solutions under entropy curvature are log-periodic oscillatory modes (§4). Their coherent superposition produces interference patterns (§5) and recovers the qualitative and quantitative features of quantum wave phenomena—specifically, the Born rule and the Schrödinger equation appear as limiting cases in low-entropy-curvature regimes.

3. **Technical Justification and Placement of Key Results:**
   - **Entropy-weighted path integral and derivation of amplitudes:** §2.1, Appendix A.
   - **Definition and properties of entropy curvature operator:** §3, with mathematical construction and spectral analysis in §3.3 and Appendix A.
   - **Log-periodic eigenmodes and emergence of oscillatory (wave) structure:** §4, supported by explicit solution of the curvature eigenproblem in Appendix A.
   - **Interference and experimental correspondence (e.g., double-slit):** §5.
   - **Connection to standard quantum mechanics (Schrödinger equation, Born rule, Hilbert space):** §4.2, §5.4, §6.
   - **Philosophical and foundational implications:** §7.
4. **Scope and Clarification:**
   - No standard quantum postulates (e.g., wavefunctions, Hilbert space, superposition, commutators) are assumed at the outset; they are shown to arise as consequences of entropy geometry and the minimal principle.
   - Key references and detailed proofs are indicated throughout (see especially [1,8], and Appendix A).

Summary: Wave-like quantum behavior, interference, quantization, and core formal structures (such as the Hilbert space and commutator relations) are *not* postulated in this work. Instead, they are rigorously derived as necessary features of entropy-stabilized dynamics governed by two explicit structural axioms. All derivations, assumptions, and results are mapped to their relevant sections for maximal transparency.

1. Introduction

Wave-particle duality lies at the heart of quantum mechanics: particles exhibit interference, yet register as discrete events. The standard formalism postulates wavefunctions, the Schrödinger equation, and the Born rule, but does not explain why wave behavior arises at all.

The *Total Entropic Quantity* (TEQ) framework offers a structural answer. From two axioms—(1) entropy geometry generates physical structure, and (2) physical trajectories are selected for entropy-stable resolution—TEQ derives [1]:

- The entropy-weighted Feynman path integral;
- The Born rule as the statistical limit of entropy-stabilized paths;
- The Schrödinger equation as an emergent evolution law in low-curvature regimes;
- Quantization and deformed commutators from entropy curvature;
- Interference as a structural effect of entropy-constrained distinguishability.

Unlike approaches that assume quantum structure—Hilbert spaces, operators, unitary dynamics—TEQ derives these as limiting cases of a deeper entropic geometry. In this framework, a configuration is resolvable only if it remains distinguishable under finite resolution, and this capacity for distinction is governed by entropy curvature. **Entropy flow tells us how quickly small differences between neighboring configurations become indistinguishable**—it quantifies the local rate at which resolution degrades. In low-curvature regions, nearby configurations remain discernible and coherence persists. In high-curvature regions, entropy flow rapidly renders fine distinctions unresolvable: neighboring configurations blend under finite precision, and coherence is lost. Crucially, TEQ inverts the conven-

 doi:10.20944/preprints202504.2263.v3

tional view: we do not begin with fixed structures and evolve them; rather, only those structures that can persist under entropy flow are physically meaningful. Thus, only entropy-stable paths contribute meaningfully to physical evolution.

Wave behavior, in this view, is not mysterious. It arises necessarily from the geometry of resolution under entropy flow. This paper develops that derivation and outlines a unified foundation for quantum, thermodynamic, and gravitational structure.

We begin in §2 by introducing the entropy-weighted action, derived from a constrained maximization principle and governed by a curved geometry of distinguishability. §3 introduces the Minimal Principle and defines the entropy curvature operator $\mathcal{H}$, whose log-periodic eigenmodes are structurally stable. In §4, we show that these oscillatory modes explain wave behavior as an entropy-stability condition. §5 extends this to the emergence of interference patterns, which reflect the coherent superposition of entropy-stable trajectories. We conclude by clarifying how quantization, commutator structure, and standard quantum evolution emerge as limiting cases, and reflect on the broader philosophical implications of entropy as the generator of physical law.

For full technical development and background, see [2–8]. Although TEQ and Caticha's entropic dynamics [6] both involve entropy-based reasoning, they differ fundamentally: Caticha assumes prior dynamical laws and derives probabilistic inferences from them, while TEQ derives physical structure itself from entropy geometry, with dynamical stability emerging from resolution constraints under entropy flow.

2. Entropy Geometry and the Weighted Action

To derive quantum structure from first principles, we begin with the foundation laid by TEQ's two core axioms. Axiom 0 asserts that physical structure is not built on a fixed spacetime background, but emerges from a pre-geometric entropy landscape—what we call *entropy geometry*. This geometry encodes which configurations are distinguishable, and how stable those distinctions remain under finite resolution. Axiom 1, the Minimal Principle, then selects trajectories that remain maximally stable under entropy flow. Together, these axioms define a variational principle not over spacetime paths, but over resolution-stable configurations.

Entropy geometry refers to a curved field of distinguishability: a geometric structure in which entropy curvature determines which transitions are structurally allowed. When entropy curvature is high, resolution degrades, and only highly stable configurations can persist. When curvature vanishes, dynamics reduce to classical or quantum evolution in flat configuration space. This underlying geometry gives rise to Planck's constant $\hbar$, the entropy-weighting parameter β, and the entropy resolution scale $\alpha = \beta\hbar$, as emergent quantities tied to resolution geometry (see [8], §3).

This section introduces the entropy-weighted action at the core of TEQ dynamics. Entropy flow modifies the classical Lagrangian, yielding a generalized action that suppresses unstable trajectories and recovers standard quantum mechanics as a limiting case. We begin with a concise overview of how this action arises from constrained entropy optimization.

2.1. *Overview of the Entropy-Weighted Path Integral Derivation*

TEQ reinterprets the Feynman path integral as the outcome of a constrained entropy maximization over trajectory space. Instead of assuming uniform path weights, TEQ introduces entropy flow as a geometric constraint: paths with high entropy curvature are suppressed, and only resolution-stable histories contribute significantly.

This entropy weighting is not an added assumption—it follows directly from maximizing path entropy under constraints on average action and apparent entropy. For the full derivation, see [1], Appendix A. The core logic and result are summarized below.

Assumptions

- Let $\phi(t)$ denote a possible configuration trajectory of the system over time—a path through configuration space. Physical evolution selects among such resolution-distinguishable trajectories.

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- Let $\mathcal{P}[\phi]$ be a probability distribution over trajectories. This distribution is selected by a principle of constrained entropy maximization: among all possible ensembles of paths, the one realized is the one that maximizes path entropy subject to physical constraints.
- The maximization is performed under two constraints:
  - Average action: $\langle S[\phi] \rangle = \bar{A}$, where $S[\phi]$ is the classical action associated with trajectory ϕ;
  - Average apparent entropy: $\langle \tilde{S}_{\text{apparent}}[\phi] \rangle = \bar{S}$, where $\tilde{S}_{\text{apparent}}[\phi]$ quantifies the entropy cost of resolving the trajectory ϕ under finite informational precision (see [2]).
- Two Lagrange multipliers govern the constrained maximization:
  - $\hbar$ controls phase coherence (and recovers quantum amplitudes),
  - β governs entropy resolution, selecting paths that remain distinguishable under entropy flow.
- The normalization constant Z ensures that $\mathcal{P}[\phi]$ defines a proper probability distribution:

$$Z = \int \exp\left(\frac{i}{\hbar} S[\phi] - \beta \tilde{S}_{\text{apparent}}[\phi] \right) \mathcal{D}\phi,$$

  analogous to the partition function in statistical mechanics. It captures the total entropy-weighted amplitude over all possible trajectories. Here, $\mathcal{D}\phi$ denotes the functional integration measure over the space of resolution-distinguishable paths $\phi(t)$—that is, over all trajectories with finite apparent entropy $\tilde{S}_{\text{apparent}}[\phi]$.

Derivation Steps

1. Maximize the entropy functional:

$$\mathcal{S}[\mathcal{P}] = -\int \mathcal{P}[\phi] \log \mathcal{P}[\phi] \, \mathcal{D}\phi,$$

   under the above constraints;
2. Solve the resulting variational problem to obtain the path distribution:

$$\mathcal{P}[\phi] = \frac{1}{Z} \exp\left(\frac{i}{\hbar} S[\phi] - \beta \tilde{S}_{\text{apparent}}[\phi] \right);$$

3. Identify this as the entropy-weighted amplitude structure, with the standard Feynman integral recovered for $\beta = \frac{i}{\hbar}$.

$$\mathcal{A}_{\text{eff}}[\phi] = \exp\left(\frac{i}{\hbar} S[\phi] - \beta \tilde{S}_{\text{apparent}}[\phi] \right) \tag{1}$$

Interpretation: As shown in (1), amplitudes are weighted by both action and entropy flow. Quantum structure emerges as the limiting case of entropy-stabilized trajectory ensembles.

2.2. Axiom 1: Entropy as Structural Generator

Physical configuration space is not defined by spacetime coordinates alone but by an underlying entropy geometry. Let $\phi(t)$ denote a configuration trajectory. The entropy gradient defines a local flow $g(\phi, \dot{\phi})$, capturing the rate of distinguishability change under finite resolution. This entropy flux modifies the standard variational principle.

The resulting effective action is:

$$S_{\text{eff}}[\phi] = \int dt \left(L(\phi, \dot{\phi}) - i\hbar\beta \, g(\phi, \dot{\phi}) \right), \tag{2}$$

where L is the classical Lagrangian and g encodes the local entropy flux (see [1], §2.3). The term $i\hbar\beta\, g$ introduces entropy sensitivity into the variational structure, selecting trajectories that remain stable under entropy curvature.

 doi:10.20944/preprints202504.2263.v3

This action is not postulated, but derived from constrained entropy-maximizing variation (see §2.1). The structure reflects the deeper geometry defined by Axiom 0: stable distinctions are those that persist under entropy curvature. The entropy term penalizes unstable configurations, effectively shaping the geometry of allowable motion.

2.3. Axiom 2: The Minimal Principle

The second axiom of TEQ states that physical configurations evolve along paths that remain maximally stable under entropy flow:

> **Minimal Principle (MP):** *Among all entropy-resolvable configurations, physical trajectories are those that minimize instability under entropy curvature.*

This principle defines the mechanism of selection in entropy geometry. Where Axiom0 generates a space of distinguishable configurations, Axiom1 selects those that persist. Physical trajectories extremize the entropy-weighted action according to (3):

$$\delta S_{\text{eff}}[\phi] = 0. \tag{3}$$

This variational condition extends the principle of least action to entropy-curved configuration space. In classical mechanics, extremizing the action selects physical paths. In TEQ, the entropy-weighted action replaces the classical functional, and physical trajectories are those that extremize this augmented quantity.

The Minimal Principle introduces two structural multipliers: Planck's constant $\hbar$, governing phase coherence, and the entropy-weighting parameter β, governing distinguishability. Their geometric interaction defines the resolution regime of the system (see [1], §3).

In the high-resolution limit $\beta \to \infty$, TEQ recovers standard unitary quantum mechanics. In entropy-dominant regimes, coherence degrades and trajectories are governed by entropy flow, leading to decoherence and thermodynamic behavior. The Minimal Principle thus serves as the unifying selection rule for quantum, classical, and gravitational structure (see [1], §3).

Interpretation. The Minimal Principle does not postulate dynamics—it selects them. Entropy geometry defines what can be resolved; the Minimal Principle defines what persists. Together, they replace the conventional foundations of quantum theory with a single structural constraint.

3. Stability and the Minimal Resolution Principle

The Minimal Principle selects trajectories that remain maximally stable under entropy flow. This selection is not limited to the extremization of the entropy-weighted action, but extends into the stability analysis of paths under second variations. Structural stability is governed by the local curvature of the entropy functional, determining which perturbations are suppressed and which persist.

3.1. Entropy-Resolvable Trajectory Space

Let $\mathcal{C}$ denote the space of piecewise smooth trajectories $\phi : [0, T] \to \mathbb{R}^n$ for which the apparent entropy is finite:

$$\tilde{S}_{\text{apparent}}[\phi] := \int_0^T g(\phi(t), \dot{\phi}(t))\, dt,$$

where $g(\phi, \dot{\phi})$ is the local entropy flux functional, and given explicitly by

$$g(\phi, \dot{\phi}) = \frac{1}{2} G_{ij}(\phi) \dot{\phi}^i \dot{\phi}^j, \tag{4}$$

where $G_{ij}(\phi)$ is a smooth, symmetric, positive-definite entropy metric (see [1], Appendix B).

This definition imposes no a priori Hilbert space structure; the space $\mathcal{C}$ is organized purely by resolvability under entropy curvature.

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3.2. Variational Dynamics and Second Variation

The entropy-weighted action reads

$$S_{\text{eff}}[\phi] = \int_0^T (L(\phi, \dot{\phi}) - i\hbar\beta\, g(\phi, \dot{\phi}))dt,$$

where L is the classical Lagrangian and g encodes the local entropy flux. Variation of the entropy-weighted action (2) yields the entropy-corrected Euler–Lagrange equation:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\phi}} - i\hbar\beta\frac{\partial g}{\partial \dot{\phi}}\right) - \left(\frac{\partial L}{\partial \phi} - i\hbar\beta\frac{\partial g}{\partial \phi}\right) = 0,$$

which selects entropy-stationary trajectories $\phi_{\text{st}} \in \mathcal{C}$.

To assess the stability of an entropy-stationary trajectory $\phi_{\text{st}}(t)$, we compute the second variation of the apparent entropy functional (see [1], §5.1):

$$\delta^2 \tilde{S}_{\text{apparent}}[\phi] = \int dt\, dt'\, \delta\phi(t) H(t, t') \delta\phi(t'). \tag{5}$$

The second variation (5) defines the entropy curvature operator $H(t, t')$, representing the second functional derivative of $\tilde{S}_{\text{apparent}}$ evaluated at ϕ_{st}.

3.3. Spectral Structure and Log-Time Operator

To reveal the natural spectral structure of entropy curvature, we reparameterize time via the logarithmic map:

$$\tau = \log t.$$

This reparameterization reflects the scale-invariant nature of distinguishability: entropy flow varies logarithmically with physical resolution scale.

In logarithmic time, the second variation structure simplifies, and the entropy curvature operator takes the form:

$$\mathcal{H} := -e^{\tau}\frac{d^2}{d\tau^2} \tag{6}$$

where $\mathcal{H}$ acts on perturbations $\delta\phi(\tau)$.

The operator $\mathcal{H}$ governs the stability of entropy-resolvable perturbations around stationary paths, with its spectrum $\{\lambda_n\}$ encoding the modes that remain distinguishable under entropy curvature.

Under the structural assumptions developed in the TEQ framework—namely:

- A compact domain $t \in [t_0, t_1]$,
- A smooth, strictly positive-definite entropy metric $G_{ij}(\phi)$,
- A perturbation space $\delta\phi(t) \in H^1([t_0, t_1])$ with fixed or periodic boundary conditions,

the second variation operator $\mathcal{H}$ is densely defined, symmetric, and elliptic, and thus admits a discrete, real, positive spectrum with a complete orthonormal eigenbasis [9,10].

Thus, Hilbert space structure—complete inner product spaces of resolvable perturbations—emerges naturally from entropy curvature, not from foundational postulates.

Remark 1. *For a formal construction and detailed analysis of the spectral theory of $\mathcal{H}$ in the TEQ framework, see [8], §4–7.*

Remark 2. *Logarithmic time is not an arbitrary technical convenience; it emerges structurally from entropy geometry. Stability analysis in TEQ must be performed in log-time to correctly capture the entropy curvature landscape.*

Structural Insight. The entropy curvature operator selects resolvable modes: a discrete spectrum of entropy-stable perturbations emerges naturally from the structure of entropy geometry. The physical

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consequences of this stability—including wave-like behavior and quantization—will be developed in the following sections.

4. Emergence of Wave Behavior

Having identified the entropy curvature operator in (6), we now characterize its eigenmodes to determine which perturbations remain stable under entropy flow.

Physical perturbations must satisfy the eigenvalue equation

$$\mathcal{H}\psi(\tau) = \lambda\psi(\tau), \tag{7}$$

where $\lambda > 0$ represents the entropy curvature associated with a perturbation mode $\psi(\tau)$.

Solving the eigenvalue equation (7) reveals the structure of stable perturbations.

Explicitly, this yields the differential equation:

$$-e^{\tau}\frac{d^2\psi}{d\tau^2} = \lambda\psi(\tau),$$

or equivalently,

$$\frac{d^2\psi}{d\tau^2} + \omega^2 e^{-\tau}\psi(\tau) = 0,$$

where we define $\omega^2 := \lambda$ for compactness.

For the exact solution, see Appendix A. In certain regimes, however, a useful simplification arises.

In the *quasi-static regime*—where the entropy curvature $e^{-\tau}$ varies slowly compared to the oscillatory timescale of $\psi(\tau)$—we can treat $e^{-\tau}$ as approximately constant over small intervals. Physically, this corresponds to regions where the background entropy geometry changes negligibly over the characteristic oscillation scale of the perturbation. Such conditions are met near leading-order entropy-flat configurations, or in domains where entropy curvature varies gently over logarithmic time.

Under this quasi-static approximation, the eigenvalue equation simplifies to

$$\frac{d^2\psi}{d\tau^2} + \omega^2\psi(\tau) \approx 0. \tag{8}$$

The solutions to (8) are oscillatory in log-time.

Remark 3. *The quasi-static approximation is valid locally when the variation of entropy curvature $e^{-\tau}$ across one oscillation period of $\psi(\tau)$ is negligible. Corrections arise when curvature gradients become non-negligible, leading to slow modulations of the oscillatory modes. These effects are analyzed in Appendix A.*

Remark 4. *This simplification is not exact. It is a local approximation, valid under specific conditions:*

- *Near entropy-flat configurations, where entropy curvature varies slowly across scales of interest;*
- *When τ changes slowly compared to the oscillation period of $\psi(\tau)$;*
- *Over small intervals where the background $e^{-\tau}$ can be considered effectively constant.*

Intuitively, if the background entropy curvature evolves much more slowly than the frequency of oscillations, local stability structures emerge. The approximation is thus valid locally in resolution space, near stable entropy configurations.

The resulting solution in this regime is:

$$\psi(\tau) = Ae^{i\omega\tau} + Be^{-i\omega\tau}$$

where $A, B \in \mathbb{C}$ are constants determined by boundary conditions.

Thus, the entropy-stable perturbations selected by $\mathcal{H}$ are oscillatory in logarithmic time: *log-periodic modes*.

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Remark 5. *The oscillatory structure is not postulated. It emerges necessarily because only log-periodic solutions maintain distinguishability under entropy curvature. Exponential growth or decay modes would correspond to runaway entropy instability and are suppressed by the Minimal Principle.*

4.1. Resolution, Entropy Flow, and the Asymmetry of Structure

In the TEQ framework, entropy curvature governs not only the stability of local perturbations, but also imposes a fundamental asymmetry between past and future resolution.

In low-curvature (entropy-flat) regions, configurations remain stably resolvable across log-time: both past and future distinctions persist. However, in regions where entropy curvature increases, resolution collapses progressively forward in log-time. Small distinctions that are stable in the past become unresolvable in the future unless protected by exceptional entropy stability.

Thus, physical structure inherits its coherence from regions of low past entropy curvature. The emergence and persistence of distinguishable configurations are time-asymmetric consequences of entropy geometry:

- The past encodes the survival of stable resolution.
- The future reflects the progressive loss of resolvable distinctions under entropy flow.

This structural asymmetry clarifies the emergence of an arrow of time within the TEQ framework: not imposed externally, but selected by the entropy geometry of resolution stability.

4.2. Structural Interpretation

Log-periodic oscillations in $\tau = \log t$ correspond to scale-invariant oscillations in physical time t. That is, under a scaling $t \mapsto \kappa t$ for any $\kappa > 0$, the phase shift is linear:

$$\tau \mapsto \tau + \log \kappa, \quad \Rightarrow \quad \psi(\tau) \mapsto \psi(\tau + \log \kappa) = e^{i\omega \log \kappa} \psi(\tau).$$

Thus, entropy-stable modes acquire a scale-dependent phase factor but preserve their structure. This reflects the fundamental principle that resolvability in TEQ is scale-relative: only scale-invariant oscillatory structures remain stable across entropy flow.

Structural Insight. Wave behavior is the signature of resolution stability in entropy geometry. Oscillations in logarithmic time encode the fundamental requirement that distinguishable configurations persist under entropy flow across scales.

4.3. Comparison with Standard Quantum Mechanics

In standard quantum theory, wave behavior is introduced axiomatically via the Schrödinger equation and the wavefunction formalism. In TEQ, oscillatory modes arise *structurally* from entropy curvature stability, without assuming wavefunctions or Hilbert spaces as primitive entities.

This derivation highlights a profound shift:

- Quantum behavior is not an imposed structure, but the inevitable outcome of entropy-stabilized distinguishability.
- Wave-particle duality arises because log-periodic modes govern both stable coherence (waves) and localization (quantized modes).

This rederivation reframes the foundational mystery of quantum theory as a necessary feature of resolution geometry.

5. Interference and Resolution Structure

Having established that entropy-stable perturbations are log-periodic oscillatory modes of the form

$$\psi(\tau) = Ae^{i\omega\tau} + Be^{-i\omega\tau},$$

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we now show how interference phenomena arise naturally within the TEQ framework, without invoking a wavefunction postulate.

5.1. Superposition of Resolution-Stable Modes

Since $\mathcal{H}$ is self-adjoint and positive-definite under the entropy-induced inner product (see [8]), its eigenfunctions form a complete orthonormal basis for entropy-resolvable perturbations.

Thus, a general resolvable perturbation can be expanded as a superposition:

$$\psi(\tau) = \sum_n \left(A_n e^{i\omega_n \tau} + B_n e^{-i\omega_n \tau} \right),$$

where each mode ω_n corresponds to an eigenvalue $\lambda_n = \omega_n^2$ of $\mathcal{H}$.

Because the space of perturbations is governed by entropy curvature, only those combinations of modes that preserve overall distinguishability—that is, that remain stable under entropy flow—are dynamically favored.

Remark 6. *Superposition in TEQ is not an arbitrary principle but a reflection of the linear stability structure of entropy geometry. Only entropy-stationary combinations of oscillatory modes persist.*

5.2. Interference as a Resolution Phenomenon

When multiple stable modes coexist, their amplitudes combine coherently. The observable effect is interference: regions where oscillatory modes constructively or destructively enhance or suppress resolution distinguishability.

This interference pattern arises structurally because:

– Each mode carries phase information relative to log-time τ,
– Their superposition leads to constructive or destructive contributions to local entropy curvature,
– The resulting interference pattern reflects the stability or instability of distinguishability across configuration space.

In TEQ, interference is thus a direct manifestation of the underlying entropy geometry:

- Constructive interference corresponds to enhanced local distinguishability,
- Destructive interference corresponds to suppression of resolution.

5.3. Application to the Double-Slit Experiment

In the traditional quantum double-slit experiment, interference fringes are observed when particles are not measured to determine which slit they pass through. In the TEQ framework, this phenomenon finds a natural explanation:

– The particle's trajectory is not a single classical path but a coherent superposition of entropy-stable modes across possible configurations.
– The absence of which-path information preserves coherence between modes associated with different slit passages.
– The resulting interference pattern is the structural expression of modal superposition under entropy geometry constraints.

Thus, the double-slit experiment does not require postulating wave-particle duality. It reflects the fundamental principle that entropy geometry governs the stability and interference of distinguishable configurations.

Structural Insight. Interference patterns arise naturally from the superposition of entropy-stable modes. No mysterious duality is needed: interference is the resolution signature of oscillatory stability in entropy-curved configuration space.

5.4. Summary

Wave-like behavior, superposition, and interference emerge as necessary structural features within the TEQ framework:

- Log-periodic oscillations in entropy geometry are the only entropy-stable modes.
- Interference patterns arise from coherent superposition of these modes.
- Observed quantum phenomena, such as the double-slit interference fringes, reflect the underlying scale-relativistic structure of distinguishability.

This completes the derivation of quantum wave behavior from first principles: *not postulated, but structurally selected by entropy geometry and the Minimal Principle*.

Concluding Perspective: From Geometry to Wave Structure

In classical physics, oscillations arise from restoring forces; in quantum theory, they are postulated through wavefunctions. In TEQ, wave behavior emerges from a deeper structural source: the stability of resolution under entropy curvature.

We have shown that:

- The entropy-weighted action selects stationary paths via the Minimal Principle [1];
- Stability under entropy flow requires spectral decomposition of the curvature operator $\mathcal{H} = -e^{\tau} \frac{d^2}{d\tau^2}$;
- The only entropy-stable perturbations are log-periodic oscillations: oscillatory modes in logarithmic time that remain stable under entropy curvature flow. These log-periodic modes arise as the structural solutions selected by the scale-relative geometry of distinguishability, where persistence across scales requires coherent phase behavior relative to log-time.
- Interference arises from coherent superposition of these modes, not from dualistic assumptions about particle or wave identity.

This reframes foundational quantum behavior as a structural consequence of distinguishability geometry. What is observed is what remains resolvable. The architecture of interference, stability, and modal structure is selected by entropy curvature—not imposed by axioms.

Paradigm Shift. Quantum wave behavior is not a mystery. It is the only resolution-stable structure in an entropy-curved universe. Entropy selects what persists. Geometry encodes what can be resolved.

6. Conclusions

This work has shown that quantum wave behavior, modal quantization, and interference emerge as necessary features of entropy-stabilized dynamics. The derivation of commutator structure from entropy geometry appears in [2], §4. Starting from two axioms—entropy geometry as the generator of structure (Axiom 0) and the Minimal Principle of resolution stability (Axiom 1)—we derived:

- The entropy-weighted action as a generalized variational principle;
- The entropy-curvature operator $\mathcal{H} = -e^{\tau} \frac{d^2}{d\tau^2}$, selecting stable log-periodic modes;
- Quantization as discrete spectral filtering under entropy stability;
- Interference as modal superposition within the geometry of distinguishability;
- The Schrödinger equation and Born rule as limiting cases of entropy-flat dynamics.

No standard quantum postulates were assumed. Hilbert space structure, discrete eigenmodes, and complex amplitudes were shown to emerge from the deeper geometry of resolution.

TEQ thus offers a structural unification of thermodynamic and quantum reasoning. It compresses multiple independent assumptions—wavefunctions, operators, superposition, commutators—into a single entropic principle governing what distinctions can persist. In regimes of high entropy curvature, it predicts deviations from standard quantum behavior, providing a route to testable generalizations.

This framework reinterprets physical law not as dynamics imposed on a spacetime manifold, but as geometry selected by stability under finite resolution. In this view, quantum structure is not fundamental—it is what survives entropy flow.

For full derivations and formal justification of the operator structure, entropy curvature, and spectral assumptions, see [8], §4–5.

7. Philosophical Implications

The TEQ framework reframes foundational questions in physics. Where conventional quantum mechanics introduces wave-particle duality as an unresolved mystery, TEQ shows that wave behavior is the only structurally stable configuration under entropy curvature. This resolves duality by revealing that what appears as wave-like interference is the geometric consequence of resolution-preserving trajectories in entropy space.

In this light, particles, events, and fields are not ontological primitives, but entropy-resilient structures: what endures through the loss of resolution. Measurement, decoherence, and even spacetime localization arise as dynamical projections of this deeper structure.

TEQ replaces the traditional "observer problem" of quantum mechanics—the unexplained transition from unitary evolution to discrete outcomes—with a structural answer. In TEQ, the observer is not an external agent but an emergent property of the resolution geometry: only those distinctions that can persist under entropy curvature are physically realized. Classicality does not arise from a mysterious collapse, but from the structural suppression of unstable, non-resolvable configurations by entropy flow.

Structural Insight. In TEQ, the observer is not an external agent but an emergent feature of entropy geometry. Observation corresponds to the persistence of stable distinctions under entropy flow. Measurement outcomes are not imposed by collapse, but selected by the structural dynamics of resolution stability (see [2] for a conceptual development).

The guiding intuition is this: *what we call physical law is the architecture of what can persist under entropy flow*. This reorientation places entropy not as a statistical artifact, but as the first principle of physical structure. It opens a path to reinterpreting gravity, cosmology, and the foundations of information theory within a unified entropy geometry.

Philosophical Insight. What exists is what resists dissolution under finite resolution. Physical law is not imposed—it is selected by the structure of what can stably be distinguished.

Remark 7 (Structural Clarification of Quantum Mysteries)**.** *Two longstanding puzzles in quantum theory—its deep connection to Fourier analysis, and the convergence of infinite-mode sums—are clarified by TEQ.*

- *The Fourier structure of quantum mechanics arises from the entropy curvature operator $\mathcal{H} = -e^{\tau}\frac{d^2}{d\tau^2}$, whose eigenfunctions are log-periodic modes $e^{\pm i\omega\tau}$. These oscillatory basis functions are selected by the Minimal Principle as the only entropy-stable solutions (see [8], §4–7).*
- *Infinite sums over quantum modes (e.g., in partition functions, path integrals, or trace formulas) are regularized structurally via the spectral zeta function $\zeta_H(s) = \sum_n \lambda_n^{-s}$. This leads to zeta-regularized determinants and finite amplitudes:*

$$\log \mathcal{Z} = -2\beta\tilde{S}_{apparent}[\phi_{\mathrm{st}}] - \frac{1}{2}\zeta_H'(0),$$

as derived in [8], §4–7. This connects directly to mathematical structures in quantum field theory [11,12] and number theory [13,14].

TEQ thus provides principled explanations for phenomena that standard quantum mechanics accommodates but does not explain: the wave structure of nature, and the well-behavedness of its infinities.

Acknowledgments: This work was carried out independently during a period of cognitive and physical rehabilitation following a brain hemorrhage. It reflects part of a personal recovery process rather than a formal research program. ChatGPT was used for language refinement and structural organization; all theoretical content is the

 doi:10.20944/preprints202504.2263.v3

author's own. The ideas are offered with no claim to certainty—only the hope that their structure may prove useful or clarifying to others.

Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	Linear dichroism

Appendix A. General Solution of the Entropy Curvature Eigenproblem

The main text derived the entropy curvature operator in logarithmic time,

$$\mathcal{H} := -e^{\tau}\frac{d^2}{d\tau^2},$$

leading to the eigenvalue equation

$$\mathcal{H}\psi(\tau) = \lambda\psi(\tau), \quad \text{or explicitly} \quad \frac{d^2\psi}{d\tau^2} + \omega^2 e^{-\tau}\psi(\tau) = 0,$$

where $\omega^2 := \lambda > 0$.

In the main text, we employed a quasi-static approximation valid near leading-order entropy-flat configurations, where $e^{-\tau}$ varies slowly compared to the oscillation scale of $\psi(\tau)$. In this regime, the eigenproblem reduces locally to

$$\frac{d^2\psi}{d\tau^2} + \omega^2\psi(\tau) \approx 0,$$

with oscillatory solutions $\psi(\tau) \sim e^{\pm i\omega\tau}$. However, the exact general solution to the eigenproblem can be obtained rigorously by change of variables. Define

$$z := 2\omega e^{-\tau/2},$$

so that $\tau = -2\log(z/2\omega)$. Then, applying the chain rule yields:

$$\frac{d}{d\tau} = -\frac{z}{2}\frac{d}{dz}, \quad \frac{d^2}{d\tau^2} = \frac{z^2}{4}\frac{d^2}{dz^2} + \frac{z}{4}\frac{d}{dz}.$$

Substituting into the eigenvalue equation leads to

$$z^2\frac{d^2\psi}{dz^2} + z\frac{d\psi}{dz} + z^2\psi = 0,$$

which is the standard Bessel differential equation of order zero [15,16].

Thus, the general solution is

$$\psi(\tau) = C_1 J_0\left(2\omega e^{-\tau/2}\right) + C_2 Y_0\left(2\omega e^{-\tau/2}\right), \tag{A1}$$

where J_0 and Y_0 are the Bessel functions of the first and second kind, respectively, and $C_1, C_2 \in \mathbb{C}$ are constants determined by boundary conditions.

 doi:10.20944/preprints202504.2263.v3

Validity of the Quasi-Static Approximation. In the regime where $e^{-\tau}$ varies slowly relative to the oscillation timescale of $\psi(\tau)$, the Bessel functions behave locally as oscillatory modes, and the eigenproblem reduces approximately to the harmonic form

$$\frac{d^2\psi}{d\tau^2} + \omega^2\psi(\tau) \approx 0.$$

This quasi-static regime corresponds physically to near-entropy-flat configurations, where local entropy curvature is approximately constant across scales of interest.

Remark A1. *The emergence of oscillatory wave behavior in TEQ thus arises not from assuming constant coefficients, but as the local manifestation of Bessel function structure under slow entropy flow.*

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