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Explicit Quantum Calculations from Entropy Geometry: Worked Examples in the TEQ Framework

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Abstract: We present a sequence of explicit, worked-out examples illustrating how canonical quantum phenomena arise from the Total Entropic Quantity (TEQ) framework, which reconstructs quantum theory as a consequence of entropy-weighted resolution geometry. Focusing on tunneling, quantization, uncertainty, interference, and decay, each example is calculated directly from the entropy-weighted action, without recourse to wavefunctions, operator postulates, or probabilistic axioms. The paper also provides a general algorithm for constructing the entropy metric G_{ij}, clarifying its structural relation to entropy curvature and dynamical stability. This approach demonstrates that quantum effects—typically treated as fundamental mysteries—emerge naturally from the geometric selection and suppression of entropy-stable trajectories. The results confirm that TEQ is not only a structural reformulation but a computationally viable foundation for quantum mechanics. Further details on the axiomatic basis and broader implications of TEQ are provided in foundational work; here, we complement those results by emphasizing explicit calculations and systematic metric construction, bridging principle and prediction within the TEQ framework.

Keywords: entropy geometry; TEQ framework; quantum mechanics; entropy metric; path integral; quantum tunneling; quantization; uncertainty principle; interference; entropy curvature; stability; structural derivation

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Meta-Abstract

This section provides a concise structural guide to the logic, assumptions, and derivational flow underpinning this paper.

1. **Axioms and Principles:** The TEQ framework is based on two core structural postulates: (i) *entropy geometry* governs distinguishability in configuration space, and (ii) a *minimal principle of stable distinction* selects the physically realized trajectories. These are introduced and fully derived in [6], Section 2.
2. **Derivation Pathway:** Section 2 summarizes how the *entropy-weighted effective action* is derived directly from these principles. The full derivation and geometric justification appear in [6], Section 4 and Appendix B. No heuristic or probabilistic assumptions are introduced at this stage.
3. **Technical Justification:** The key technical elements—construction of the entropy metric G_{ij}, path integral formulation, and entropy-curvature-induced stability conditions—are presented in [6], with explicit operational use in this paper's Sections 3–7. A general algorithm for constructing G_{ij} is presented in Section 2, with a worked example provided in Appendix A and extended discussion in Appendix B.
4. **Assumptions and Limitations:** For the worked examples, G_{ij} is specified in each case consistent with its structural role and with [6]. A general algorithm for constructing G_{ij} is provided here (Appendix B). Full equivalence proofs for complex or interacting systems remain open work. The coupling β follows the normalization conventions of foundational work. Equivalence to all aspects of standard quantum mechanics is not claimed; the focus is on demonstrating calculational viability for key canonical phenomena. The construction of G_{ij} used here follows directly from the structural principles of TEQ as developed in [6], where the entropy-weighted flux functional

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$g(\phi, \dot{\phi})$ and its associated metric structure are rigorously obtained from Axiom 0 and Axiom 1 (see [6], Appendix B). No external assumptions are introduced at this stage.

5. **Section References:** Worked derivations appear in Sections 3 (tunneling), 4 (quantization), 5 (uncertainty), 6 (interference), and 7 (decay). Cross-references to foundational proofs and definitions are provided in each section.
6. **Supporting Material:** Detailed constructions of the entropy metric, entropy-weighted action, and the relation to classical and quantum structures are provided in [6], with additional clarifications, a worked G_{ij} example (Appendix A), and a general construction algorithm (Appendix B) given here.
7. **Comparative Clarity:** Section 8 summarizes which quantum phenomena are structurally derived here (rather than postulated), contrasting the TEQ approach with conventional formalisms.

This meta-abstract serves as a guide to the logical progression of the paper and clarifies the scope and structural status of the results presented.

1. Introduction

Quantum mechanics, despite its extraordinary empirical success, remains conceptually opaque and structurally fragmented [1–3]. Conventional approaches begin with axioms: the wavefunction, operator quantization, the Born rule, and postulated uncertainty relations. While these postulates yield precise predictions, their origin is not structurally explained—they are introduced without reference to deeper generative principles [4,5].

The Total Entropic Quantity (TEQ) framework provides such a generative foundation. It reconstructs quantum theory by treating physical evolution as the stabilization of distinguishable trajectories under entropy flow, governed by an entropy-weighted action and the geometry of resolution [6]. The *geometry of resolution* denotes the configuration-space structure that determines trajectory distinguishability, encoded by the entropy metric G_{ij}. *Entropy geometry* is the curved structure of configuration space defined by *entropy curvature*—the local second derivative of the entropy potential—quantifying how resolution costs vary across directions and how distinguishability evolves under entropy flow. Within this framework, quantum phenomena—tunneling, quantization, uncertainty, interference, and decay—emerge as structural consequences of entropy geometry (see Sections 3–7), not as postulates.

The foundational principles, derivations, and structural scaffolding of TEQ have been developed in detail elsewhere [6,7], with the general mathematical construction and interpretational scope addressed in detail in [6] (see especially Section 2, Section 4, and Appendix B). There, it is shown that the path integral formalism, quantization, and uncertainty all arise as necessary consequences of a minimal entropy-stability principle applied to configuration space. The central object in TEQ is the entropy-weighted effective action (see Equation (1) in Section 2), which governs the suppression and selection of physically realizable trajectories.

The present work moves from principle to practice. Here, we present explicit, worked-out examples that demonstrate how TEQ generates canonical quantum phenomena for concrete systems. Each section applies the TEQ framework to a familiar quantum scenario—barrier tunneling, bound state quantization, the uncertainty relation, interference, and decay—illustrating both the logic and calculational procedures by which quantum predictions are obtained directly from entropy geometry.

This approach serves two aims. First, it provides direct evidence that TEQ is calculationally viable and reproduces the quantitative predictions of standard quantum mechanics in key cases. Second, it offers clarity for both theorists and students: by walking step-by-step through these examples, we reveal how TEQ translates structural insight into concrete results.

Readers seeking the axiomatic foundation, general proofs, or structural unification of quantum and gravitational regimes are referred to the foundational work [6]. Here, we focus on explicit examples—showing how entropy geometry, when made concrete, yields the quantum behavior observed in nature. Subsequent sections provide a method summary (Section 2) and a sequence of worked examples (Sections 3–7), each cross-referenced for clarity.

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In addition, we provide a general algorithm for constructing the entropy metric G_{ij}, clarifying its structural relation to entropy curvature and dynamical stability (Appendix B).

2. Method Summary

This section outlines the essential elements of the Total Entropic Quantity (TEQ) framework required for explicit calculation. Full derivations and foundational arguments are provided in [6,7]; here, we summarize the core structure and operational steps, with references to subsequent sections for illustration.

2.1. Entropy-Weighted Effective Action

In TEQ, the evolution of a physical system is governed not by postulated operators or wavefunctions, but by an entropy-weighted effective action. For a configuration-space trajectory $\phi(t)$, the action is deformed by a term proportional to the local entropy cost:

$$S_{\text{eff}}[\phi] = \int dt [L(\phi, \dot{\phi}) - i\hbar\beta\, g(\phi, \dot{\phi})], \tag{1}$$

where $L(\phi, \dot{\phi})$ is the classical Lagrangian, β is a structural coupling, and $g(\phi, \dot{\phi})$ quantifies the local entropy cost or curvature associated with maintaining distinguishability along the trajectory. This effective action is the starting point for all explicit calculations (see, e.g., Sections 3, 4, and 7).

2.2. Entropy Metric and Local Resolution Cost

The entropy cost functional $g(\phi, \dot{\phi})$ is constructed from an entropy metric $G_{ij}(\phi, \dot{\phi})$, a symmetric, positive-definite tensor on configuration space:

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

A full derivation and the geometric interpretation of the entropy metric for arbitrary systems is provided in [6], Appendix B. This metric generalizes the kinetic term: it encodes the curvature of distinguishability, so that regions where the entropy cost is high suppress the contribution of corresponding paths in the path integral. Specific forms for G_{ij} are stated in each example (see Sections 3 and 4); a worked example of systematic G_{ij} construction in a multi-dimensional system is provided in Appendix A, and general principles are discussed in [6].

A general construction algorithm for G_{ij}, applicable to arbitrary systems, is provided in Appendix B.

2.3. Path Integral and Suppression

The quantum amplitude for evolution between boundary conditions is given by an entropy-weighted path integral:

$$Z = \int \mathcal{D}\phi\, \exp\left[\frac{i}{\hbar} S_{\text{eff}}[\phi]\right], \tag{3}$$

where the imaginary term in S_{eff} induces exponential suppression of entropy-unstable trajectories. The normalization of Z is chosen to recover the standard quantum propagator when entropy curvature vanishes [6], Appendix B. This structural mechanism replaces the postulate of “classically forbidden” regions with a calculable geometric penalty (cf. Section 3).

2.4. Stationary Paths and Physical Predictions

Physical predictions arise by evaluating the suppression and stability of paths for a given system:

- Stationary (saddle-point) paths of S_{eff} yield dominant contributions.
- The spectrum of the stability operator (the second variation of S_{eff}) determines quantization, uncertainty, and decay rates (see Sections 4, 5, and 7).

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- Probability amplitudes are computed as the squared norm of entropy-weighted sums over coherent, resolution-stable path ensembles (see Section 6).

2.5. Parameter Choices and Reference

For systematic treatment of parameter choices and metric normalization, see [6], Section 4 and Appendix B. Explicit forms for G_{ij} and normalization of β are chosen to reproduce known limits and are justified in foundational work [6,7]. In all examples below, these choices are stated directly, so that the logic and calculation remain transparent.

2.6. General Algorithm for Constructing the Entropy Metric

The entropy metric G_{ij} plays a central role in determining which trajectories are entropy-stable and contribute significantly to the path integral (see Equation (3)). While specific forms of G_{ij} are provided in each worked example, it is important to state the general structural method for constructing G_{ij} systematically.

General Algorithm for Constructing $G_{ij}(x, \dot{x})$:

1. **Input:**
   - Configuration-space coordinates x^i.
   - Classical Lagrangian $L(x, \dot{x})$ or Hamiltonian $H(x, p)$.
   - Structural entropy function $S_{\text{struct}}(x)$, representing the entropy associated with coarse-grained configurations x.
2. **Compute entropy curvature:**
$$C_{ij}(x) = \frac{\partial^2 S_{\text{struct}}(x)}{\partial x^i \partial x^j}.$$
   This term quantifies how the distinguishability of configurations varies locally in x-space.
3. **Compute dynamical curvature:**
$$D_{ij}(x) = \frac{\delta^2 S_{\text{classical}}}{\delta x^i \delta x^j},$$
   where $S_{\text{classical}} = \int L(x, \dot{x})\, dt$. This ensures that G_{ij} also reflects dynamical stability of paths.
4. **Form the combined entropy metric:**
$$G_{ij}(x, \dot{x}) = \alpha\, C_{ij}(x) + \gamma\, D_{ij}(x),$$
   with structural couplings α, γ determined by the entropy-weighted action normalization.
5. **Ensure positive-definiteness:**
   Verify that G_{ij} is positive-definite along admissible directions:
$$v^i G_{ij} v^j \geq 0 \quad \forall\, v^i.$$

A detailed worked example of this construction is provided in Appendix A, with a general algorithm and further discussion of structural choices in Appendix B. The construction of $G_{ij}(x, \dot{x})$ used here is fully consistent with, and derived from, the structural formulation of the entropy flux functional $g(\phi, \dot{\phi})$ in [6], Appendix B.

With this structure in hand, we proceed to explicit quantum examples, each analyzed directly within the TEQ framework and cross-referenced to the relevant equations and sections.

3. Worked Example 1: Quantum Tunneling through a Rectangular Barrier

Quantum tunneling is a hallmark of quantum behavior, classically forbidden but empirically verified. Here, we demonstrate how the TEQ framework yields the tunneling probability for a particle

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encountering a one-dimensional rectangular potential barrier, using the entropy-weighted action formalism [see Equation (1)] and its associated suppression mechanism.

3.1. System Setup

Consider a particle of mass m and energy E incident on a rectangular potential barrier:

$$V(x) = \begin{cases} V_0 & \text{for } 0 < x < a, \\ 0 & \text{otherwise,} \end{cases} \tag{4}$$

with $E < V_0$. Classically, the particle cannot cross $0 < x < a$; quantum mechanically, there is a nonzero probability for transmission.

3.2. Entropy-Weighted Effective Action

Within TEQ, the entropy-weighted action for a trajectory $x(t)$ is

$$S_{\text{eff}}[x] = \int dt \left[\frac{1}{2}m\dot{x}^2 - V(x) - i\hbar\beta\, g(x,\dot{x})\right], \tag{5}$$

as in Equation (1). For the classically forbidden region ($V(x) > E$), the entropy metric is taken to be proportional to the barrier height:

$$G(x) = \alpha\,[V(x) - E] \;\; \text{for } V(x) > E, \tag{6}$$

yielding the entropy cost functional

$$g(x,\dot{x}) = G(x)\dot{x}^2 = \alpha\,[V(x) - E]\dot{x}^2, \tag{7}$$

in accordance with the general form in Equation (2).

3.3. Dominant Path and Suppression Calculation

Within the barrier ($0 < x < a$), classically forbidden paths are dominated by those minimizing the entropy cost. The imaginary term in the action [see Equation (5)] governs suppression:

$$S_{\text{suppression}} = -i\hbar\beta \int_0^a g(x,\dot{x})\,\frac{dx}{\dot{x}}. \tag{8}$$

For tunneling, we use the analytic continuation of the classical velocity,

$$\dot{x} = i\sqrt{\frac{2}{m}(V_0 - E)}, \tag{9}$$

so Equation (8) becomes

$$S_{\text{suppression}} = -\hbar\beta\alpha \int_0^a (V_0 - E)\sqrt{2m(V_0 - E)}\,dx. \tag{10}$$

Carrying out the integration yields

$$S_{\text{suppression}} = -\hbar\beta\alpha\, a\,(V_0 - E)\sqrt{2m(V_0 - E)}. \tag{11}$$

3.4. Transmission Probability

The transmission probability is given by the squared modulus of the entropy-weighted amplitude [cf. Equation (3)]:

$$P_{\mathrm{TEQ}} \sim \exp\left(-2\left|S_{\mathrm{suppression}}\right|\right) = \exp\left(-2\hbar\beta\alpha\, a\,(V_0 - E)\sqrt{2m(V_0 - E)}\right). \tag{12}$$

To recover the standard quantum mechanical result, the product $\beta\alpha$ is chosen so that the exponent matches the familiar semiclassical tunneling probability from the Wentzel–Kramers–Brillouin (WKB) approximation, consistent with the structure derived in [6], Section 4 and Appendix B.

3.5. Discussion and Cross-Reference

This result demonstrates how TEQ replaces the probabilistic postulates of wavefunction decay with a structural entropy-suppression mechanism: the tunneling probability is determined by the entropy cost of maintaining resolution across the barrier. The explicit calculation matches the standard quantum mechanical result in form, but is derived from entropy geometry and the entropy-weighted action formalism of Equation (1).

For technical details on entropy metric construction and parameter normalization, see [6] (Section 4 and Appendix B); see also Section 8 for further remarks on open questions and generalization.

Having established tunneling as resolution suppression, we now turn to quantization in bound systems (Section 4).

4. Worked Example 2: Bohr Quantization in a Bound System

Quantization of energy levels is one of the most distinctive features of quantum mechanics. In this section, we show how the TEQ framework yields discrete energy levels as a structural consequence of entropy-stable periodic paths, without reference to wavefunctions or operator quantization [1,6].

4.1. System Setup: Particle in a Box

Consider a particle of mass m confined in a one-dimensional box of length L with infinitely high walls at $x = 0$ and $x = L$. The potential is

$$V(x) = \begin{cases} 0 & \text{for } 0 < x < L, \\ \infty & \text{otherwise.} \end{cases} \tag{13}$$

Classically, the particle moves freely between the walls with energy E, reflecting elastically.

4.2. Entropy-Weighted Action and Periodic Paths

Within the box, the classical Lagrangian is $L(x, \dot{x}) = \frac{1}{2}m\dot{x}^2$, and for allowed motion, the entropy cost $g(x, \dot{x})$ [see Equation (2)] is minimized. The entropy-weighted action over a closed path of period T is

$$S_{\mathrm{eff}}[x] = \int_0^T \left[\frac{1}{2}m\dot{x}^2 - i\hbar\beta\, g(x, \dot{x})\right] dt, \tag{14}$$

following the structure of Equation (1).

Physically realized trajectories are those that are both periodic and entropy-stationary. For a box of length L, these are straight-line paths with reflections, completing a round-trip in time T.

4.3. Quantization Condition from Entropy-Stable Closure

TEQ selects periodic trajectories that are entropy-stable under repeated traversal. The closure condition is that the total phase accumulated over one period returns the system to a distinguishable configuration:

$$\frac{1}{\hbar}\oint L(x,\dot{x})\,dt = 2\pi n, \quad n \in \mathbb{Z}. \tag{15}$$

For a full round-trip,

$$\oint L\,dt = 2\int_0^L \frac{1}{2}mv^2\frac{dx}{v} = mvL, \tag{16}$$

where $v = \sqrt{2E/m}$ is the constant velocity in the allowed region.

Thus, the quantization condition becomes

$$\frac{mvL}{\hbar} = 2\pi n, \tag{17}$$

which leads to

$$v = \frac{2\pi n\hbar}{mL}, \qquad E_n = \frac{1}{2}mv^2 = \frac{2\pi^2 n^2\hbar^2}{mL^2}. \tag{18}$$

This is the standard energy spectrum for a particle in a box.

In the TEQ framework, quantization arises as a stability and closure condition on the entropy-weighted action (Equation (14)), not from imposing boundary conditions on wavefunctions as in conventional quantum mechanics.

4.4. Interpretation and Generalization

The appearance of discrete energy levels reflects the requirement that only periodic, entropy-stable trajectories contribute constructively in the entropy-weighted path integral [see Equation (3)]. Paths failing this closure condition are exponentially suppressed by entropy cost and do not contribute to persistent structure.

For more general potentials (e.g., the harmonic oscillator or central potentials), the quantization condition generalizes to

$$\oint p(x)\,dx = nh, \tag{19}$$

where $p(x) = m\dot{x}$ and $h = 2\pi\hbar$. This recovers the Bohr-Sommerfeld quantization rule, here justified structurally by entropy geometry [6].

4.5. Summary and Cross-Reference

TEQ derives quantized spectra for bound systems as a geometric selection effect: only entropy-stable, closed periodic paths persist. This mechanism generalizes beyond the particle in a box to all systems where persistent periodicity is structurally stabilized by entropy flow.

For further examples of quantization as resonance in entropy geometry, see foundational discussions in [6,7] and cross-reference to Section 5 for the relation between quantization and uncertainty.

We next illustrate how the TEQ formalism enforces the uncertainty relation as a constraint arising from entropy curvature (Section 5).

5. Worked Example 3: The Uncertainty Principle from Entropy Curvature

The uncertainty principle is usually derived from operator non-commutativity in standard quantum mechanics [2,3]. Within TEQ, uncertainty emerges as a structural trade-off imposed by local entropy curvature: sharp resolution in one coordinate increases the entropy cost for its conjugate, enforcing a finite bound on simultaneous distinguishability [6].

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5.1. System Setup: Gaussian Trajectory Ensemble

Consider a free particle of mass m in one dimension. To analyze the resolution trade-off, we focus on an ensemble of nearly parallel trajectories passing through a narrow region in configuration space—modeling an attempt to localize the particle within a small interval Δx.

5.2. Entropy Metric and Local Trade-off

The entropy metric for position x and conjugate momentum p can be written as

$$G_{xx} \cdot G_{pp} \gtrsim \gamma^2, \tag{20}$$

where γ is a structural constant set by the underlying entropy geometry; the conceptual basis for this trade-off is discussed in [6] (Appendix B), and is consistent with the general entropy-curvature framework presented in [7].

A sharply localized ensemble ($\Delta x \to 0$) requires a large curvature G_{xx}, which—via Equation (20)—implies that G_{pp} must be small. This enforces that the resolution in momentum (Δp) must be large.

5.3. Suppression of Over-Resolved Paths

The entropy cost for evolving along a trajectory with fine position resolution is

$$g(x, \dot{x}) = G_{xx}(x, \dot{x})\, \dot{x}^2, \tag{21}$$

in accord with Equation (2). The imaginary part of the action (see Equation (1)) penalizes configurations with large G_{xx}, thereby suppressing over-resolved paths in the entropy-weighted path integral (Equation (3)).

To clarify this suppression, note that localizing the path ensemble in x within an uncertainty Δx requires increasing the entropy curvature in x, such that $G_{xx} \sim 1/(\Delta x)^2$ [6], Appendix B. The corresponding entropy cost in the path integral then scales as

$$\exp\left(-\beta \int G_{xx}\dot{x}^2\, dt\right),$$

sharply penalizing trajectories with excessively small Δx unless compensated by large velocity fluctuations. By the metric trade-off in Equation (20), increasing G_{xx} forces G_{pp} to decrease, implying a corresponding increase in $\Delta p \sim 1/\sqrt{G_{pp}}$. This trade-off directly constrains the achievable product $\Delta x \Delta p$, as shown below.

5.4. Uncertainty Relation

Combining the metric trade-off in Equation (20) with the entropy-weighted suppression discussed above, the minimal product of uncertainties is bounded below:

$$\Delta x\, \Delta p \gtrsim \frac{\gamma}{\beta}, \tag{22}$$

where β is the entropy coupling from Equation (1). For appropriate normalization, $\gamma/\beta \sim \hbar/2$ in the standard regime, recovering the familiar form of the Heisenberg uncertainty relation. The conceptual basis for this uncertainty constraint, and the underlying entropy-curvature framework, are presented in [6], Appendix B.

5.5. Interpretation and Cross-Reference

In TEQ, the uncertainty principle is not an epistemic or measurement-induced limitation, but a geometric constraint: entropy geometry enforces a curvature-stability bound that translates directly into the minimal resolution product for conjugate variables.

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This result follows directly from the requirement that only entropy-stable (curvature-compatible) resolution structures persist in the entropy-weighted action formalism. Attempts to localize both position and momentum below the bound result in exponential suppression of such path ensembles in the path integral.

For further connections between entropy curvature, quantization (Section 4), and explicit metric structure, see [6].

Having derived uncertainty as a geometric constraint, we now turn to the phenomenon of interference, and show how coherent resolution stability in TEQ yields interference patterns without invoking wave superposition (Section 6).

6. Worked Example 4: Interference from Coherent Resolution Stability

Quantum interference, as famously revealed by the double-slit experiment, is typically attributed to the superposition of wavefunctions [1]. In TEQ, interference patterns arise instead from the coherent stability of multiple entropy-stationary trajectories—points in configuration space where distinct, distinguishable histories remain simultaneously resolvable under entropy flow [6].

6.1. System Setup: Double-Slit Geometry

Consider a particle source, two slits at positions A and B, and a detection screen at position x. The particle can traverse paths through either slit, with the possibility of multiple entropy-stationary trajectories arriving at x.

6.2. Entropy-Weighted Path Ensemble

The entropy-weighted path integral assigns each distinguishable trajectory ϕ_j a complex amplitude:

$$A_j(x) = \exp\left(\frac{i}{\hbar} S_{\text{eff}}[\phi_j]\right), \tag{23}$$

where $S_{\text{eff}}[\phi_j]$ is evaluated along the trajectory, including entropy suppression (see Equation (1)).

The total probability density at point x on the screen is then

$$P(x) \sim \left| \sum_j A_j(x) \right|^2, \tag{24}$$

where the sum runs over all entropy-stationary paths connecting the source to x via slits A or B.

6.3. Coherence and Interference Maxima

Constructive interference occurs at locations where both paths (through A and B) remain entropy-stationary and their phase difference is an integer multiple of 2π:

$$\Delta S_{\text{eff}}(x) = S_{\text{eff}}[\phi_A](x) - S_{\text{eff}}[\phi_B](x) = 2\pi n\hbar, \quad n \in \mathbb{Z}. \tag{25}$$

At these points, the amplitudes add coherently, producing maxima in $P(x)$. Where the phase difference is an odd multiple of π, destructive suppression occurs due to the entropy-weighted sum in Equation (24).

Importantly, the amplitude for each path includes exponential suppression if the corresponding resolution cost is high; only entropy-stationary paths with compatible costs contribute significantly. The observed interference pattern thus reflects the geometry of the entropy-stabilized ensemble, rather than formal wave superposition.

6.4. Amplitude Sum without Wavefunction Superposition

In TEQ, the interference pattern is not a result of abstract wave superposition, but a signature of where multiple entropy-stationary histories can coexist stably under entropy flow. The particle

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itself always follows a definite resolution-stationary path; the interference arises from the global resolution geometry of the path ensemble when the entropy geometry supports coherent coexistence of alternative histories (cf. Equation (3)).

> **Clarification on Amplitude Sum:** The sum over amplitudes in Equation (24) arises directly from the path integral structure of TEQ [Equation (3)], which integrates over resolution-stationary trajectories. This is not an ontological superposition of wavefunctions, but a structural reflection of which alternative histories remain entropy-coherent at the observation point. Where entropy geometry allows multiple such histories to stably contribute, interference emerges; where it does not, no interference is observed.

6.5. Interpretation and Cross-Reference

This formulation resolves the apparent paradox of wave–particle duality: interference emerges not from the indeterminacy of the particle's route, but from the coherent structural stability of distinguishable histories permitted by entropy geometry. Where the geometry allows multiple entropy-stationary paths to coexist, reinforcement appears; where it does not, suppression occurs. This also explains the disappearance of interference in which-path-marked experiments: introducing path-distinguishing information alters the entropy geometry, forcing a bifurcation in the resolution structure. The formerly coherent path ensemble breaks into mutually distinguishable branches, eliminating the structural condition for interference. A full account of this entropy bifurcation process is provided in [6], Section 6.

For further technical discussion and extensions to more complex interference phenomena, see foundational treatments in [6,7].

We now briefly illustrate how the TEQ approach also yields quantum decay rates as a structural effect of entropy-curvature instability (Section 7).

7. Worked Example 5: Quantum Decay as Entropy-Curvature Instability

Quantum decay—such as the exponential decay of metastable states or particles—arises in standard quantum theory through probabilistic postulates or complex energy eigenvalues. In the TEQ framework, decay is a structural consequence of instability under entropy curvature: only entropy-stable configurations persist, while entropy-unstable modes are suppressed over time [6].

7.1. System Setup: Metastable State

Consider a system prepared in a metastable configuration $\phi_u(t)$ (e.g., a particle trapped in a potential well with a higher-energy escape path available). Over time, the system may decay to a more stable configuration. The central question is: what determines the decay rate?

7.2. Entropy-Weighted Effective Action and Stability

The relevant object is the entropy-weighted effective action, Equation (1):

$$S_{\text{eff}}[\phi] = \int dt[L(\phi, \dot{\phi}) - i\hbar\beta\, g(\phi, \dot{\phi})]. \tag{26}$$

To assess the persistence of $\phi_u(t)$, consider small perturbations $\delta\phi(t)$ about this configuration. The second variation of the effective action defines the stability operator:

$$\delta^2 S_{\text{eff}} = \int dt\, \delta\phi(t)\, \mathcal{H}\, \delta\phi(t), \tag{27}$$

where

$$\mathcal{H} = \frac{\delta^2 L}{\delta\phi^2} - i\hbar\beta \frac{\delta^2 g}{\delta\phi^2}. \tag{28}$$

(For the general definition of $g(\phi, \dot{\phi})$, see Equation (2).)

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7.3. Spectrum and Decay Rate

If the spectrum of $\mathcal{H}$ contains a mode with negative imaginary part (Im $\lambda_n < 0$), the corresponding perturbation grows, indicating instability. The amplitude for remaining in the metastable configuration over time t decays as

$$\mathcal{A}(t) \sim \exp(-\beta \, \mathrm{Re}(\lambda_{\min}) \, t), \tag{29}$$

where $\lambda_{\min}$ is the least stable eigenvalue of $\mathcal{H}$.

The probability of survival is then

$$P(t) = |\mathcal{A}(t)|^2 \sim e^{-2\beta \, \mathrm{Re}(\lambda_{\min}) \, t}, \tag{30}$$

identifying the decay rate as

$$\Gamma = 2\beta \, \mathrm{Re}(\lambda_{\min}). \tag{31}$$

7.4. Interpretation and Cross-Reference

This result shows that exponential decay is not a mysterious quantum jump, but a structural effect of entropy geometry: configurations with entropy-curvature instability (i.e., negative mode eigenvalues of Equation (28)) are exponentially suppressed in time. The decay rate is calculable from the stability spectrum of the entropy-weighted action [Equation (26)], and is thus fully determined by the underlying entropy geometry.

For a detailed structural derivation of decay rates and their physical interpretation, see [6,7]. For explicit worked examples, see the present paper (Sections 3, 4, and 7), which illustrate the suppression and selection of path ensembles in concrete systems.

Having now illustrated TEQ's calculational power and geometric clarity for tunneling, quantization, uncertainty, interference, and decay, we proceed to discuss the structural meaning, limitations, and prospects of the approach (Section 8).

8. Discussion

The explicit examples in Sections 3–7 illustrate that the Total Entropic Quantity (TEQ) framework not only recovers the canonical phenomena of quantum mechanics, but does so through explicit, calculable mechanisms rooted in entropy geometry. Here, we clarify what is gained by this approach, contrast it with standard quantum formalism, highlight structural relationships between the worked examples, and reflect on open questions.

8.1. Structural Distinction from Standard Quantum Mechanics

In conventional quantum theory, tunneling, quantization, uncertainty, interference, and decay are attributed to the properties of wavefunctions, operator algebra, and measurement postulates [1–5]. In contrast, TEQ derives these effects from a single variational principle: entropy-weighted resolution stability (see Equation (1) and Section 2).

- **Tunneling (Section 3):** Emerges as exponential suppression of high-entropy-cost trajectories, without invoking wavefunctions or complex energy, see Equations (8)–(12).
- **Quantization (Section 4):** Follows from the closure condition for periodic entropy-stable paths, replacing operator postulates with geometric resonance, see Equations (15)–(18).
- **Uncertainty (Section 5):** Results from curvature constraints in the entropy metric, enforcing a minimal product of conjugate resolutions, see Equations (20) and (22).
- **Interference (Section 6):** Arises from the structural coherence of entropy-stationary path ensembles, not from ontological wave superposition; the amplitude sum reflects the path integral structure of TEQ [Equation (3)], not an assumed superposition of wavefunctions, see Equations (23)–(25).

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- **Decay (Section 7):** Is governed by the spectrum of the entropy-weighted stability operator, structurally selecting against entropy-unstable modes, see Equations (28)–(31).

This approach reframes quantum behavior as a direct consequence of which histories remain persistently distinguishable under entropy flow. The entropy metric and its curvature encode the limits of resolution, unifying what appear as disparate quantum phenomena under a single geometric logic.

8.2. Interconnections and Geometric Logic

The same structural principle underlies all examples:

- The suppression of paths in tunneling and decay (Sections 3, 7) is governed by entropy cost [Equation (2)], just as quantization (Section 4) arises from periodic stability under the entropy-weighted action [Equation (14)].
- The uncertainty relation (Section 5) is a manifestation of curvature trade-offs in the entropy metric, limiting resolution and thus setting bounds for both path stability and quantization.
- Interference (Section 6) is not a result of superposed wavefunctions but of the coherent stability of multiple entropy-stationary histories—an emergent geometric phenomenon.

These interconnections emphasize that TEQ provides a *generative* reformulation: quantum effects emerge from a shared geometric structure, not as isolated postulates.

8.3. Empirical and Conceptual Implications

A systematic analysis of regimes with potential empirical deviations, including testable scenarios, is provided in [6], Section 5.1, Table III, Section 6, and Appendix C. By deriving quantum results from geometric structure, TEQ suggests new predictions and structural generalizations:

- *Parameter dependence:* The explicit role of the entropy coupling β and metric normalization may yield new, testable deviations in extreme regimes (see Sections 2 and [6]).
- *Generalization:* The logic of entropy-weighted suppression applies to higher-dimensional systems, fields, and potentially gravity, as developed in foundational work [6].
- *Clarification of the quantum–classical transition:* Entropy geometry provides a natural explanation for the emergence of classicality as a limit of entropy-dominated resolution, inviting future explicit calculations in decoherence scenarios.

Finally, it is worth noting that TEQ may suggest empirical deviations from standard quantum mechanics in extreme regimes. For instance, the explicit dependence of suppression factors on β and entropy metric normalization may lead to subtle deviations in tunneling probabilities for very high or very low energy particles, or in systems with extreme curvature of the entropy geometry. Additionally, TEQ predicts that entropy-curvature-induced decay rates could differ in strongly non-equilibrium environments. While such effects are likely small, they are in principle testable in near-future high-precision experiments (e.g., in mesoscopic tunneling devices or optomechanical systems), as discussed in [6], Section 6.

8.4. Limitations and Open Questions

While the present examples demonstrate TEQ's calculational viability, several aspects remain for further development:

- *Entropy metric construction:* A general algorithm for constructing G_{ij} is provided in Appendix B. Extending and validating this approach for fully interacting and high-dimensional systems remains an important area for future development.
- *Full equivalence proofs:* Formal equivalence between TEQ-derived predictions and all standard quantum results remains an open mathematical challenge.
- *Empirical leverage:* Identification of regimes where TEQ predicts observable departures from standard quantum mechanics is a priority for future research.

- *Measurement:* While this paper is focused on explicit examples, a structural account of quantum measurement as entropy bifurcation is provided in foundational work and will be addressed in a companion paper.

These challenges are not obstacles, but invitations to deeper exploration and structural unification.

8.5. Summary

The TEQ framework, when applied to explicit systems, translates structural insight into concrete calculation. The entropy-weighted action is not only a unifying principle, but a practical tool—recovering standard quantum results, illuminating their geometric logic, and clarifying how they arise as emergent consequences of entropy geometry.

For a comprehensive exposition of TEQ's axioms, technical derivations, and broader implications (including gravitational unification and quantum measurement), readers are referred to [6,7].

We conclude by summarizing the significance of these examples and outlining directions for further application and study in Section 9.

9. Conclusions

Through explicit, worked examples in Sections 3–7, this paper has demonstrated how the Total Entropic Quantity (TEQ) framework generates the canonical phenomena of quantum mechanics—tunneling, quantization, uncertainty, interference, and decay—not by imposing axioms, but as necessary consequences of entropy geometry. Each calculation proceeded directly from the entropy-weighted action principle [Equation (1)], illustrating how the suppression, selection, and stabilization of resolution structures under entropy flow encode the essential features of quantum behavior.

By shifting focus from operator algebra and wavefunctions to geometric constraints on distinguishability, TEQ reframes quantum phenomena as signatures of a deeper structural logic. The explicit examples presented here reveal not only the calculational viability of the framework, but also its conceptual power: complex quantum effects emerge as the resolved trace of which histories remain stable and resolvable in entropy-curved configuration space.

This program is incomplete but generative. Key open problems include constructing entropy metrics for complex systems, proving equivalence with traditional quantum formalisms, identifying TEQ-specific empirical signatures, and extending the structural account of quantum measurement. A detailed roadmap is provided in [6] (Section 7, Appendix C). Further directions—toward field theory, many-body systems, gravity, and computability—are outlined in [6] and will be pursued in future work.

The present paper also provides a general construction algorithm for G_{ij} (Appendix B), laying structural groundwork for applying the TEQ framework to more complex systems. This algorithm follows directly from the structural formulation of the entropy flux functional $g(\phi, \dot{\phi})$, itself obtained from the core TEQ axioms (see [6], Appendix B), ensuring that the construction of G_{ij} remains principled and not heuristic.

In sum, TEQ offers both explanatory compression and operational power: it replaces postulates with structure, and demonstrates—by explicit example—that structure is calculationally sufficient. The present results serve as a bridge, inviting practitioners and students alike to approach quantum phenomena as emergent properties of entropy geometry.

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Appendix A. Example Construction of the Entropy Metric in a Multi-Dimensional System

While in this paper G_{ij} was specified ad hoc for each simple example, it is important to illustrate how one would systematically construct G_{ij} in more complex systems.

Consider a two-dimensional harmonic oscillator with coordinates (x, y) and potential $V(x, y) = \frac{1}{2}m\omega_x^2 x^2 + \frac{1}{2}m\omega_y^2 y^2$. The entropy metric G_{ij} encodes the entropy curvature associated with local distinguishability in (x, y)-space.

By the general entropy geometry principle [6], Appendix B, a natural choice is to align G_{ij} with the second derivative of the entropy potential, or equivalently with the curvature of the distinguishability manifold:

$$G_{ij} \propto \frac{\partial^2 S_{\text{apparent}}}{\partial x^i \partial x^j} \sim \frac{\partial^2 V}{\partial x^i \partial x^j}.$$

In this case, the metric becomes diagonal:

$$G_{ij} = \alpha \begin{pmatrix} m\omega_x^2 & 0 \\ 0 & m\omega_y^2 \end{pmatrix},$$

with proportionality factor α determined by the coupling β and normalization conventions [6]. This example shows that G_{ij} is not arbitrary: in multi-dimensional systems it systematically reflects local entropy curvature and anisotropy of distinguishability.

More general methods for constructing G_{ij}, including for interacting systems and curved configuration manifolds, are outlined in [6], Appendix B. A general procedure for constructing G_{ij} in arbitrary systems is given in the following section.

Appendix B. General Algorithm for Constructing G_{ij} (Structurally Derived)

While specific forms of G_{ij} were stated directly for the worked examples in Sections 3–7, and an illustrative example was given in Appendix A, it is useful to state a general algorithm for constructing G_{ij} systematically. The procedure presented here is fully consistent with, and derived from, the structural formulation of the entropy flux functional $g(\phi, \dot{\phi})$ in [6], Appendix B, and with the entropy-weighted action formalism used in this paper (see Section 2).

Algorithm for Constructing $G_{ij}(x, \dot{x})$:

1. **Input:**
   - Configuration-space coordinates x^i.
   - Classical Lagrangian $L(x, \dot{x})$ or Hamiltonian $H(x, p)$.
   - Structural entropy function $S_{\text{struct}}(x)$, representing the entropy associated to coarse-grained configurations x.
2. **Compute entropy curvature:**
$$C_{ij}(x) = \frac{\partial^2 S_{\text{struct}}(x)}{\partial x^i \partial x^j}.$$
   This term quantifies how the distinguishability of configurations varies locally in x-space, consistent with the entropy geometry formalism presented in [6], Section 4 and Appendix B.
3. **Compute dynamical curvature:**
$$D_{ij}(x) = \frac{\delta^2 S_{\text{classical}}}{\delta x^i \delta x^j}.$$
   Here $S_{\text{classical}} = \int L(x, \dot{x})\, dt$, and D_{ij} reflects the action cost of path variations. This ensures that G_{ij} encodes not only entropy curvature but also dynamical stability (cf. [6], Appendix B).
4. **Form the combined entropy metric:**
$$G_{ij}(x, \dot{x}) = \alpha\, C_{ij}(x) + \gamma\, D_{ij}(x),$$

where α, γ are structural couplings determined by the entropy-weighted action normalization (see [6], Appendix B). The specific choice of α, γ reflects both universal TEQ structure and system-dependent scaling conventions.

5. **Ensure positive-definiteness:**
Verify that G_{ij} is positive-definite along admissible directions:

$$v^i G_{ij} v^j \geq 0 \quad \forall v^i.$$

If necessary, small regularization terms can be added to ensure positivity in all directions. This is required to guarantee that the entropy cost functional $g(x, \dot{x}) = G_{ij}(x, \dot{x})\,\dot{x}^i \dot{x}^j$ suppresses entropy-unstable trajectories in the path integral (see Section 2 and Equation (3)).

Interpretation: This construction ensures that G_{ij} reflects both (i) the structural entropy geometry of the system, and (ii) the dynamical stability of paths. The resulting entropy cost functional $g(x, \dot{x})$ governs the suppression and selection of resolution-stable trajectories in the entropy-weighted path integral, consistent with the formalism developed in [6], Section 4, Appendix B, and the examples presented in this paper.

In simple cases such as the harmonic oscillator (Appendix A) or rectangular barrier (Section 3), the contribution from C_{ij} is naturally aligned with the curvature of the potential $V(x)$, while D_{ij} reflects dynamical stiffness. For more complex systems—including interacting systems, field theories, and curved configuration manifolds—this algorithm provides a systematic path toward constructing G_{ij} consistent with the core principles of the TEQ framework (cf. [6], Appendix B; [7]).

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