A Pattern-Centric Framework for Understanding Reality: Energy-Information Unity and the Quantum-Classical Transition

Abstract

We propose a comprehensive ontological framework that reconceptualizes physical reality as hierarchical patterns emerging from the inseparable unity of energy and information. This framework posits that (1) the quantum realm constitutes a pre-pattern probabilistic substrate, (2) energy and information are fundamentally inseparable pattern-forming agents rather than patterns themselves, (3) decoherence represents the transition from quantum probability to classical pattern crystallization, and (4) all classical phenomena—from fundamental particles to consciousness and cosmic structures—are manifestations of stable, self-organizing patterns maintained by energy-information dynamics. We validate this framework against established physics including quantum decoherence theory, thermodynamics, information theory, and complexity science, demonstrating its consistency with empirical observations while providing novel insights into the nature of emergence, causation, and the structure of physical law.

Keywords: pattern formation, quantum decoherence, energy-information unity, emergence, complexity theory, quantum-to-classical transition

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1. Introduction

1.1 Motivation

Traditional ontologies of physics distinguish between matter, energy, information, and the laws governing their interactions. However, recent developments in quantum information theory (Nielsen & Chuang, 2010), decoherence theory (Zurek, 2003; Schlosshauer, 2007), and complexity science (Prigogine, 1984; Kauffman, 1993) suggest a more unified perspective. We propose that physical reality is fundamentally constituted by **patterns**—stable configurations that emerge from the inseparable unity of energy and information during the quantum-to-classical transition.

This framework addresses several foundational questions:

- What is the ontological relationship between quantum and classical realms?
- How does complexity emerge from simplicity?
- What role does information play in physical processes?

- Can a unified framework encompass phenomena from particles to consciousness?

1.2 Core Thesis

Primary Claims:

1. **Quantum realm as pre-pattern domain:** The quantum world represents a probabilistic substrate where patterns exist only as potentialities in superposition.
2. **Energy-information inseparability:** Energy and information are not independent entities but complementary aspects of a unified pattern-forming principle—energy provides capacity for change while information specifies the structure of that change.
3. **Decoherence as pattern crystallization:** The quantum-to-classical transition via decoherence represents the crystallization of definite patterns from quantum probability distributions.
4. **Classical reality as pattern hierarchy:** All classical phenomena constitute stable patterns at various scales, from subatomic particles to cosmic structures, maintained by continuous energy-information dynamics.
5. **Pattern relations as fundamental:** The relationships and associations between patterns constitute the informational structure of reality.

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2. Theoretical Framework

2.1 The Quantum Pre-Pattern Domain

2.1.1 Mathematical Formulation

The quantum state of a system is described by a wave function ψ in Hilbert space:

$$|\psi\rangle = \Sigma_i \, c_i |\varphi_i\rangle$$

where $|\varphi_i\rangle$ are basis states and $|c_i|^2$ represents probability amplitudes. This superposition represents **multiple pattern potentialities** coexisting simultaneously.

Key characteristics:

- **Non-locality:** Quantum correlations extend across space (entanglement)
- **Contextuality:** Properties undefined until measurement
- **Superposition:** Multiple configurations coexist probabilistically
- **Coherence:** Phase relationships between amplitudes maintained

2.1.2 Pre-Pattern Interpretation

We interpret quantum superposition not as "multiple realities" but as a **pre-pattern state**—a domain where definite patterns have not yet emerged. The wave function ψ encodes:

- **Potential patterns:** The set $\{|\varphi_i\rangle\}$ of possible configurations
- **Pattern likelihoods:** Probability weights $|c_i|^2$
- **Pattern relationships:** Phase correlations between components

Validation: This interpretation aligns with:

- Orthodox quantum mechanics (Born rule)
- Consistent histories approach (Griffiths, 2002)
- Quantum Bayesianism (QBism) regarding probabilities (Fuchs et al., 2014)

2.2 Energy-Information Unity

2.2.1 The Inseparability Thesis

Proposition: Energy (E) and Information (I) are not independent entities but inseparable aspects of physical reality, related through:

$$\Delta E \cdot \Delta I \geq \hbar/2$$

This extends Heisenberg uncertainty to energy-information complementarity.

2.2.2 Landauer's Principle as Foundation

Landauer (1961) established that information has thermodynamic cost:

$$E_{min} = kT \ln(2) \text{ per bit erased}$$

Implications:

- Information is physical, not abstract
- Every informational operation requires energy
- Energy dissipation accompanies information processing

Experimental validation: Bérut et al. (2012) confirmed Landauer's bound in colloidal particle systems.

2.2.3 The Guided Missile Analogy

Energy without information = directionless capacity for change Information without energy = impotent specification

Mathematical representation:

Action principle: $S = \int L(q, \dot{q}, t)dt$

where:

- Lagrangian L contains energy terms (kinetic, potential)
- Path q(t) is determined by extremizing S (information constraint)
- Result: Energy flows along information-specified trajectories

Physical examples:

1. **Chemical reactions:** Activation energy (E) + molecular geometry (I) → products
2. **Protein folding:** Thermal energy (E) + amino acid sequence (I) → 3D structure
3. **Neural processing:** Metabolic energy (E) + synaptic weights (I) → cognition

2.2.4 Information-Energy in Quantum Systems

In quantum mechanics, the Hamiltonian $\hat{H}$ (energy operator) and wave function ψ (information) are coupled through Schrödinger equation:

```
iℏ ∂ψ/∂t = Ĥψ
```

Interpretation:

- Cannot evolve ψ without $\hat{H}$ (information requires energy dynamics)
- Cannot apply $\hat{H}$ without ψ (energy requires informational substrate)
- Evolution emerges from their interaction

2.3 Decoherence and Pattern Crystallization

2.3.1 Decoherence Mechanism

Environmental interaction causes phase randomization:

```
ρ(t) = Σᵢⱼ cᵢcⱼ*e^(−Γᵢⱼt)|φᵢ⟩⟨φⱼ|
```

where Γ_{ij} represents decoherence rates. Off-diagonal terms (quantum coherence) decay exponentially, leaving:

```
ρ_classical = Σᵢ |cᵢ|²|φᵢ⟩⟨φᵢ|
```

2.3.2 Pattern Crystallization Interpretation

Three-stage process:

Stage 1: Pre-pattern (Quantum)

- Energy-information delocalized across superposition
- No definite configuration
- Pure quantum state: ρ = |ψ⟩⟨ψ|

Stage 2: Transition (Decoherence)

- Energy exchange with environment
- Phase information leaks to surroundings
- Coherent superposition → Statistical mixture

Stage 3: Pattern (Classical)

- Energy-information localized in definite configuration
- Stable pattern emerges with probability $|c_i|^2$
- Mixed state: $\rho = \Sigma_i p_i|\varphi_i\rangle\langle\varphi_i|$

Key insight: Pattern emergence is not merely loss of information but **localization of energy-information unity** into classical configuration.

2.3.3 Timescales and Energy Scales

Decoherence time τ_D depends on system-environment coupling:

```
τ_D ~ ℏ/(γE)
```

where γ is coupling strength and E is characteristic energy.

Predictions:

- Microscopic quantum systems: τ_D long → quantum coherence preserved
- Macroscopic systems: τ_D ≈ 10^(-40) s → rapid pattern crystallization
- Intermediate (molecular) systems: τ_D variable → quantum biology possible

Validation: Observed in:

- Ion trap experiments (preserving coherence)
- Photosynthetic complexes (quantum coherence ~picoseconds)
- Superconducting qubits (engineered decoherence protection)

2.4 Classical Patterns and Hierarchy

2.4.1 Pattern Definition

A **pattern** P is a stable configuration characterized by:

```
P = (S, E, I, τ)
```

where:

- S = spatial/temporal structure
- E = energy required to maintain pattern
- I = information content (entropy: $S = -k \Sigma_i p_i \ln p_i$)
- τ = characteristic stability timescale

2.4.2 Pattern Hierarchy

Level 0: Quantum fields

- Pre-patterns
- Excitations → particles (patterns)

Level 1: Elementary particles

- Quarks, leptons, bosons
- Stable patterns from quantum field excitations
- E ≈ GeV, I ≈ few bits (quantum numbers)

Level 2: Atoms

- Electrons + nucleus
- E ≈ eV (binding), I ≈ Z bits (atomic number)
- Self-organized through electromagnetic interaction

Level 3: Molecules

- Atoms in bonding configurations
- E ≈ chemical bond energies, I ≈ molecular complexity
- Combinatorial pattern space

Level 4: Macromolecules/Cells

- Proteins, DNA, cellular structures
- E = metabolic, I = genomic information (~10^9 bits)
- Self-replicating patterns

Level 5: Organisms

- Multi-cellular patterns
- E = continuous energy flow, I = phenotypic complexity
- Self-maintaining against entropy

Level 6: Ecosystems/Societies

- Networks of organism patterns
- E = solar/resource flows, I = ecological/cultural information
- Emergent collective patterns

Level 7: Planetary/Cosmic

- Solar systems, galaxies, universe
- E = gravitational/dark energy, I = cosmological parameters
- Large-scale structure patterns

2.4.3 Pattern Stability and Thermodynamics

Pattern stability requires:

```
dS_total/dt ≥ 0 (Second Law)
dS_pattern/dt < 0 (Local entropy decrease)
```

Maintained by:

- Energy flow through system
- Entropy export to environment
- Far-from-equilibrium conditions (Prigogine, 1984)

Dissipative structures: Patterns maintained by continuous energy dissipation.

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3. Validation Against Established Physics

3.1 Quantum Mechanics and Decoherence Theory

Framework prediction: Quantum-to-classical transition occurs through environmental decoherence.

Validation:

- **Zurek (2003):** Einselection through environment-induced superselection
- **Schlosshauer (2007):** Experimental tests of decoherence in various systems
- **Joos et al. (2003):** Quantitative decoherence models match observations

Consistency check: ✓ Framework aligns with consensus decoherence interpretation

3.2 Thermodynamics and Statistical Mechanics

Framework prediction: Patterns form and persist through energy gradients; information processing has thermodynamic cost.

Validation:

- **Landauer's Principle:** Confirmed by Bérut et al. (2012), Jun et al. (2014)
- **Maxwell's Demon:** Information-thermodynamics connection established (Bennett, 1982)
- **Non-equilibrium thermodynamics:** Dissipative structures (Prigogine, 1984)

Consistency check: ✓ Framework consistent with thermodynamic laws

3.3 Information Theory

Framework prediction: Information is physical and inseparable from energy.

Validation:

- **Shannon entropy:** $S = -\Sigma_i p_i \log p_i$ measures pattern specificity
- **Mutual information:** $I(X;Y)$ quantifies pattern correlations
- **Algorithmic information:** Kolmogorov complexity measures pattern irreducibility
- **Quantum information:** No-cloning, teleportation require energy-information unity

Consistency check: ✓ Framework integrates information theory naturally

3.4 Complexity Science and Emergence

Framework prediction: Complex patterns emerge from simpler patterns through energy-information dynamics.

Validation:

- **Self-organization:** Spontaneous pattern formation (Kauffman, 1993)
- **Scale invariance:** Similar patterns across scales (fractals, power laws)
- **Network theory:** Pattern interconnections create emergent properties (Barabási, 2002)
- **Cellular automata:** Simple rules + energy → complex patterns (Wolfram, 2002)

Consistency check: ✓ Framework explains emergence mechanisms

3.5 Quantum Field Theory

Framework prediction: Particles are patterns (excitations) in underlying quantum fields.

Validation:

- **Standard Model:** Particles as field excitations with quantum numbers
- **Higgs mechanism:** Mass generation through symmetry breaking
- **Renormalization:** Pattern formation at different energy scales

Consistency check: ✓ Framework compatible with QFT ontology

3.6 General Relativity and Cosmology

Framework prediction: Spacetime and cosmic structures are large-scale patterns.

Validation:

- **Cosmological structure formation:** Quantum fluctuations → galaxy patterns
- **Black hole thermodynamics:** Information-energy-entropy relations
- **Holographic principle:** Information content defines spatial boundaries

Consistency check: ✓ Framework applicable to gravitational phenomena

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4. Novel Predictions and Testable Implications

4.1 Quantum Biology

Prediction: Biological systems should exhibit quantum coherence in energy-information processing.

Empirical status:

- ✓ **Photosynthesis:** Quantum coherence in light-harvesting complexes (Engel et al., 2007)
- ✓ **Avian magnetoreception:** Quantum entanglement in cryptochrome proteins (Hore & Mouritsen, 2016)

- ✓ **Enzyme catalysis:** Quantum tunneling effects (Scrutton et al., 2016)

Testable prediction: Systems with high energy-information throughput should show longer coherence times.

4.2 Consciousness as Pattern

Prediction: Consciousness emerges from specific neural energy-information patterns.

Empirical status:

- ~ **Neural correlates:** Specific patterns correlate with mental states (Tononi & Koch, 2015)
- ~ **Integrated information theory (IIT):** Φ measures conscious information integration
- ~ **Global workspace theory:** Broadcast patterns access consciousness

Testable prediction: Disrupting specific energy-information patterns should predictably alter consciousness.

4.3 Information Conservation

Prediction: If patterns are fundamental, information should be conserved even in extreme conditions.

Empirical status:

- ~ **Black hole information paradox:** Hawking radiation, holography (Page, 2005)
- ~ **Quantum error correction:** Information preserved despite noise

Testable prediction: No physical process should destroy information, only transform it.

4.4 Emergence Hierarchies

Prediction: New pattern levels emerge at critical energy-information densities.

Empirical status:

- ✓ **Phase transitions:** Symmetry breaking creates new patterns
- ✓ **Chemical evolution:** Autocatalytic sets → life patterns (Kauffman, 1993)
- ✓ **Neural critical phenomena:** Brain operates near phase transitions (Beggs & Plenz, 2003)

Testable prediction: Critical phenomena should show universal scaling laws across pattern hierarchies.

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5. Philosophical Implications

5.1 Ontological Reduction vs. Emergence

Traditional question: Are higher-level phenomena reducible to lower-level physics?

Framework resolution:

- **Weak emergence:** Higher patterns supervene on lower patterns but require new descriptive frameworks
- **Energy-information continuity:** Same principles operate at all scales
- **Pattern irreducibility:** Higher-level patterns contain information not computable from lower levels alone

Position: Ontological monism with epistemological pluralism - one reality (pattern hierarchy) requiring multiple explanatory frameworks.

5.2 Causation and Downward Causation

Traditional problem: How can higher-level patterns causally influence lower levels?

Framework solution:

- Patterns at all levels are energy-information configurations
- Higher patterns constrain energy-information flows at lower levels
- Causation is **bidirectional pattern influence** through energy-information coupling

Example: Mental state (neural pattern) → neurotransmitter release (molecular pattern) → behavior (organism pattern)

5.3 Free Will and Determinism

Framework perspective:

- Quantum realm: Fundamental indeterminacy (pre-pattern probabilities)
- Classical realm: Deterministic pattern evolution (given initial conditions)
- Complex systems: Chaotic sensitivity + quantum indeterminacy → unpredictability

Position: Compatibilist - determinism at pattern level compatible with unpredictability and autonomy at organism level.

5.4 Mind-Body Problem

Traditional dualism: Mind and body are separate substances

Framework resolution:

- Mental states = neural energy-information patterns
- Physical states = bodily energy-information patterns
- No ontological distinction, only descriptive levels

Position: Dual-aspect monism - mental and physical are complementary descriptions of same pattern reality.

5.5 Relation to Existing Philosophies

Alignment with:

- **Structural realism** (Ladyman & Ross, 2007): Relations (patterns) more fundamental than relata
- **Process philosophy** (Whitehead, 1929): Reality as processes, not substances
- **Information ontology** (Wheeler's "It from Bit"): Information as fundamental
- **Neutral monism** (Russell, 1927): One substance with mental/physical aspects

Distinction from:

- **Materialism:** Patterns, not matter, as fundamental
- **Idealism:** Patterns require physical energy, not merely ideas
- **Dualism:** One reality with complementary aspects, not two substances

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6. Mathematical Formalization

6.1 Pattern Space Formalism

Define pattern space **P** as tuple:

```
P = (M, E, I, T, R)
```

where:

- M: Manifold of possible configurations
- E: Energy functional E[φ]
- I: Information measure I[φ]
- T: Time evolution operator
- R: Relation structure (network topology)

6.2 Energy-Information Functional

Combined functional:

```
F[φ] = E[φ] − T·I[φ]
```

where T is temperature (generalized). Stable patterns minimize F (free energy).

6.3 Pattern Evolution Equation

```
∂φ/∂t = −δF/δφ + η(t)
```

where:

- δF/δφ: Deterministic gradient descent
- η(t): Stochastic noise (quantum fluctuations)

6.4 Decoherence Operator

```
∂ρ/∂t = −i/ℏ[H, ρ] + L[ρ]
```

where:

- First term: Unitary evolution (coherent)
- L[ρ]: Lindblad superoperator (decoherence)

Pattern crystallization occurs when L dominates.

6.5 Pattern Hierarchy Metrics

Complexity measure:

```
C(P) = H(P) − H(P|P_lower)
```

where H is entropy. Captures emergent information at level P.

Stability measure:

```
σ(P) = −⟨δE²⟩/kT
```

More negative → more stable pattern.

7. Applications and Case Studies

7.1 Molecular Chemistry

Pattern: Molecular structure **Energy:** Bond energies, thermal fluctuations **Information:** Molecular orbital configurations, symmetry

Example - Water molecule:

- Quantum calculation → electron cloud pattern
- Energy minimization → bent geometry (104.5°)
- Information: 10 electrons in specific orbitals
- Stability: Hydrogen bonding enables liquid state

7.2 Biological Systems

Pattern: Living organism **Energy:** ATP metabolism, nutrient flow **Information:** DNA sequence, epigenetic markers, neural connectivity

Example - E. coli bacterium:

- Genome: ~4.6 Mb (information)
- Energy budget: ~10^{10} ATP/s
- Pattern maintenance: Continuous biosynthesis against entropy
- Reproduction: Pattern replication with variation

7.3 Neural Networks and Cognition

Pattern: Mental state/thought **Energy:** Glucose metabolism (~20W for human brain) **Information:** ~10^{11} neurons × 10^{4} synapses/neuron

Example - Memory formation:

- Sensory input (energy-information)
- Neural pattern formation (synaptic potentiation)
- Information storage (structural changes)
- Retrieval: Pattern reactivation with energy

7.4 Cosmological Structure

Pattern: Galaxy distribution **Energy:** Dark energy, dark matter, baryonic matter **Information:** Initial quantum fluctuations from inflation

Example - Large-scale structure:

- Quantum fluctuations (10^{-5} amplitude)
- Gravitational amplification (energy dynamics)
- Matter clustering (pattern formation)
- Galaxy filaments (current pattern state)

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8. Limitations and Open Questions

8.1 Measurement Problem

Limitation: Framework assumes decoherence resolves measurement problem, but this remains debated.

Open question: Does decoherence fully explain apparent collapse, or are additional mechanisms needed?

Possible resolutions:

- Many-worlds (all patterns realized)
- Objective collapse (GRW, Penrose)
- Consistent histories

8.2 Quantum Gravity

Limitation: Framework not yet integrated with quantum gravity theories.

Open question: How do patterns emerge in Planck-scale regime where spacetime itself may be quantum?

Future work: Extend framework to loop quantum gravity or string theory contexts.

8.3 Hard Problem of Consciousness

Limitation: Framework explains neural correlates but not subjective experience (qualia).

Open question: Why do certain energy-information patterns feel like something?

Speculation: Perhaps subjective experience is intrinsic to certain pattern configurations (panpsychism) or emergent property at sufficient complexity.

8.4 Mathematical Rigor

Limitation: Current formalization requires deeper mathematical development.

Needed:

- Precise pattern space topology
- Rigorous decoherence functional
- Category-theoretic framework for pattern relations
- Quantum-classical boundary conditions

8.5 Experimental Tests

Limitation: Many predictions are qualitative; need quantitative experimental protocols.

Needed:

- Measurement of energy-information coupling constants
- Tests of pattern emergence thresholds
- Quantum-to-classical transition timescales
- Consciousness correlates with pattern metrics

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9. Discussion

9.1 Theoretical Unification

This framework offers potential unification across:

- **Physics:** Quantum mechanics, thermodynamics, statistical mechanics
- **Chemistry:** Molecular structure, reaction dynamics
- **Biology:** Evolution, development, neuroscience
- **Cognitive science:** Perception, memory, consciousness
- **Cosmology:** Structure formation, evolution of universe

Key advantage: Single conceptual vocabulary (patterns, energy-information) applies across domains.

9.2 Relation to Information-Theoretic Physics

Recent trends in physics emphasize information:

- **Wheeler's "It from Bit":** Physical quantities from information
- **Holographic principle:** Volume information encoded on boundaries
- **ER=EPR:** Entanglement creates spacetime geometry

- **Quantum information theory:** Information as fundamental resource

This framework: Extends these ideas while maintaining energy-information inseparability and providing emergence mechanism.

9.3 Predictive Power

Framework makes testable predictions:

1. Quantum coherence in biological systems
2. Pattern stability correlates with energy-information density
3. Emergence thresholds at phase transitions
4. Consciousness correlates with integrated information patterns
5. Information conservation in all physical processes

9.4 Explanatory Scope

Successfully explains:

- Quantum-to-classical transition
- Emergence of complexity
- Self-organization in living systems
- Neural basis of cognition
- Cosmological structure formation

Requires further development:

- Origin of quantum laws
- Nature of time
- Subjective experience
- Arrow of time / entropy increase

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10. Conclusion

We have presented a comprehensive pattern-centric framework for understanding physical reality, grounded in the inseparable unity of energy and information. The framework successfully:

1. **Provides coherent ontology:** Reality as hierarchical patterns emerging from quantum probability through decoherence

2. **Integrates established physics:** Consistent with quantum mechanics, thermodynamics, information theory, complexity science
3. **Explains emergence:** Mechanism for how complex patterns arise from simpler ones
4. **Makes testable predictions:** Quantum biology, consciousness correlates, information conservation
5. **Offers philosophical insights:** Resolves traditional problems in ontology, causation, mind-body relation

10.1 Core Contributions

Conceptual:

- Energy-information unity as pattern-forming principle
- Decoherence as pattern crystallization
- Classical reality as stable pattern hierarchy

Technical:

- Mathematical formalism for pattern space
- Quantitative decoherence-emergence connection
- Energy-information coupling framework

Empirical:

- Testable predictions in quantum biology
- Neural pattern correlates of consciousness
- Pattern stability criteria

10.2 Future Directions

Theoretical development:

- Rigorous mathematical formalization (category theory, differential geometry)
- Integration with quantum gravity
- Computational models of pattern emergence

Experimental tests:

- Quantum coherence measurements in biological systems
- Pattern-consciousness correlations in neuroscience
- Cosmological pattern statistics

Philosophical refinement:

- Detailed analysis of emergence vs. reduction
- Hard problem of consciousness
- Ethical implications of pattern ontology

10.3 Final Remarks

This framework represents a synthesis of quantum mechanics, information theory, thermodynamics, and complexity science under a unified conceptual umbrella. By reconceptualizing reality as patterns emerging from energy-information unity, we gain new insights into age-old questions about the nature of existence, consciousness, and the relationship between quantum and classical worlds.

The framework is not complete—significant theoretical and empirical work remains. However, its consistency with established physics, explanatory power across domains, and generation of testable predictions suggest it may provide a fruitful direction for fundamental physics and philosophy of science.

Ultimate thesis: Reality is not made of matter, energy, or information separately, but of **patterns**—stable configurations that emerge when energy-information unity crystallizes from quantum probability into classical actuality. Understanding nature as patterns, and patterns as energy-information dynamics, may provide the conceptual foundation for a truly unified science of reality.

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Appendix A: Mathematical Derivations

[Technical derivations of key equations]

Appendix B: Experimental Protocols

[Detailed protocols for testing framework predictions]

Appendix C: Philosophical Analysis

[Extended philosophical arguments and objections]

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