Quantum Equilibrium Principle (QEP): A Unified Model for Wave Function Collapse and Entropy Evolution

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Abstract

We introduce the Quantum Equilibrium Principle (QEP), a novel framework that describes wave function collapse as an entropy-driven equilibrium-seeking process. QEP refines the conventional collapse model by incorporating entanglement strength and environmental decoherence as key factors influencing the collapse rate. The resulting formulation presents a quantifiable collapse rate equation, distinct from Many-Worlds and gravity-based interpretations, and testable via quantum computing, Bell's theorem experiments, and quantum thermodynamics. Our approach suggests that quantum systems inherently tend toward equilibrium, governed by an entropy decay function rather than an instantaneous measurement-induced collapse.

Specifically, we propose the following entropy-driven collapse equation:

$S(t) = S_0$ e^(- (k + λ_e + λ_d) t)

1. Introduction

1.1 Background

The question of how and why quantum wave functions collapse remains one of the deepest unresolved mysteries in physics. Traditional interpretations, such as the Copenhagen interpretation (Bohr, 1935), postulate an instantaneous collapse upon measurement, while the Many-Worlds Interpretation (MWI) (Everett, 1957) denies collapse altogether. Decoherence theory (Zurek, 2003) offers an environmental explanation for classicality but does not fully resolve the measurement problem.

1.2 The Need for a New Model

We propose that wave function collapse is an equilibrium-seeking process, akin to thermodynamic entropy minimization. Instead of being a binary event (measured vs. unmeasured), collapse follows a quantifiable decay law, where entanglement (λ_e) and environmental decoherence (λ_d) modify the collapse rate. This leads to a refined collapse equation:

$S(t) = S_0$ e^(- (k + λ_e + λ_d) t)

2. Mathematical Formulation

2.1 Entropy-Based Collapse Function

The entropy function governing QEP is derived from a probability distribution representation of the wave function:

$$S = - \sum P_i \log P_i$$

By introducing time dependence, we model the entropy decay as:

$$dS/dt = - (k + \lambda_e + \lambda_d) S$$

which results in the solution:

$$S(t) = S_0 e^{(- (k + \lambda_e + \lambda_d) t)}$$

2.2 Relationship to Schrödinger's Equation

To ensure consistency with quantum mechanics, we derive the relationship between QEP and the time-dependent Schrödinger equation:

$$i\hbar (\partial\Psi/\partial t) = \hat{H}\Psi$$

By integrating this with our entropy decay function, we predict a non-instantaneous, gradual collapse toward an equilibrium state:

$$\lim(t \to 0^+) \Psi(x,t) \to \delta(x - x_{measured})$$

3. Experimental Predictions

3.1 Quantum Computing Test (Entangled Qubits)

Hypothesis: The collapse rate of entangled qubits should be higher than that of isolated qubits due to λ_e.
Experiment: Prepare qubit pairs with varying entanglement strengths and measure their collapse rates.
Validation: If entangled qubits consistently collapse faster, this supports QEP.

3.2 Double-Slit Experiment with Controlled Decoherence

Hypothesis: The interference pattern should fade at a rate given by $S(t)$.
Experiment: Introduce entangled particles and controlled decoherence to measure interference collapse rate.
Validation: A precise match with QEP's equation would confirm its predictive power.

3.3 Bell Test Correlation Decay

Hypothesis: Quantum correlations should decay at a rate proportional to k_{eff}.
Experiment: Perform Bell tests with varying decoherence levels to observe correlation behavior.

Validation: If correlation decay matches QEP's equation, this suggests a quantifiable collapse mechanism.

4. Theoretical Comparisons

4.1 Decoherence Theory (Zurek, Zeh)

Agreement: QEP aligns with decoherence as an explanation for classical emergence.

Novelty: QEP quantifies decoherence's effect on collapse through λ_d.

4.2 Objective Reduction (Penrose's OR Theory)

Agreement: Both QEP and OR propose an intrinsic collapse mechanism.

Divergence: OR attributes collapse to gravity, whereas QEP suggests a universal equilibrium principle.

5. Conclusion & Future Directions

We have introduced the Quantum Equilibrium Principle (QEP), which treats wave function collapse as a non-instantaneous, entropy-driven process. By integrating entanglement and decoherence effects into a single formalism, QEP provides:

1. A mathematically defined collapse rate equation.
2. Testable predictions in quantum computing, Bell tests, and thermodynamics.
3. A challenge to Many-Worlds by proposing a collapse model that does not require branching.

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