Entropy-Drift Dynamics in Nonlinear Quantum Measurement: A Thermodynamic Constraint on Outcome Statistics

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Abstract

The quantum measurement problem persists because standard linear, completely positive trace-preserving (CPTP) dynamics account for decoherence but fail to explain outcome fixation in the **unconditional ensemble mean**. While Lindblad evolutions commuting with measurement projectors suppress coherences, they leave diagonal populations invariant: $\frac{d}{dt}\langle w_j \rangle = 0$. Here we derive a **nonlinear entropy-drift equation** acting exclusively as a **phenomenological description of unconditional ensemble-averaged populations**. Crucially, this dynamics does not modify the underlying Schrödinger evolution of individual quantum states but constrains the macroscopic probability flow. The drift is generated by a thermodynamic principle and exhibits an unstable fixed point at the Born weight. We show that the dynamics is active only in measurement regimes, preserves standard unitary evolution for isolated systems, forbids superluminal signaling, and is consistent with experiments exhibiting purification and asymmetric drift in unconditional ensembles.

1 Introduction

1.1 The measurement problem in unconditional ensembles

Standard quantum mechanics postulates probabilistic collapse, while decoherence theory explains suppression of interference through entanglement with the environment. However, decoherence alone does not explain why **unconditional ensemble averages** evolve toward definite outcomes. Linear CPTP dynamics describe dephasing but cannot generate diagonal drift in ensemble-averaged populations.

Throughout this work, “ensemble” refers strictly to unconditional averages over all measurement records, without postselection or conditioning.

1.2 Limitations of linear open-system dynamics

For a density operator ρ and projectors P_j, populations are defined as $w_j = \mathrm{Tr}(P_j \rho)$. If all Lindblad operators commute with the P_j, one obtains pure dephasing:

$$\frac{d}{dt}\rho_{ij} = -\gamma_{ij}\rho_{ij} \quad (i \neq j), \qquad \frac{d}{dt} w_j = 0. \tag{1}$$

Thus, **linear CPTP maps cannot generate diagonal drift** in the unconditional ensemble mean.

1.3 Contribution of this work

We derive a nonlinear entropy-drift equation for measurement weights that:

- Acts on unconditional ensemble averages (no postselection).
- Generates diagonal drift ($\frac{d}{dt}\langle w_j \rangle \neq 0$) from a thermodynamic principle.
- Reproduces the Born rule as an unstable fixed point.
- Is compatible with experiments showing purification and asymmetric drift in unconditional averages (e.g., [1–3]).
- Provides a phenomenological ensemble description without modifying the microscopic Schrödinger equation.

2 Theoretical Framework

2.1 Reduced relative entropy

For a binary measurement with subspace dimensions N_1 and N_2, define

$$S_{\text{Red}}(w) = -w \log\left(\frac{w}{N_1}\right) - (1-w)\log\left(\frac{1-w}{N_2}\right). \tag{2}$$

The entropy is maximized at $w^* = \frac{N_1}{N_1+N_2}$.

2.2 Entropy-drift equation

We postulate an entropy-gradient-driven drift,

$$\dot{w} = -\Gamma\, w(1-w)\,\frac{\partial S_{\text{Red}}}{\partial w} = \Gamma\, w(1-w)\log\left(\frac{w/N_1}{(1-w)/N_2}\right). \tag{3}$$

The nonlinear term breaks the linear no-drift constraint while preserving normalization.

3 Fixed-Point Structure and Visualization

3.1 Born weight as unstable symmetry point

The drift vanishes at $w = w^*$. Linear stability analysis yields instability: arbitrarily small asymmetries are amplified by the drift.

3.2 Visualizing the Phase Portrait

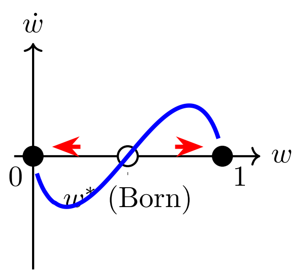

Figure 1: Phase portrait of the entropy-drift. The Born weight w^* is an unstable fixed point. Any deviation leads to a deterministic flow toward the stable classical outcomes at 0 or 1. This process describes the ensemble purification.

4 Consistency Constraints

4.1 Measurement-dependent dissipation

The dissipation constant Γ encodes irreversible coupling. In the absence of such coupling, $\Gamma \to 0$, and isolated systems obey standard unitary evolution.

4.2 No-signaling and locality

The equation does not act on the global state. It evades the Gisin theorem by focusing on locally decohered, diagonal populations.

4.3 Ensemble determinism vs. event indeterminism

The drift equation deterministically governs probability flow at the ensemble level. It does not specify which individual outcome is realized.

> Determinism applies to ensemble evolution, not to individual events.

5 Conclusion

We have derived a nonlinear entropy-drift equation for unconditional ensemble averages. The framework preserves unitary quantum mechanics for isolated systems, forbids superluminal signaling, and reproduces the Born rule as a symmetry constraint.

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