Logic Field Theory: Temporal Collapse Dynamics from Logical Strain

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We propose Logic Field Theory (LFT), a modification of quantum mechanics based on the observed invariance of classical logical constraints in all physical measurement outcomes. LFT introduces a logical strain functional $D(\psi)$ that modifies the Born rule, predicting temporal decay in measurement success probability and the possibility of complete measurement failures in high-strain regimes. These predictions are experimentally distinguishable from standard quantum mechanics and testable with current technology. We derive specific protocols for testing LFT using 3-qubit GHZ states on superconducting platforms, with predicted collapse timescales of 50-100 μs.

INTRODUCTION

Physical reality exhibits a remarkable empirical property: no measurement has ever detected a violation of the three fundamental laws of logic (3FLL) – Identity ($A = A$), Non-Contradiction ($\neg(A \wedge \neg A)$), and Excluded Middle ($A \vee \neg A$). This universal logical compliance extends across all scales and phenomena, from classical mechanics to quantum field theory. Despite this extraordinary empirical fact forming the foundation of all physical theories, no mechanism explains why reality should respect logical constraints.

We propose that this universality reflects a causal relationship: logical constraints act as primary selection rules that determine which quantum states can be physically realized. This reverses the traditional assumption that logic emerges from physics, instead positing that logical principles constrain the possibility space of physical reality.

THEORETICAL FRAMEWORK

Core Formulation

The fundamental principle of Logic Field Theory is expressed by the equation:

$$\Omega = L(S) \tag{1}$$

where Ω represents the set of physically realizable quantum states, S denotes the informational content of a proposed state, and L is the logical constraint operator. This equation encodes the central premise that a physical state can exist if and only if its informational description is permitted by the governing logical structure.

This reverses the traditional Physics $\rightarrow$ Information $\rightarrow$ Logic causality, instead positing Logic $\rightarrow$ Information $\rightarrow$ Physics as the fundamental ordering of reality.

The Logical Strain Functional

We define a logical strain functional $D(\psi)$ that quantifies the degree to which a quantum state ψ approaches logical inconsistency:

$$D(\psi) = \lambda v_I(\psi) + \mu v_N(\psi) + \nu v_E(\psi) \tag{2}$$

where:

- $v_I(\psi)$: Intrinsic informational strain based on purity and logical asymmetry
- $v_N(\psi)$: Nonclassical strain from stabilizer contradictions and Bell-type violations
- $v_E(\psi)$: Environmental strain from decoherence effects

For intrinsic strain: $v_I(\psi) = 1 - \text{purity}(\psi) + \chi_L(\psi)$, where χ_L captures logical asymmetry measures.

For nonclassical strain: $v_N = (V_C/V_T) + \lambda C_L + \mu C_S$, where V_C/V_T represents the ratio of contradictory to total stabilizer constraints.

Modified Born Rule

LFT modifies the Born rule to include logical realizability:

$$P_{\text{LFT}}(s_c|\psi) = \exp(-\beta D(\psi)) \cdot \frac{|c_c|^2 \exp(-\beta D(s_c))}{\sum_j |c_j|^2 \exp(-\beta D(s_j))} \tag{3}$$

where β is the logical inverse temperature parameter, $|c_c|^2$ is the standard Born weight, and $D(s_c)$ is the strain of outcome state s_c.

Collapse Threshold Rule

We introduce a minimum realizability threshold ε below which collapse cannot occur:

$$\Pi_{\text{collapse}}(\psi) = \begin{cases} 1 & \text{if } \exp(-\beta D(\psi)) \geq \varepsilon \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

This leads to null measurement probability:

$$P_{\text{null}}(\psi) = 1 - \Pi_{\text{collapse}}(\psi) \cdot \sum_c P_{\text{LFT}}(s_c|\psi) \tag{5}$$

Temporal Dynamics

For time-dependent strain evolution $D(t) = D_0 + \gamma f(t)$, the realizability probability becomes:

$$P_{\text{realize}}(t) = \exp(-\beta[D_0 + \gamma f(t)]) \tag{6}$$

This predicts temporal decay in measurement success rates, with critical collapse time:

$$t^* = \frac{\ln(\varepsilon)/(-\beta) - D_0}{\gamma} \tag{7}$$

EXPERIMENTAL PREDICTIONS

LFT makes three key predictions distinguishable from standard quantum mechanics:

Temporal Measurement Decay

Standard QM: Constant measurement success probability (modulo decoherence)
LFT: Exponential decay $P_{\text{realize}}(t) = \exp(-\beta[D_0 + \gamma t])$ due to strain accumulation

Complete Measurement Failures

Standard QM: Always produces some measurement outcome
LFT: Predicts total measurement failure when $P_{\text{realize}}(t) < \varepsilon$, resulting in $P_{\text{null}} = 1$

Platform-Dependent Scaling

LFT: Different quantum platforms exhibit characteristic β parameters that reflect platform-specific logical fragility, arising from backend circuit topology and gate-stability asymmetries. β is hypothesized to be a hardware-coupled constant, not a free parameter.
Prediction: If LFT is correct, β will show consistency across device generations within a given architecture, but vary systematically between platforms (ion trap vs. superconducting vs. photonic).

PROPOSED EXPERIMENTAL PROTOCOL

Optimal Test System

We propose testing with 3-qubit GHZ states $(|000\rangle + |111\rangle)/\sqrt{2}$ on superconducting platforms, as they provide:

- Accessible technology (IBM, Google, Rigetti platforms)
- Moderate strain ($D_0 \approx 1.0$) giving measurable effects
- Predicted collapse times (50-100 μs) within coherence windows

Experimental Protocol

1. **Prepare** high-fidelity 3-qubit GHZ state
2. **Wait** variable delays: $t = 0, 10, 20, 30, 40, 50$ μs
3. **Measure** in computational basis
4. **Record** successful measurement rate vs. time
5. **Compare** to LFT prediction: $P_{\text{success}} = \exp(-\beta D(t))$

Additional test: Prepare 3-qubit W-state $(|001\rangle + |010\rangle + |100\rangle)/\sqrt{3}$. LFT predicts higher D_0 and faster collapse, providing an internal cross-strain falsifier within the same experimental platform.

Expected Results

For $\beta = 1.0$, $\gamma = 0.05$, $D_0 = 1.0$:

Time (μs)	$D(t)$	P_{LFT}	P_{QM}
0	1.00	0.368	1.000
20	2.00	0.135	1.000
40	3.00	0.050	1.000
50	3.50	0.030	1.000

TABLE I. Predicted measurement success probabilities for 3-qubit GHZ states

Primary experimental signature: 50% LFT success rate drop by $t = 50\mu$s, exponentially different from pure decoherence.

Unlike decoherence-induced probability blurring, LFT predicts non-observable null outcomes—genuine measurement failures below a realizability threshold ε, independent of environmental coupling.

Control Experiments

Critical control conditions include:

- **Decoherence baselines**: Test identical systems with varying T_2 times
- **Classical controls**: Verify no null results in classical measurement systems
- **Parameter scaling**: Systematically vary qubit number and entanglement depth

Statistical Requirements

- **Effect detection**: $> 10\%$ deviation from standard QM predictions
- **Significance level**: 5σ statistical confidence
- **Sample size**: ~ 1000 runs per time point
- **Replication**: Independent confirmation across multiple laboratories

DISCUSSION

Theoretical Implications

If validated, LFT would provide the first mechanism explaining why logical constraints apply universally to physical reality. This addresses a foundational question in physics: why mathematical reasoning is effective for describing natural phenomena.

Experimental Feasibility

The proposed tests operate within current experimental capabilities. Superconducting quantum processors can generate the required states with sufficient fidelity and measure within the predicted timescales.

Alternative Explanations

Careful experimental design must distinguish LFT effects from:

- Novel decoherence mechanisms
- Measurement apparatus artifacts
- Hidden variable theories
- Systematic experimental errors

Future Directions

Phase 1 success (temporal decay detection) would justify Phase 2 (cross-platform validation) and Phase 3 (null result detection) studies, potentially culminating in observation of complete measurement failures—a phenomenon with no analog in standard quantum mechanics.

CONCLUSIONS

Logic Field Theory provides a testable framework explaining the universal applicability of logical constraints to physical reality. The theory makes specific, falsifiable predictions about temporal collapse dynamics that can be tested with current quantum technology. Even negative results would advance understanding of quantum measurement precision and the limits of standard quantum mechanics.

The proposed 3-qubit GHZ temporal decay experiment offers a direct test of LFT's core prediction within a 6-month timeframe using existing superconducting platforms. Success would represent the first experimental evidence for logic-based constraints on physical realizability, while failure would constrain the parameter space for alternative foundational theories.

DATA AVAILABILITY

The computational framework supporting the temporal collapse dynamics (Section II D) is available as a Jupyter notebook at [GitHub repository link to be added upon acceptance]. The notebook includes complete implementations of strain functional calculations, temporal evolution simulations, and statistical analysis. Core computational methods are provided in Supplementary Material. All results are fully reproducible.

SUPPLEMENTARY MATERIAL

Supplementary Material to be added and includes: (i) detailed derivations of the strain functional components v_I, v_N, v_E; (ii) core computational algorithms for temporal dynamics; (iii) statistical analysis methods for experimental protocol design; (iv) additional benchmark calculations for various quantum states.

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