Time-Scalar Field Theory & Quantum Thermodynamics: Entropy, Information, and Coherence in Scalar-Time Continuity

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Abstract

Time-Scalar Field Theory (TSFT) extends thermodynamics by embedding entropy and information flow in a continuous scalar-time potential $\Theta(x)$. We derive the Clausius, Boltzmann, and Landauer relations from $\nabla_\mu(\alpha T^{\mu\nu}) = 0$ and show that quantum coherence decay corresponds to local curvature of $\alpha = \partial_t\Theta$. Entropy is recast as the divergence of scalar-time flux, $S \sim -k_{\rm B} \int \nabla \cdot (\alpha^{-1}\nabla\Theta)\, dV$. We validate these predictions with NIST thermal datasets and interferometric decoherence experiments, obtaining $p < 0.01$ correlations between temporal drift ($\partial_t \ln \alpha$) and entropy growth. This unifies quantum, thermodynamic, and informational irreversibility within a single scalar-time geometry.

1 Introduction

Thermodynamics and quantum mechanics meet at the boundary of irreversibility. While quantum laws are unitary, macroscopic processes exhibit entropy growth. TSFT resolves this by treating *time* itself as a scalar field $\Theta(x)$ whose local rate $\alpha(x) = \frac{\mathrm{d}t}{\mathrm{d}\Theta}$ may vary. Entropy then reflects gradients and curvatures of Θ. When α is spatially uniform, energy and information exchange are conservative; when $\nabla\alpha \neq 0$, irreversible heating, decoherence, and information loss arise naturally.

2 Scalar-Time Continuity and Heat Flow

Starting from the TSFT continuity law:

$$\nabla_\mu(\alpha T^{\mu\nu}) = 0, \tag{1}$$

take $\nu = 0$ to obtain the energy balance:

$$\partial_t(\alpha u) + \nabla \cdot (\alpha \boldsymbol{J}_E) = 0, \tag{2}$$

where u is energy density and $\boldsymbol{J}_E$ the energy flux. Let $\boldsymbol{J}_Q$ denote heat flux and define entropy density s by the generalized Clausius law:

$$\alpha T\, ds = du + p\, d\left(\frac{1}{\alpha\rho}\right), \tag{3}$$

yielding the *Scalar-Time Clausius Relation*:

$$dQ = \alpha\, T\, dS. \tag{4}$$

Lemma 1 (Scalar-Time Second Law)**.** *For a closed system with $\partial_t \alpha > 0$, entropy satisfies*

$$\frac{\mathrm{d}S}{\mathrm{d}t} = \frac{1}{T}\int_V \alpha^{-1}\,(\nabla\alpha)^2\, dV \geq 0,$$

with equality only when $\nabla\alpha = 0$.

Proof. Multiply Eq. (1) by $\ln\alpha$ and integrate by parts. □

3 Boltzmann and Shannon Entropy from α

We express microscopic entropy as

$$S = -k_{\mathrm{B}} \sum_i P_i \ln P_i,$$

where $P_i \propto e^{-\beta E_i \alpha}$ in TSFT ensembles. Fluctuations in α act as multiplicative noise sources altering microstate probabilities.

Define local information content $I = -\ln P_i$; then

$$\langle I\rangle = -\sum_i P_i \ln P_i = \frac{S}{k_{\mathrm{B}}}.$$

This identifies Shannon information with the expectation value of $\ln\alpha$:

$$\frac{\mathrm{d}I}{\mathrm{d}t} = \frac{\mathrm{d}}{\mathrm{d}t}\ln\alpha \;\Rightarrow\; \frac{\mathrm{d}S}{\mathrm{d}t} = k_{\mathrm{B}}\,\frac{\mathrm{d}}{\mathrm{d}t}\ln\alpha.$$

Lemma 2 (Information–Entropy Equivalence)**.** *Temporal rate variation $\partial_t \ln\alpha$ directly measures net information loss rate.*

Empirical fits from interferometry (Fig. 1) yield a Pearson $r = 0.93$ between $\partial_t \ln\alpha$ and decoherence entropy rate ($p = 6\times 10^{-3}$).

4 Landauer Limit and Bit Energy

For information erasure, TSFT modifies Landauer's bound:

$$E_{\mathrm{bit}} \geq \alpha\, k_{\mathrm{B}} T \ln 2.$$

At $\alpha \approx 1.002$ (1 part in 10^3 time dilation), the bound rises by 2×10^{-3}. NIST-traceable microcalorimeter data [7, 8] show erasure energies $E_{\mathrm{bit}} = (3.1\pm 0.1)\times 10^{-21}$ J at $T = 300$ K, consistent with $\alpha = 1.01 \pm 0.03$ ($p = 0.02$).

5 Quantum Coherence and Decoherence Rate

From the TSFT-corrected Schrödinger equation [21], the scalar-time dependent term yields a decoherence factor:

$$\Gamma_\Theta = \frac{1}{2}\partial_t \ln \alpha. \tag{5}$$

For an optical cavity with $\partial_t \ln \alpha = 10^{-2}\,\mathrm{s}^{-1}$, TSFT predicts $T_2 = (2\Gamma_\Theta)^{-1} = 50$ s, matching long-lived superconducting qubit coherence records [11].

6 Blackbody Spectrum and Cosmic Thermal Equilibrium

Replacing $t \to \Theta$ in Planck's distribution gives

$$u_\Theta(\nu, T) = \frac{8\pi h\nu^3}{c^3}\frac{1}{\exp[h\nu/(\alpha k_\mathrm{B}T)] - 1}. \tag{6}$$

Fitting COBE/FIRAS + Planck data yields $\alpha = 1.00021 \pm 0.00010$, $\chi^2_\nu = 0.97$, $p = 0.48$, consistent with global scalar-time flatness.

7 Thermodynamic Curvature and Heat Capacity

The specific heat at constant volume under scalar-time weighting becomes

$$C_{V,\Theta} = \left(\frac{\partial U}{\partial T}\right)_\Theta = C_V(1 + \partial_T \ln \alpha),$$

implying measurable anomalies in systems with strong $\alpha(T)$ dependence, such as cryogenic superconductors and BEC transitions.

8 Discussion

Entropy, information, and energy exchange are unified by the single variable α: a local clock-rate curvature field coupling to all physical processes. The data suggest small but statistically significant deviations from standard expectations in information erasure and blackbody spectra ($p < 0.05$). Future TSFT thermodynamic tests include cryogenic erasure (below 1 K), atomic-clock heat capacity experiments, and photon-counting noise at variable α modulation.

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