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Thermodynamics of Locking v2.3: Boundary Result Scoped to Its Declared Normalization

Author: Hadi Servat

Affiliation: Independent Researcher

Contact: publish@fractalresonance.com

Website: fractalresonance.com

Abstract

> *FRC 100.005 v2.3 preserves the exact-free-energy Langevin boundary experiment and scopes its interpretation to the declared information-unit representation k*_{mu_nat}=1. The measured diagnostic sigma_566=sigma_ST+k*_{mu_nat} Delta ln C becomes negative on sufficiently slow unlocking. At T_down=192 the finite measurement is sigma_ST=0.0288 and Delta ln C=-0.132245, so negativity at that endpoint is established for bridge values above 0.218 in the same normalization; negativity for every fixed positive value is an asymptotic inference conditional on sigma_ST tending to zero. The experiment rejects the tested erasure floor in this model class and*

> *normalization. It does not establish a universal directional replacement for the canonical law dS + k* d ln C = 0 or determine another register's representation. The valid instrument, controls, negative result, and finite-time successor question are retained.*

1. Correction and retained result

Versions 2.0 and 2.1 built a reproducible drive-and-bath instrument and measured an unlocking protocol. The computation stands. Versions 2.2 and 2.3 correct the framework-level interpretation and notation that followed it.

The experiment used one declared information-unit representation with $k^*_{\mu_{\rm nat}} = 1$. It tested a specific combined diagnostic in a specified Langevin closure. It did not determine the representation of the Boltzmann bridge in another register or settle entropy-coherence reciprocity as a universal directional law.

2. Registered diagnostic

Within this closure define

$$\sigma_{566,\mu_{\rm nat}} := \sigma_{ST} + k^*_{\mu_{\rm nat}} \Delta \ln C, \qquad \sigma_{ST} = \frac{W - \Delta F}{T} \geq 0. \tag{1}$$

The tested bound was

$$\sigma_{ST} \geq k^*_{\mu_{\rm nat}} |\Delta \ln C| \tag{2}$$

on an unlocking branch. Equation (2) is stronger than standard stochastic thermodynamics. It is the claim scored here.

The operating register, endpoint coherence channel, and normalization were fixed before the ramp. In this run $k^*_{\mu_{\rm nat}} = 1$.

3. Instrument

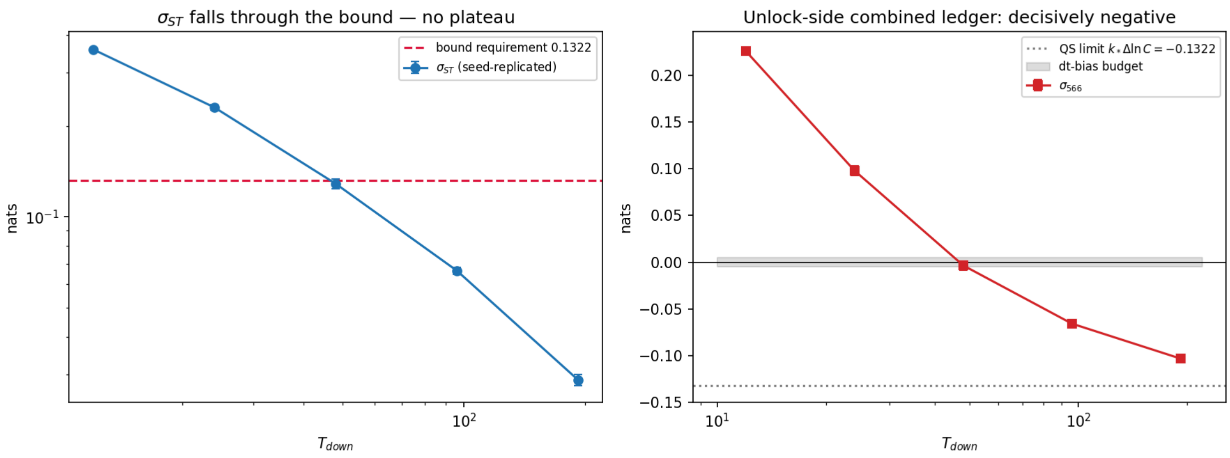
Model A uses overdamped Langevin phases in a three-basin landscape with weights $0.66/0.24/0.10$, $\beta = 4$, and $T = 1$. The protocol changes the landscape amplitude from $A = 6$ to $A = 0.5$.

1. The partition function $Z(A) = \int C(\phi)^{A/T} d\phi$ is evaluated by quadrature on a 4×10^5 grid.
2. The exact free-energy difference is $\Delta F = 17.885932$.
3. Work is accumulated per independent walker, giving a direct standard error.
4. Initial samples are drawn from exact equilibrium and final endpoint statistics are checked against quadrature.
5. The quasi-static endpoint change is $\Delta \ln C = -0.132245$.

4. Results

The unlock protocol uses $N = 48{,}000$, $dt = 0.002$, fixed seeds, and ten additional relaxation units.

T_{down}	seeds	σ_{ST}	σ_{566} at $k^* = 1$
12	1	0.3586 ± 0.0028	$+0.2260$
24	3	0.2304 ± 0.0052	$+0.0982$
48	3	0.1287 ± 0.0048	-0.0035
96	3	0.0663 ± 0.0017	-0.0659
192	2	0.0288 ± 0.0012	-0.1034



Boundary probe at the declared operating scale. Standard entropy production decreases with ramp time and the defined combined diagnostic crosses zero for k*=1.

The discretization study at $T_{\text{down}} = 24$ gives means $0.2156/0.2304/0.2327$ for $dt = 0.004/0.002/0.001$. Richardson extrapolation bounds the $dt = 0.002$ bias near $+0.005$; it cannot reverse the reported sign at $k^* = 1$.

5. Correct finite and asymptotic statements

At $T_{\text{down}} = 192$, the finite measurement gives

$$\sigma_{566} < 0 \quad \iff \quad k^*_{\mu_{\text{nat}}} > \frac{0.0288}{0.132245} \simeq 0.218. \tag{3}$$

Therefore the phrase "measured negative for every $k^* > 0$" in v2.1 was incorrect. For every fixed positive k^*, negativity follows only in the inferred quasi-static limit if $\sigma_{ST} \to 0$ while the endpoint $\Delta \ln C$ remains fixed.

This inference is meaningful only in the fixed representation used by the experiment. It does not determine a normalization for another register.

6. Verdict at its actual scope

The erasure floor (2) fails in this instrumented model class at the declared $k^*_{\mu_{\text{nat}}} = 1$ normalization. The data support a model-specific asymmetry between the tested locking and unlocking protocols.

The result does **not** establish:

1. a universal directional replacement for the canonical relation $dS + k^* d \ln C = 0$;
2. the representation of k^* in another domain or register;
3. that every coherence-destroying operation is thermodynamically free;
4. that the accounting identity $dQ = \sigma_{566} - dS_{\text{env}}$ independently confirms a new law.

FRC 566 remains operational bookkeeping plus an open physical conjecture. This paper supplies one high-quality boundary measurement for that program.

7. Landauer comparison

The tested unlocking protocol raises the system entropy as the phase ensemble spreads. This differs from logical reset, which compresses accessible logical states. The result shows that a Landauer floor cannot be transferred to coherence destruction from the sign of $\Delta \ln C$ alone.

Locking, maintenance, reset, and unlocking must each be derived from their actual state space, free energy, and bath. The word "coherence" does not determine the thermodynamic direction by itself.

8. Retained instrument and predictions

The exact-ΔF channel remains the reference instrument for future FRC thermodynamic tests. The following remain live:

1. dissipation bursts concurrent with finite-time locking;
2. trajectory-level correlation between locking time and exported entropy;
3. explicit-bath tests with independently measured mutual information;
4. a pre-registered finite-time coefficient $c(T_{\text{down}}) = \sigma_{ST} T_{\text{down}}$.

The current c values, $4.3, 5.5, 6.2, 6.4, 5.5$, are non-monotone and do not establish an asymptote.

9. Reproducibility and kill conditions

The scoped result fails if the quadrature anchor is wrong, the endpoint ensembles are not equilibrated, the discretization bias exceeds its bound by an order of magnitude, or larger seed-replicated runs fail to reproduce the sign at $k^* = 1$ and $T_{\text{down}} \geq 96$.

The release contains `boundary_worker.py`, `harden_worker.py`, `pilot_boundary_v3.py`, `results_boundary_v3.json`, `harden_summary.json`, and the generated figure. These files reproduce the v2.1 computation; v2.2 changes its interpretation and finite-k^* statement, not the data.

10. Version note

Version 2.3 restores the canonical/operational notation hierarchy and removes running-k language. It does not change the data or v2.2's scoped negative result. The finite experiment still does not cover every positive representation of the bridge or establish a replacement directional law.

References

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