Thermodynamics from Irreversible Commitment: A Closure-to-Macrostate Derivation in the VERSF Framework

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For the General Reader

Everything around us—heat, temperature, the tendency of things to wear out and disorder—is described by thermodynamics. But where do these laws come from? Why does heat always flow from hot to cold? Why can you never unscramble an egg?

The usual answer invokes statistics: there are vastly more ways for things to be disordered than ordered, so disorder wins by sheer weight of numbers. This is a good answer, but it leaves something out. Statistical arguments tell us disorder is *likely*—not that order is *impossible*. They don't explain why time has a direction at all.

This paper offers a deeper explanation rooted in a simple idea: **some physical events are genuinely, irreversibly final**. When a quantum measurement occurs, when a particle decays, when any physical process "makes a fact"—that fact is recorded in the fabric of reality and cannot be undone. We call these *commitment events*.

Thermodynamics, we argue, is what you get when you zoom out and look at the large-scale consequences of countless commitment events happening all the time. Entropy—the quantity that always increases—is simply a count of how many distinct ways the underlying facts could have been arranged to produce the same large-scale appearance. The second law of thermodynamics is not a statistical likelihood: it is the logical consequence of the fact that new facts are always being made and old ones are never erased.

Temperature, heat, and free energy all fall out of this picture naturally, without any additional assumptions. The result is a unified account in which quantum measurement, the arrow of time, and the laws of thermodynamics all trace back to a single principle: **irreversible fact production**.

Technical Abstract

Thermodynamics is traditionally introduced as an autonomous macroscopic theory governed by empirical laws of heat, work, and entropy. In this paper, we show that within the Void Energy-Regulated Space Framework (VERSF), thermodynamics emerges naturally from the microscopic structure of irreversible commitment events acting on a closure-defined distinguishability space.

Starting from the prior result that physical entropy is uniquely identified with closure entropy, we construct thermodynamic macrostates as coarse-grained equivalence classes of closure microstates under finite record resolution. We prove that the coarse-graining map is constrained—not arbitrary—by admissibility conditions on physical records, which uniquely selects closure multiplicity as the entropy measure. We derive the Boltzmann entropy as the logarithm of closure multiplicity, show that equilibrium distributions follow from entropy maximisation under conserved closure-compatible constraints, and establish that temperature emerges as the conjugate variable to closure entropy.

We derive the first law as a differential identity over macrostate space, and the second law as a structural consequence of the unidirectionality of commitment events. Crucially, we show that commitment events cannot cancel: each produces a logically irreversible increment in the closure record, so entropy increments are strictly non-negative and directionally consistent. We also address the origin of the entropy functional itself, deriving the Gibbs–Shannon form from constraints on closure-compatible probability assignments.

This establishes thermodynamics as the large-scale description of closure dynamics under admissible coarse-graining, and provides a unified interpretation in which quantum measurement, entropy, and thermodynamic irreversibility all arise from a single underlying principle: irreversible commitment in a finite distinguishability structure.

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1. Introduction

Thermodynamics occupies a unique position in physics. Its laws apply across domains, yet are not derived from first principles in the way dynamical theories are. Statistical mechanics provides a bridge by relating macroscopic quantities to ensembles of microstates, but leaves open a fundamental ambiguity: *which microstates should be counted, and by what measure?*

Several programs have attempted to resolve this. Jaynes [1] recast statistical mechanics as inference under incomplete information, deriving the Gibbs distribution from maximum entropy subject to constraints. Lieb and Yngvason [2] axiomatised thermodynamics from the relation of adiabatic accessibility, deriving entropy as the unique function ordering equilibrium states. Information-theoretic approaches [3,4] have further explored the connection between thermodynamic entropy and Shannon entropy, with Landauer's principle [5] linking logical irreversibility to heat dissipation.

The VERSF framework provides a distinct foundation. Rather than treating entropy as a measure of missing information or as an axiomatic primitive, VERSF derives entropy from the structure of distinguishability itself. Prior results establish that physical entropy is uniquely identified with *closure entropy*—the logarithm of the number of distinguishability classes compatible with a given physical configuration [6]. This identification is not assumed but derived from admissibility constraints on physical records.

The purpose of this paper is to show that once entropy is fixed in this way, thermodynamics follows without additional postulates.

Three specific gaps in earlier presentations are addressed here:

1. **Uniqueness of coarse-graining.** We show that admissibility constraints on physical records select a preferred class of coarse-graining maps, so closure multiplicity is the uniquely determined entropy.
2. **Non-cancellation of commitment increments.** We prove that commitment events cannot produce cancelling entropy increments, grounding the second law in logical rather than statistical irreversibility.
3. **Origin of the entropy functional.** We derive the Gibbs–Shannon form of entropy from constraints on closure-compatible probability assignments rather than importing it from information theory.

The result is a self-contained derivation of thermodynamics from closure dynamics. We note that this paper establishes the derivation structure and states the key propositions with proof sketches or complete arguments at the level of rigour appropriate for a first account; fully detailed proofs of Propositions 1 and 2 and a complete treatment of the energy spectrum from VERSF dynamical postulates are developed in companion papers [6,7].

2. Background and Prior Results

We briefly summarise the VERSF results on which this paper builds. Full derivations are given in [6,7].

Void substrate. The VERSF framework begins with a void substrate carrying no intrinsic distinguishability. Physical structure emerges through the formation of distinguishability classes—*closures*—that represent stable, record-constituting distinctions.

Closure equivalence classes. Closure classes form a quotient space over admissible distinguishability relations, defined operationally by indistinguishability under all physically realisable record-generating transformations. Formally, two void substrate configurations are closure-equivalent if and only if no finite sequence of admissible commitment events produces a different record structure when initiated from one versus the other. This is not a relabelling of microstates: the equivalence relation is determined by the physical record structure itself, not imposed by convention. The set of all closure classes defines a distinguishability space Γ, whose cardinality is fixed by the physical dynamics.

Commitment processes and primitive commitment events. A *commitment process* is any physical process that irreversibly establishes new distinctions in the closure record. Within this general class, a *primitive commitment event* is a fully resolved, idealised binary irreversible record — one that selects completely between two previously open alternatives. Prior results show that each primitive commitment event produces a minimal entropy increment:

$$\Delta S\_min = k\_B \ln 2$$

corresponding to the formation of exactly one binary distinction. Primitive commitment events are logically irreversible: once a distinction is recorded in the closure structure, it cannot be erased by any admissible physical operation without producing a compensating increment elsewhere. Weak measurements and partial decoherence are treated as incomplete commitment processes rather than primitive commitment events; their effective entropy increments may be smaller at intermediate stages, but a full binary resolution accumulates to the primitive increment $k\_B \ln 2$. Throughout this paper, all thermodynamic derivations are conducted in terms of primitive commitment events unless otherwise stated.

Closure entropy. The entropy of a physical configuration is:

$$S = k\_B \ln |\Gamma\_compatible|$$

where $|\Gamma\_compatible|$ denotes the number of closure classes compatible with the configuration. This identification is derived—not postulated—from the requirement that entropy be a monotone function of distinguishability under admissible coarse-graining [6].

Energy in the closure framework. For completeness we note how energy enters the VERSF picture, since it is used explicitly in Sections 5 and 6. In the VERSF framework, energy is the conserved scalar quantity conjugate to the continuous parameter of reversible Type R evolution

(Section 7.1)—precisely as energy is conjugate to time in Hamiltonian mechanics. Concretely, each closure microstate γ_i carries an energy eigenvalue E_i defined by its behaviour under the reversible evolution generator. This is consistent with standard quantum mechanics: closure classes that are in the same pointer subspace can still carry distinct energy labels, because energy eigenstates within a pointer subspace are distinguished by the reversible Hamiltonian evolution (Type R dynamics), not by any commitment event — the closure partition is set by which branch was selected, while the energy spectrum within that branch is determined by the continuing unitary evolution. Energy and closure structure are therefore orthogonal: one is a property of the reversible generator, the other of the irreversible record. The energy constraint $\Sigma_i\, p_i\, E_i = U$ in Section 5 is therefore a constraint on reversible structure, orthogonal to the closure record constraints (C1)–(C3). A full derivation of the energy spectrum from VERSF dynamical postulates is given in [7].

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3. Admissible Coarse-Graining and Uniqueness of Entropy

3.1 The Coarse-Graining Problem

Physical observations do not resolve all closure distinctions. Thermodynamic descriptions use coarse-grained states. This raises an immediate question: if we define macrostates by a coarse-graining map

$$\Pi: \Gamma \to \mathcal{M}$$

then the resulting entropy $S(m) = k\_B \ln |\Pi^{-1}(m)|$ depends on the choice of Π. In standard statistical mechanics, this is an acknowledged ambiguity. In VERSF, we claim it is resolved.

3.2 Admissibility Constraints

A coarse-graining map Π is *admissible* if and only if:

(A1) Record consistency. Two microstates $\gamma, \gamma' \in \Gamma$ are mapped to the same macrostate only if no admissible physical record can distinguish them. Formally: $\Pi(\gamma) = \Pi(\gamma')$ only if there exists no sequence of commitment events that produces different closure increments starting from γ versus γ'.

(A2) Monotonicity. If m_1 and m_2 are macrostates with $\Pi^{-1}(m_1) \subset \Pi^{-1}(m_2)$, then $S(m_1) \leq S(m_2)$.

(A3) Closure invariance. The partition induced by Π must be stable under reversible closure evolution: if $\gamma \to \gamma'$ by reversible dynamics, then $\Pi(\gamma) = \Pi(\gamma')$.

(A4) Subsystem independence. For physically independent subsystems A and B—systems with no shared commitment history and no closure correlations—the joint multiplicity satisfies $W\_{AB} = W\_A \cdot W\_B$.

The physical justification for (A4) is direct: independent systems have disjoint closure records. A commitment event in A appends a fact to A's record without touching B's, and vice versa. The number of jointly compatible closure classes is therefore the Cartesian product of the individually compatible classes, so multiplicities compose multiplicatively. This is not an auxiliary axiom imported for convenience—it is a structural consequence of the operational definition of closure independence—but it is stated explicitly here to keep the uniqueness proof free of implicit assumptions.

Proposition 1. Under (A1)–(A4), the entropy $S(m) = k\_B \ln |\Pi^{-1}(m)|$ is uniquely determined up to an overall positive multiplicative constant, fixed physically by the thermodynamic calibration k_B.

Proof. Condition (A1) forces the equivalence classes of Π to coincide with the physically indistinguishable closure classes at the resolution of the observational record. Condition (A3) ensures these classes are well-defined under dynamics. We now derive the logarithmic form from (A2) and (A4) without additional assumptions.

By (A4), for independent subsystems with closure multiplicities W_A and W_B, the joint multiplicity is $W\_{AB} = W\_A \cdot W\_B$. Any admissible entropy map $f: \mathbb{N} \to \mathbb{R}$ must therefore satisfy:

$$f(W\_A \cdot W\_B) = f(W\_A) + f(W\_B)$$

for all positive integers W_A, W_B. This is Cauchy's multiplicative functional equation. By (A2), f must be monotonically increasing. Under monotonicity (which implies measurability), the unique solution to the functional equation is $f(W) = C \ln W$, where C is a positive constant [cf. Aczél, *Lectures on Functional Equations*, 1966 [9]]. The positivity of C follows from monotonicity: larger multiplicity must correspond to higher entropy. The constant C is not fixed by the closure structure alone; it is set by the thermodynamic calibration $C = k\_B$, which identifies closure entropy with the entropy scale of the surrounding thermodynamic formalism. ∎

This establishes that closure multiplicity is not one possible entropy measure among many—it is the *unique* admissible one.

3.3 Macrostates

Given an admissible Π, define:

- A **microstate** as a closure-equivalence class $\gamma \in \Gamma$.
- A **macrostate** m $\in \mathcal{M}$ as the image $\Pi(\gamma)$.
- The **multiplicity** of a macrostate: $W(m) = |\Pi^{-1}(m)|$.

Closure entropy as macrostate entropy:

$S(m) = k\_B \ln W(m)$

This is the Boltzmann entropy—derived, not postulated.

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4. The Entropy Functional from Closure Constraints

Standard treatments import the Gibbs–Shannon entropy functional

$$S = -k\_B \sum_i p_i \ln p_i$$

from information theory (Jaynes [1]) or justify it by appeal to extensivity. A common objection is that any derivation invoking Khinchin's axioms [8] is circular — Khinchin's theorem characterises Shannon entropy, so citing it recovers a known result rather than deriving something new from VERSF structure.

We address this directly. The key claim is not that (C1)–(C3) below are mathematically novel constraints — they are not — but that they are *specifically grounded in closure physics*, in a way that Jaynes's epistemic derivation is not. Jaynes treats entropy as a measure of the observer's uncertainty, and his constraints are principles of rational inference. Our constraints are physical: they are forced by the operational structure of closure records, independently of any observer or inference framework. The entropy functional that results is therefore objective — a property of the closure structure itself — not a property of an agent's state of knowledge.

Setup. Consider a system whose closure microstate is not fully determined by the available macrostate record. We assign a probability distribution $\{p_i\}$ over microstates $\{i\}$. The constraints on this distribution are:

Constraint C1: Closure compatibility. The distribution must be consistent with the observed macrostate:

$$\sum\_{\{i \in \Pi^{-1}(m)\}} p_i = 1$$

This is not a normalisation convention — it is a physical requirement that the distribution only assigns weight to closure microstates that are compatible with the actual closure record.

Constraint C2: No spurious distinctions. The distribution may not encode distinctions that are not present in the closure record. Formally, if microstates i and j are closure-equivalent at the macrostate level, the distribution must treat them symmetrically in the absence of additional record structure. This is grounded in (A1): two states that no sequence of commitment events can distinguish must receive equal probability, since any asymmetric assignment would constitute an unrecorded distinction — a violation of admissibility.

Constraint C3: Independence under composition. For independent subsystems A and B, the joint distribution must factorise: $p\_{ij} = p_i^A \cdot p_j^B$. This is grounded in (A4): independent subsystems have disjoint closure records, so the probability over their joint microstates must respect their factorised closure structure.

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Proposition 2. The unique functional $S[\{p_i\}]$ satisfying (C1)–(C3), taking its maximum at the uniform distribution over $\Pi^{-1}(m)$, and reducing to $k\_B \ln W$ when all accessible states are equally probable, is:

$$S = -k\_B \, \Sigma_i \, p_i \ln p_i$$

Proof. (C2) enforces permutation symmetry over closure-equivalent states — grounded in (A1), not in epistemic indifference, because two states that no commitment event can distinguish are operationally identical by the record structure itself, and any asymmetric weighting would encode a distinction absent from the closure record. (C3) enforces the chain rule — grounded in (A4), not in compositional convention, because independent closure records compose as Cartesian products, forcing the joint probability to factorise. These two constraints, together with continuity and the maximum-at-uniform requirement, are exactly the conditions of Khinchin's characterisation theorem [8], whose unique solution is the Shannon functional. What is new here is not the mathematics but the physical grounding: (C2) is not an epistemic symmetry principle but a constraint from (A1), and (C3) is not a compositional convention but a consequence of (A4). The entropy functional is therefore not a measure of missing information — it is the unique probability-weighted measure of closure multiplicity compatible with the operational record structure. ∎

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5. Equilibrium and the Canonical Distribution

5.1 Entropy Maximisation

We now derive the equilibrium distribution. Given a system with microstates $\{i\}$, energies $\{E_i\}$, and the entropy functional from Section 4, we maximise

$$S = -k\_B \, \Sigma_i \, p_i \ln p_i$$

subject to:

- **Normalisation:** $\Sigma_i \, p_i = 1$
- **Fixed mean energy:** $\Sigma_i \, p_i \, E_i = U$

Using Lagrange multipliers λ_0 and β, differentiating with respect to p_i and setting to zero:

$$(\partial/\partial p_i) \, [-k\_B \, \Sigma_j \, p_j \ln p_j - \lambda_0 \, \Sigma_j \, p_j - \beta \, \Sigma_j \, p_j \, E_j] = 0$$

$$-k\_B \, (\ln p_i + 1) - \lambda_0 - \beta \, E_i = 0$$

$$p_i = \exp(-1 - \lambda_0/k\_B) \cdot \exp(-\beta \, E_i \, / \, k\_B)$$

Normalisation fixes the prefactor, giving the canonical distribution:

$$p_i = e^{\wedge}(-\beta\ E_i)\ /\ Z,\ Z = \Sigma_i\ e^{\wedge}(-\beta\ E_i)$$

5.2 Temperature as a Closure Constraint Variable

The Lagrange multiplier β enforces the energy constraint. Define temperature by:

$$\beta = 1\ /\ (k\_B\ T)$$

Interpretation in VERSF: Temperature is not a fundamental quantity. It is the Lagrange multiplier conjugate to mean energy in the closure-compatible entropy maximisation. It measures how rapidly the closure-compatible probability weight decreases with energy given the prevailing record constraints.

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6. The First Law

6.1 Macrostate Geometry

Consider macrostates parameterised by entropy S and external variables $\{X_a\}$ (volume, particle number, etc.). Define internal energy as a function of state:

$$U = U(S, \{X_a\})$$

The total differential is:

$$dU = (\partial U/\partial S)\_\{X_a\}\ dS + \Sigma_a\ (\partial U/\partial X_a)\_S\ dX_a$$

6.2 Thermodynamic Conjugates

Define:

$$T \equiv (\partial U/\partial S)\_\{X_a\},\ Y_a \equiv (\partial U/\partial X_a)\_S$$

Then:

$$dU = T\ dS + \Sigma_a\ Y_a\ dX_a$$

For a simple fluid with $X_a = V$:

$$dU = T\ dS - P\ dV$$

This is the **first law of thermodynamics**.

6.3 Interpretation in VERSF

Term	VERSF interpretation
dS	Change in closure multiplicity
T dS	Energy carried by new closure records (heat)
$Y_a dX_a$	Energy change from reversibly modifying external structure (work)

Heat and work are distinguished by whether they alter the closure record count ($dS \neq 0$) or only the external structural parameters ($dX_a \neq 0$).

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7. The Second Law from Irreversible Commitment

7.1 Irreversibility of Commitment

The second law requires that entropy cannot decrease in an isolated system. In standard statistical mechanics this is a probabilistic statement—entropy decrease is merely unlikely. In VERSF we derive a stronger, structural result.

Process classification. Within the idealised version of the VERSF framework used in this paper, physical processes are classified into two limiting categories:

- **(Type R) Reversible unitary evolution.** These processes permute closure classes without creating new ones. They leave the cardinality of Γ and the multiplicity $W(m)$ unchanged. Reversible evolution does not touch the closure record and produces no entropy increment. In quantum-mechanical language, these correspond to unitary operations on the pre-decoherence state.
- **(Type C) Commitment events.** These processes create new distinctions in the closure record—irreversibly selecting one branch of a previously open alternative. They are non-invertible maps on Γ, strictly increasing the closure record and thereby producing a non-negative entropy increment in the coarse-grained thermodynamic description. In quantum-mechanical language, these correspond to decoherence events that couple the system to environmental degrees of freedom, producing a stable classical record. The identification of Type C processes with decoherence is argued in §7.4; the key point here is the exhaustiveness of the classification: no physical process in the VERSF framework can decrease the closure record, because any process that is not a reversible permutation of existing classes must be a new fact-creating commitment.

This classification is the physical underpinning of Lemma 1 below.

Lemma 1 (Non-cancellation of primitive commitment increments). Primitive commitment events cannot cancel. That is, no pair of primitive commitment events produces a net zero change in closure entropy.

Proof. A primitive commitment event C irreversibly establishes a new distinction d in the closure record. Formally, C corresponds to a non-invertible branch-selection map on the closure state

space: it coarse-grains away the branch not taken, which is no longer accessible after the commitment. This is the defining property distinguishing primitive commitment from reversible unitary evolution, which permutes closure classes without eliminating any.

By definition of admissibility (A1), once d is recorded, no subsequent admissible physical operation can remove it. Any operation that appears to "erase" d must itself constitute a new commitment event C′ that records the erasure—it is not the inverse of C, but a distinct forward operation that appends a new fact to the closure record. Erasure is a new commitment, not a reversal. The map C′ ∘ C is not the identity: the record now contains both the original distinction and its removal, which is a strictly larger record than either alone.

Thus every commitment event produces a closure record increment that is logically independent of all prior records, and increments accumulate monotonically. No two commitment events produce records that are logical negations of each other within the same closure branch, because such negation would require inverting a non-invertible map—which is not an admissible operation. ∎

Corollary. All commitment events produce entropy increments of the same sign.

Note on weak measurements and partial decoherence. The classification above is stated for idealised limiting processes. In practice, weak measurements and partial decoherence occupy an intermediate regime and are treated within the VERSF framework as incomplete commitment processes rather than primitive commitment events. Each such process may produce a sub-binary entropy increment at intermediate stages; a full binary resolution accumulates to the primitive increment k_B ln 2. Whether incomplete commitment processes are better modelled as continuous Type R evolution approaching a Type C threshold, or as a distinct intermediate category, is a question for further development of the framework. For the thermodynamic derivations in this paper, we work throughout with primitive commitment events, and the staircase prediction in §10.4 is explicitly conditioned on this idealisation.

7.2 Entropy Growth

Each primitive commitment event produces a minimal entropy increment $\Delta S_{min} = k_B \ln 2$. For N^c primitive commitment events:

$$\Delta S \geq N^c \cdot k_B \ln 2 \geq 0$$

Since $N^c \geq 0$ always:

dS/dt ≥ 0

7.3 Comparison with Standard Treatments

This derivation differs from Boltzmann's H-theorem (which requires molecular chaos assumptions), from the probabilistic argument (which establishes that decrease is *unlikely*), and from Lieb–Yngvason (which takes adiabatic accessibility as axiomatic). In VERSF, entropy

increase is a *logical consequence* of the structure of commitment: records are created, never destroyed. The arrow of time is the accumulation of irreversible facts.

7.4 Connection to Standard Physical Processes

To situate commitment events within conventional physics, we note the following correspondence. In quantum mechanics, a commitment event corresponds to irreversible decoherence into a stable pointer basis—the process by which a quantum superposition loses phase coherence through entanglement with environmental degrees of freedom, producing a definite classical record [10]. In conventional quantum settings, stable pointer sectors provide a natural physical realisation of closure distinctions: states within the same pointer subspace are closure-equivalent; states in distinct subspaces are closure-distinct.

A quantum measurement is thus a primitive commitment event in the VERSF sense: for an idealised binary commitment outcome, it selects a branch irreversibly, appending a new fact to the closure record and producing a minimum entropy increment of $k_B \ln 2$. The associated minimum heat dissipated to an environment at temperature T is bounded below by Landauer's value $k_B T \ln 2$, which in the VERSF interpretation reflects the minimal thermodynamic cost of an idealised binary closure record increment.

More generally, any physical process that produces a stable, environment-coupled record—radioactive decay, chemical bond formation, a photon absorption event—constitutes a commitment process. The irreversibility of these processes in conventional physics is the macroscopic manifestation of the non-invertibility of the underlying branch-selection maps established in Lemma 1.

8. Thermodynamic Equilibrium

8.1 Entropy Maximisation at Equilibrium

Consider two subsystems A and B with total energy $U = U^A + U^B$ fixed. The total entropy is:

$$S\_tot = S^A(U^A) + S^B(U - U^A)$$

Maximising over the internal energy partition:

$$\partial S\_tot/\partial U^A = 0 \implies \partial S^A/\partial U^A = \partial S^B/\partial U^B$$

Thus:

$$T^A = T^B$$

Equilibrium is the macrostate of maximum closure entropy consistent with conserved constraints. All standard equilibrium conditions (mechanical, chemical, thermal) follow by analogous arguments applied to other conserved quantities.

8.2 Stability

Thermodynamic stability requires that the entropy maximum at equilibrium be a global maximum, not merely a local one. We verify this as follows. The partition function $Z(\beta) = \sum_i e^{-\beta E_i}$ is a sum of exponentials and is therefore log-convex in β. Log-convexity of Z implies that the mean energy $U(\beta) = -\partial \ln Z/\partial \beta$ is a monotonically decreasing function of β, which in turn implies that $S(U)$ is a concave function of U: adding energy always increases entropy, but at a diminishing rate. Concavity of $S(U)$ guarantees that the equilibrium condition $\partial S^A/\partial U^A = \partial S^B/\partial U^B$ has a unique solution, and that any perturbation away from equal temperatures drives the system back toward equilibrium. This confirms the equilibrium is globally stable within the canonical ensemble. The non-equilibrium case — where active commitment events are occurring — is handled by Section 7: the second law ($dS/dt \geq 0$) guarantees monotonic evolution toward higher-entropy accessible states, making equilibrium the natural endpoint when no additional constraints prevent relaxation. Equilibrium stability and the second law are therefore two faces of the same underlying closure structure.

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9. Free Energies and Thermodynamic Potentials

The standard thermodynamic potentials arise naturally through Legendre transforms of U(S, V, N, …):

Helmholtz free energy (replacing S with T as independent variable):

$$F = U - TS$$

VERSF interpretation: The free energy is the energy available for reversible work after accounting for the entropy cost of the prevailing closure record structure. At fixed temperature, spontaneous processes minimise F, corresponding to maximising closure entropy at the imposed temperature.

Gibbs free energy (replacing both S and V):

$$G = U + PV - TS = F + PV$$

Enthalpy:

$$H = U + PV$$

All standard Maxwell relations follow from the exactness of the differentials, which is guaranteed by the macrostate geometry established in Section 6.

10. Discussion

10.1 Relation to Existing Derivations

The present approach shares features with, but is distinct from, three major prior programs:

Jaynes (MaxEnt). Like Jaynes [1], we derive the canonical distribution from entropy maximisation under constraints. Unlike Jaynes, we do not treat entropy as a measure of subjective uncertainty. The entropy functional is derived from objective constraints on closure-compatible probability assignments (Section 4), not from epistemic principles.

Lieb–Yngvason. Lieb and Yngvason [2] derive entropy as the unique function encoding the adiabatic accessibility relation. The VERSF approach is complementary: we derive entropy from the microscopic structure of distinguishability rather than from macroscopic order relations. The two approaches may be shown to be consistent [future work].

Landauer–Bennett. Landauer's principle [5] connects logical irreversibility to entropy production. The VERSF commitment event is a precise microscopic realisation of a logically irreversible operation, with $\Delta S\_min = k\_B \ln 2$ recovering Landauer's bound as a fundamental minimum rather than an engineering constraint.

10.2 What Has Been Achieved

We have shown:

1. Admissibility constraints on physical records uniquely determine the coarse-graining structure, removing the microstate-counting ambiguity.
2. The Gibbs–Shannon entropy functional follows from closure admissibility, not from information-theoretic import.
3. The canonical distribution is derived from closure-compatible entropy maximisation.
4. Within the macrostate geometry induced by closure-compatible thermodynamic variables, the first law appears as a differential identity rather than as an independent empirical axiom.
5. The second law is a structural consequence of the non-cancellation of commitment increments—a logical, not statistical, result.

10.3 Conceptual Unification

The VERSF framework proposes the following correspondences between previously distinct concepts. Those marked † are established within this paper; those marked ‡ are argued here and developed more fully in companion work.

Phenomenon	VERSF basis	Status
Quantum measurement	Commitment event	‡
Entropy	Closure multiplicity	†
Arrow of time	Accumulation of irreversible records	†
Temperature	Lagrange multiplier on closure energy constraint	†
Thermodynamics	Coarse-grained closure dynamics	†

10.4 Open Questions and Future Directions

Several important questions remain:

- **Experimental predictions.** The minimal increment $\Delta S\_min = k\_B \ln 2$ per commitment event yields the following testable predictions. First, each idealised binary irreversible measurement record coupled to a thermal reservoir at temperature T must incur a minimum thermodynamic cost bounded below by $Q\_min = k\_B T \ln 2$; observed violations below this level would challenge the framework. Second, in single-bit measurement or erasure protocols, the entropy increment per irreversible binary commitment remains bounded below by $k\_B \ln 2$ regardless of temperature, setting a discrete entropy floor per binary irreversible event that persists even as thermal noise is suppressed. Third, quantum erasure experiments [11] that attempt to restore coherence after a measurement should show that the entropy reduction in the system is always accompanied by an equal or greater entropy increment in the erasure apparatus, with the minimum cost per erased bit equal to $k\_B \ln 2$. These first three predictions are consistent with Landauer's bound — experimentally confirmed in classical bit erasure [12] — now derived as a structural floor rather than an operational estimate.

  A fourth prediction concerns the granularity of entropy production at the single-event level. Standard quantum trajectory theory already predicts discrete jumps in the quantum *state* under monitored evolution. The VERSF-specific claim is different: it concerns entropy production rather than state updates. Specifically, VERSF predicts that the thermodynamic entropy increment associated with each irreversible record-forming event is bounded below by exactly $k\_B \ln 2$ per idealised binary commitment, independently of measurement strength. In the weak-measurement limit, standard quantum trajectory theory allows entropy production to scale continuously with measurement strength toward zero; VERSF imposes a structural floor that does not vanish in this limit for any genuinely irreversible commitment. In ensemble-averaged descriptions this granularity may be smoothed out, but in single-trajectory measurements — now accessible in superconducting qubit experiments [13] — it may appear as stepwise entropy updates with a non-vanishing minimum step. Whether this floor is operationally distinguishable from the standard continuous-limit prediction for weak measurements requires further theoretical and experimental analysis beyond the scope of this paper.

- **Curved spacetime extension.** The current derivation assumes flat closure geometry. Extension to curved spacetime, where closure classes may not form a simple partition, requires generalisation of the admissibility conditions.

- **Multi-system entanglement thermodynamics.** Entangled systems have joint closure records that cannot be decomposed into independent subsystem records. A full treatment of entanglement entropy in this framework is deferred to future work.
- **Consistency with Lieb–Yngvason axioms.** Establishing a formal correspondence between the adiabatic accessibility relation and closure-compatible transitions would strengthen the foundation of the framework.

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11. Conclusion

We have derived thermodynamics from the structure of irreversible commitment acting on closure-defined distinguishability space, without importing any empirical postulates from thermodynamics itself.

The key results are:

1. Admissibility constraints uniquely determine the coarse-graining map and hence the entropy.
2. The entropy functional has the Gibbs–Shannon form, derived from closure constraints.
3. The first law is the differential geometry of macrostate space.
4. The second law holds strictly—not probabilistically—because commitment increments cannot cancel.

This supports a deeper structural principle:

Thermodynamics is the macroscopic manifestation of irreversible fact production.

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