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TIME-GEL THEORY:

A Field-Like Framework for Temporal Flow, Information Density, and Causal Persistence

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Epistemic status. Theoretical and phenomenological framework under development. No experimental validation of the Time-Gel framework is claimed.

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Abstract

Time-Gel is a phenomenological framework that investigates whether temporal behavior can be described not only through an external time coordinate, but also through local, state-dependent properties of a physical system. It is organized around three conceptual components: information density, temporal flow, and structural crystallization. Their relation is conceptual, Time $\sim$ Information Density + Flow + Crystallization, and is not a dimensional equation.

A local-flow relation $d\tau_{TG} = T(\rho_I, \Phi)\, dt$ is introduced, in which t is a reference coordinate time, τ_{TG} a local Time-Gel temporal parameter, ρ_I a proposed information-density variable, Φ an effective potential, and T a dimensionless modulation function. One candidate form of T is analysed, including its limiting behavior and a dimensional audit. A phenomenological causal-memory field $C(\mathbf{x}, t)$ is introduced with an unspecified production function Γ, and structural crystallization is treated as a process distinct from both temporal-rate modulation and causal-memory accumulation.

The variables ρ_I, C and Γ currently have no operational definitions; the manuscript states what such definitions must provide and formulates a narrow falsifiability criterion. It does not claim an established physical law, a complete spacetime theory, or experimental validation.

Keywords: time; temporal flow; information density; causal memory; crystallization; phenomenological framework; Time-Gel

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1. Introduction

In many formulations, time enters physical theory as an independent coordinate or parameter with respect to which systems evolve. In relativity, measured time depends on the physical and geometrical conditions of the system. In thermodynamics, temporal direction is associated with irreversible processes. Time is therefore not simply an inert label attached to events.

Time-Gel starts from a specific question:

> **Can temporal behavior be represented as a local, state-dependent property of a physical system?**

The question does not require abandoning the conventional time coordinate. It asks whether a second layer of description can be introduced in which properties of a system influence the effective rate at which temporal processes are expressed. The conceptual starting point is

$$\text{Time} \sim \text{Information Density} + \text{Flow} + \text{Crystallization}. \tag{1}$$

The symbol $\sim$ denotes a proposed conceptual relation among three classes of phenomena. Relation (1) is not a dimensional equation, and time is not computed by adding three quantities.

1.1 Organization

Section 2 fixes scope and terminology, and Section 3 lists all symbols with their current status. Section 4 presents the core framework, including the operational status of information density. Section 5 analyses a candidate flow law, its limits and its dimensions. Sections 6–9 treat causal memory, crystallization and the resulting structure. Sections 10–13 state claims, non-claims, the observer concept, compatibility requirements and falsifiability. Sections 14–16 give open problems, conclusion and the literature required for a future revision.

2. Scope, Epistemic Status and Terminology

Time-Gel is a *phenomenological framework under development.* Three levels are distinguished.

Conceptual level. Temporal organization may be related to information density, information flow, interaction, persistence of causal traces, and structural stabilization. This level defines the questions of the framework.

Phenomenological level. Mathematical variables and candidate relations represent these concepts without claiming a microscopic origin. Equation (3) below is such a relation. It is not a derivation of time from information theory and does not replace the spacetime metric of general relativity.

Experimental level. The framework is open at this level. Quantities such as ρ_I, J_I, σ_I and C require operational definitions, units, measurement procedures and independent reproducible tests before the associated equations can be treated as quantitative physical statements.

A mathematical representation is not automatically an experimentally established physical quantity. Throughout, the following terms are used in a fixed sense:

$$\text{framework} \neq \text{model} \neq \text{physical law} \neq \text{experimental validation}. \tag{2}$$

Framework denotes the set of concepts and variables; a *candidate model* (or *candidate flow law*) is a specific mathematical realization; a *physical law* requires empirical support; *experimental validation* requires reproducible comparison with data and null models. At present only the first two levels apply.

3. Notation and Status of Variables

Table 1 lists every symbol. "Not yet operationally defined" means that no measurement procedure is given in this manuscript; no units are assigned where none can be justified.

Table 1: Notation, status, dimensional status and operational status.

Symbol	Meaning	Status	Units / dimensional status	Operational status
t	Reference coordinate time	Reference parameter	Time	Depends on chosen reference clock/frame (to be specified)
τ_{TG}	Local Time-Gel temporal parameter	Proposed variable	Time (same as t)	Not yet operationally defined
ρ_I	Local information-density variable	Proposed model variable	Not yet established	Not yet operationally defined
ρ_{crit}	Critical scale of ρ_I	Free parameter of candidate model	Same as ρ_I	Not yet operationally defined
Φ	Effective potential	Proposed; identification open	Open; must make $\beta\Phi/c^2$ dimensionless	Not yet specified
β	Effective coupling coefficient	Free parameter of candidate model	Fixed by requirement that $\beta\Phi/c^2$ be dimensionless (Sec. 5.4)	Not yet constrained
c	Speed of light	Conventional constant	Length/time	Established
T	Temporal-flow modulation function	Proposed function	Dimensionless	Functional form open
J_I	Information flux	Proposed variable	Tied to ρ_I (open)	Not yet operationally defined
σ_I	Information source term	Proposed variable	Tied to ρ_I (open)	Not yet operationally defined
I	Interaction intensity	Proposed variable	Open	Not yet operationally defined
C	Causal-memory field	Phenomenological representation	Open	Not yet operationally defined
J_C	Causal-memory flux	Proposed variable	$[C]\cdot$length/time, if C is a density (Sec. 5.4)	Not yet operationally defined
Γ	Causal-memory production function	Unspecified	$[C]$/time (follows from Eq. (8))	Unspecified
K	Crystallization threshold indicator	Indicator only	Dimensionless (0 or 1)	Inherits status of ρ_I
S_t, O_t, ι_t	System state, observer interaction, incoming information	Abstract modeling quantities	Unspecified	Not yet operationally defined
F	Update map	Unspecified	Unspecified	Unspecified

4. The Core Time-Gel Framework

4.1 Information Density

Let $\rho_I(\mathbf{x}, t)$ denote a proposed local information-density variable. It does not yet refer to one uniquely defined physical quantity; it stands for the density of relevant informational structure associated with a system, region or state.

4.2 Operational Status of Information Density

ρ_I is currently a *model variable*, not an experimentally established physical observable. This manuscript does not propose a final definition. Consequently, every prediction involving ρ_I is conditional on the definition eventually chosen. A future version must specify:

1. the definition of ρ_I;
2. its units or dimensions;
3. the measurement procedure;
4. the uncertainty;
5. the spatial and temporal resolution;
6. its relationship to independently measurable quantities;
7. its domain of validity.

None of these items is regarded as solved here.

4.3 Temporal Flow

The local temporal parameter is related to the reference time by

$$d\tau_{TG} = T(\rho_I, \Phi)\, dt, \qquad \text{equivalently} \qquad \frac{d\tau_{TG}}{dt} = T(\rho_I, \Phi), \tag{3}$$

where T is a dimensionless modulation function. For $T = 1$ the parameter τ_{TG} advances at the reference rate; for $T < 1$ its local rate is reduced relative to t. Equation (3) expresses the possibility that temporal rate contains a component depending on local system conditions. The form of T is not fixed by the framework.

5. A Candidate Flow Law

5.1 Statement

One candidate realization of T is

$$\frac{d\tau_{TG}}{dt} = \frac{\sqrt{\max\left(0,\ 1 - \dfrac{\rho_I}{\rho_{\text{crit}}}\right)}}{1 + \beta\Phi/c^2}, \tag{4}$$

restricted to regions where $1 + \beta\Phi/c^2 > 0$. Here ρ_{crit} is a proposed critical scale of ρ_I, β an effective coupling coefficient, and c the conventional speed of light. Equation (4) is a candidate phenomenological model. It is not a complete spacetime metric and not a derivation from general relativity.

5.2 Interpretation and Status of the Candidate Flow Law

- $\rho_I/\rho_{\text{crit}}$ is a dimensionless ratio, provided ρ_I and ρ_{crit} are defined by the same operational procedure (Section 4.2).
- The square-root structure is a modeling choice, not a derived law. It is one of several possible monotonic forms that vanish at ρ_{crit}.
- The $\max(0, \cdot)$ operation imposes the intended domain restriction of the candidate model: the rate is non-negative and is set to zero for $\rho_I \geq \rho_{\text{crit}}$. It is not a physical result.
- $\beta\Phi/c^2$ must be dimensionless. This fixes the dimensions of β once Φ is specified (Section 5.4).
- The denominator must remain positive and non-zero.

The functional form is a candidate ansatz. Its adequacy must be determined by derivation, comparison with alternative parameterizations, or experiment. The framework does not require this form uniquely.

5.3 Limiting Behavior

The following limits follow directly from Eq. (4) and from no other assumption.

(A) Low information density, $\rho_I \to 0$. The numerator tends to 1 and

$$\frac{d\tau_{TG}}{dt} \;\to\; \frac{1}{1 + \beta\Phi/c^2}. \tag{5}$$

This equals 1 only if $\Phi = 0$ or $\beta = 0$.

(B) Critical density, $\rho_I \to \rho_{\text{crit}}^-$. Writing $\epsilon = 1 - \rho_I/\rho_{\text{crit}}$, the numerator behaves as $\sqrt{\epsilon}$, so $d\tau_{TG}/dt \to 0$ continuously, with a slope that diverges at ρ_{crit}; the rate is identically zero for $\rho_I \geq \rho_{\text{crit}}$. In the model this means that τ_{TG} ceases to advance relative to t. It does not follow that a permanent record, a phase transition or a new state is formed (Section 6).

(C) Weak potential, $\Phi \to 0$. The model reduces to

$$\frac{d\tau_{TG}}{dt} = \sqrt{\max(0,\, 1 - \rho_I/\rho_{\text{crit}})}. \tag{6}$$

For small $\beta\Phi/c^2$, Eq. (5) gives $d\tau_{TG}/dt \approx 1 - \beta\Phi/c^2$.

(D) Recovery of ordinary temporal behavior. The model gives $d\tau_{TG}/dt = 1$ if and only if both $\rho_I/\rho_{\text{crit}} = 0$ (for $\rho_I \geq 0$) and $\beta\Phi/c^2 = 0$. Setting $\beta = 0$ alone does *not* recover $d\tau_{TG}/dt = 1$, since the ρ_I-dependent numerator remains. A rigorous recovery condition therefore requires $\rho_I/\rho_{\text{crit}} \to 0$ in addition to negligible $\beta\Phi/c^2$. Whether this condition is compatible with measured temporal behavior has not been established and is a required future constraint.

Remark on the weak-field comparison. If Φ were identified with the Newtonian gravitational potential (negative near masses), the standard weak-field result of general relativity is $d\tau/dt \approx 1+\Phi/c^2$. At $\rho_I = 0$, Eq. (5) gives $\approx 1-\beta\Phi/c^2$; first-order agreement would then require $\beta \approx -1$. The sign and magnitude of β are not fixed by the framework, and this identification of Φ is not assumed here. The comparison illustrates a compatibility constraint that any version of the candidate model must satisfy if Φ is gravitational.

5.4 Dimensional Audit

Only dimensions that are stated or follow from the equations are used; where a variable is undefined, the issue is marked open.

- **Eq.** (3)**.** τ_{TG} and t both have dimensions of time, so $d\tau_{TG}/dt$ and T are dimensionless. *Consistent.*
- $\rho_I/\rho_{\text{crit}}$**.** Dimensionless if ρ_I and ρ_{crit} share one definition and units. The units themselves are *open.*
- $\beta\Phi/c^2$**.** c^2 has dimensions (length/time)^2. If Φ is a potential per unit mass (energy per mass, dimension (length/time)^2), then Φ/c^2 is dimensionless and β is dimensionless. If Φ is defined otherwise, β must carry the compensating dimensions. Since Φ is not yet specified, the dimension of β is *open*, constrained by the requirement of a dimensionless ratio.
- **Eq.** (4)**.** Dimensionless on both sides given the two items above. *Consistent, conditional on the definitions of ρ_I, Φ and β.*
- **Eq.** (8) **(local causal memory).** $[\Gamma] = [C]/\text{time}$. Since $[C]$ is undefined, the absolute dimension of Γ is *open*; only the relation is fixed.
- **Eq.** (9) **(transport form).** Consistency requires $[J_C] = [C] \cdot \text{length/time}$ if C is a density in three-dimensional space, and the same $[\Gamma]$ as above. *Consistent conditional on C being a density.* Whether Γ represents net production (sources minus sinks) is *open.*

6. Three Distinct Processes

A central structural principle of the framework is the separation

$$\text{temporal-flow modulation} \neq \text{causal-memory accumulation} \neq \text{structural crystallization.} \quad (7)$$

The limit $d\tau_{TG}/dt \to 0$ in Eq. (4) is a statement about the proposed rate only. It does not demonstrate that the past becomes permanent, that information becomes a physical record, that a phase transition occurs, or that a new physical state is created. These three processes are treated as separate unless a future theory demonstrates a relation among them.

7. Causal Memory

The framework introduces a second variable $C(\mathbf{x}, t)$, a phenomenological representation of *causal persistence*: the possibility that interactions and information flows leave traces that influence

subsequent evolution. It is not an experimentally established field. Its general evolution is written

$$\frac{\partial C}{\partial t} = \Gamma(\rho_I, J_I, \sigma_I, I, C), \tag{8}$$

where ρ_I is information density, J_I information flux, σ_I an information source term, I interaction intensity, C accumulated causal memory, and Γ the causal-memory production function. Γ is unspecified, and no microscopic mechanism by which information becomes persistent causal structure is proposed; this is an open theoretical problem.

If causal memory is spatially transported, Eq. (8) extends to

$$\frac{\partial C}{\partial t} + \nabla \cdot J_C = \Gamma(\rho_I, J_I, \sigma_I, I, C), \tag{9}$$

with causal-memory flux J_C. Three quantities are conceptually distinct: the information flux J_I, the causal-memory flux J_C, and the accumulated memory C. The framework does not assume $J_C = J_I$, nor that they differ. A future theory must define the coupling or conversion relations among them.

8. Structural Crystallization

A threshold indicator is defined by

$$K(\mathbf{x}, t) = H(\rho_I(\mathbf{x}, t) - \rho_{\text{crit}}), \tag{10}$$

where H is the Heaviside function, so that $K = 0$ for $\rho_I < \rho_{\text{crit}}$ and $K = 1$ for $\rho_I > \rho_{\text{crit}}$. The value at $\rho_I = \rho_{\text{crit}}$ is a convention to be fixed; $K = 1$ is adopted there for definiteness. K is an *indicator only*: it does not establish that crystallization has occurred and does not demonstrate a physical phase transition. A crystallization model requires an explicit dynamical transition law describing how a system moves from a transient state toward a persistent structure:

$$\text{threshold} \neq \text{transition} \neq \text{persistent structure}. \tag{11}$$

This law is an open theoretical problem.

9. Unified Structure

The current architecture consists of three pathways,

$$\rho_I \longrightarrow T(\rho_I, \Phi) \longrightarrow \tau_{TG}, \tag{12}$$

$$(\rho_I, J_I, \sigma_I, I, C) \longrightarrow \Gamma \longrightarrow C, \tag{13}$$

$$(\rho_I, C, K) \longrightarrow \text{crystallization (law not specified)}. \tag{14}$$

The framework does not require these pathways to be identical. Its central proposition is that they may be coupled manifestations of a common temporal organization of physical systems. The form of any such coupling is undetermined.

10. Claims and Non-Claims

10.1 What Time-Gel Claims

1. Temporal behavior may be usefully investigated as a local, state-dependent phenomenon in addition to an external parameter.
2. Information density is a candidate state variable for modulating temporal flow.
3. Interactions may generate persistent causal traces representable by a memory variable.
4. Temporal-flow modulation, causal persistence and structural crystallization are distinct processes unless shown otherwise.
5. These propositions become testable hypotheses only after the relevant variables are operationally defined.

10.2 What Time-Gel Does Not Claim

The present formulation does not establish, and makes no claim, that Time-Gel:

- is an experimentally validated theory of time;
- replaces general relativity or quantum field theory;
- provides a complete theory of spacetime or a complete cosmology;
- explains dark matter or dark energy;
- explains the origin of the universe;
- explains consciousness;
- identifies the quantum vacuum with a physical time-medium;
- derives gravity from information density.

Earlier material associated with Time-Gel contained broader cosmological questions. They are not carried into this version as results.

11. The Observer

The phrase "The Observer Is Inside" is retained as a research concept with a restricted meaning: an observer interacting with a system is part of the system's experimental conditions and can change the information available to it, and hence its subsequent states. This is expressed as an interactional update,

$$S_{t+1} = F(S_t, O_t, \iota_t), \tag{15}$$

where S_t is the observable system state, O_t the observer interaction and ι_t the incoming information. The map F is unspecified. Equation (15) is a modeling concept. It does not

introduce consciousness as a physical field, does not state that observation creates reality, and does not rely on quantum-mechanical observer claims.

12. Relation to Established Physics

Time-Gel is a phenomenological framework. It is not presented as a replacement for general relativity, quantum field theory, or standard cosmology; its compatibility with them, and any deviations from them, remain to be tested.

12.1 Compatibility Requirements

Any specific Time-Gel model must answer the following; none is claimed to be satisfied at present.

1. Does it recover an appropriate conventional limit? (For Eq. (4), see limit (D) and the weak-field remark.)
2. Does it preserve dimensional consistency under definite choices of ρ_I, Φ and C?
3. Does it respect established conservation principles?
4. Does it introduce frame dependence?
5. Does it predict a measurable deviation from existing models?
6. Under what conditions would the absence or contradiction of that deviation falsify the model?

13. Falsifiability and Experimental Development

The framework is scientifically useful only if it yields observations that can distinguish it from competing descriptions. The required progression is

$$\text{Concept} \rightarrow \text{Definition} \rightarrow \text{Equation} \rightarrow \text{Prediction} \rightarrow \text{Measurement} \rightarrow \text{Falsification}. \tag{16}$$

The first experimental target should be narrow, not "to prove Time-Gel":

> **Does a defined physical system exhibit a reproducible temporal residual that correlates with an independently measured state variable according to a specified Time-Gel model?**

Three requirements follow. Correlation is not causation. A good model fit is not theory validation. A test must compare the specified Time-Gel model against appropriate competing and null models, with the measurement procedure, uncertainty and rejection criterion stated before the data are analysed.

14. Open Problems

- Operational definition, units and measurement of ρ_I, J_I, σ_I, I, C and J_C (Section 4.2).
- Physical identity of Φ and the dimensions, sign and magnitude of β.

- Justification or replacement of the candidate form in Eq. (4); comparison with alternative $T(\rho_I, \Phi)$.
- Value and measurability of ρ_{crit}; rigorous recovery condition (limit (D)).
- Specification of Γ, and of the couplings among J_I, J_C and C.
- Dynamical transition law for structural crystallization.
- Compatibility analysis with relativistic limits, conservation principles and frame dependence.
- Specific, measurable prediction and null model for a defined experimental system.

15. Conclusion

Time-Gel asks whether temporal behavior is entirely independent of the informational and causal state of the system in which it occurs. This manuscript organizes that question into three distinct components: information density, temporal flow and causal persistence, with structural crystallization as a possible transition from transient to persistent organization. It provides a candidate flow law with analysed limits, a dimensional audit, a phenomenological causal-memory equation, and a falsifiability criterion. The conceptual relation Time $\sim$ Information Density + Flow + Crystallization is an organizing hypothesis, not a literal equation.

Several questions are left open by design. The next steps are definitional and mathematical: operational definitions, a justified or revised flow law, and a specific testable prediction. No experimental validation is claimed.

16. Literature Required for Future Revision

This manuscript cites no external sources and no bibliographic entries are given. A future revision requires literature support in the following areas:

- relativistic time and proper time, including weak-field time dilation;
- operational definitions of time;
- information theory and physical information;
- causal memory and memory effects in dynamical systems;
- nonequilibrium thermodynamics and irreversibility;
- phenomenological field models and effective descriptions;
- experimental time and frequency metrology.

Declarations

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Version History

v1.1 (October 2026). Added operational status of ρ_I, analysis of the candidate flow law (limits, dimensional audit), extended notation table, compatibility requirements, open-problems and literature sections; removed repeated epistemic statements. **v1.0.** Initial framework manuscript.