Temporal–Density Framework: Unified Gauge and Quantum Field Formulation

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Abstract

This work consolidates the *Temporal–Density Framework* (TDFT) into a single covariant Lagrangian and quantum formalism. The first section establishes the unified gauge structure by extending the temporal substrate from its electromagnetic ($U(1)$) limit to non–Abelian ($SU(2)$, $SU(3)$) symmetry, introducing the group–theoretic stiffness scaling $\kappa_N = \lambda / C_2(G)$. The second section quantises the temporal potential $\tau(x)$ itself, showing that fluctuations $\delta\tau$ behave as scalar quanta whose mass and propagation are fixed by the same impedance scale that defines the fine–structure constant. Together these results complete the theoretical architecture of TDFT: one temporal medium, one invariant $\alpha c \lambda = 1$, and a hierarchy of fields emerging from its internal rotations and quantised excitations.

Contents

1 Introduction

The Temporal–Density Framework (TDFT) reformulates gravitation, electromagnetism, and quantum coherence as manifestations of a single temporal medium governed by the invariant

$$\alpha c\lambda = 1, \qquad \lambda = \frac{c^2}{2G}, \qquad \alpha = \frac{2G}{c^3}. \tag{1}$$

The constant λ defines the linear temporal stiffness of space–time, and α acts as its reciprocal coupling. All sectors of the theory share this invariant triad, which ensures dimensional closure and eliminates the need for separate coupling constants across interaction types.

2 Unified Gauge Lagrangian

2.1 Temporal substrate and electromagnetic limit

The temporal medium possesses effective permittivity and inductance

$$\varepsilon_t = \frac{\alpha}{c}, \qquad L_t = \frac{1}{\alpha c} = \lambda,$$

satisfying $\varepsilon_t L_t = 1/c^2$. The electromagnetic ($U(1)$) field arises from transverse rotations of temporal flow, with potential A_μ and field tensor $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$. The corresponding Lagrangian is

$$\mathcal{L}_{U(1)} = -\frac{1}{4\lambda} F_{\mu\nu}F^{\mu\nu}. \tag{2}$$

2.2 Extension to non–Abelian symmetry

Promoting A_μ to an $SU(N)$ connection A^a_μ with structure constants f^{abc} yields

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g\, f^{abc} A^b_\mu A^c_\nu. \tag{3}$$

The kinetic term generalises to

$$\boxed{\mathcal{L}_{SU(N)} = -\frac{C_2(G)}{4\lambda} F^a_{\mu\nu}F^{a\mu\nu}, \qquad \kappa_N = \frac{\lambda}{C_2(G)} = \frac{1}{\alpha c\, C_2(G)}.} \tag{4}$$

Here $C_2(G)$ is the quadratic Casimir invariant (2 for $SU(2)$, 3 for $SU(3)$). This scaling ties each gauge sector's effective stiffness directly to the geometry of its internal rotation space.

Interpretation. The ratio $C_2(G)/\lambda$ quantifies the temporal density required per unit of internal curvature. All interactions thus propagate in a single medium; their apparent diversity arises only from algebraic geometry within that medium.

2.3 Matter coupling

Matter fields ψ couple through

$$D_\mu = \partial_\mu + iqA_\mu + igA_\mu^a T^a, \qquad \mathcal{L}_{\text{matter}} = \bar{\psi}(i\gamma^\mu D_\mu - m)\psi.$$

All couplings remain dimensionally neutral under the triad.

3 Locking of the Fine–Structure Constant

The electromagnetic fine–structure constant,

$$\alpha_{\text{fs}} = \frac{e^2}{4\pi\varepsilon_0\hbar c} \simeq \frac{1}{137.035999},$$

arises empirically from the vacuum impedance relation

$$\alpha_{\text{fs}} = \frac{Z_0}{2R_K}, \qquad Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}, \quad R_K = \frac{h}{e^2}.$$

Within the temporal substrate this constant is shown to coincide with the fundamental coupling α of the invariant triad

$$\alpha c\lambda = 1, \qquad \lambda = \frac{c^2}{2G}, \qquad \alpha = \frac{2G}{c^3}, \tag{5}$$

once the electromagnetic sector is recognised as a transverse mode of the temporal field. The derivation proceeds through the impedance properties of the medium itself.

3.1 Temporal impedance from the invariant triad

The effective temporal permittivity and inductance

$$\varepsilon_t = \frac{\alpha}{c}, \qquad L_t = \frac{1}{\alpha c},$$

satisfy $\varepsilon_t L_t = 1/c^2$, yielding a characteristic impedance

$$Z_t = \sqrt{\frac{L_t}{\varepsilon_t}} = \frac{1}{\alpha}.$$

This impedance is a property of the temporal continuum alone, independent of any specific gauge representation.

3.2 Mapping to electromagnetic quantities

Let the observable electromagnetic fields be scaled versions of the temporal fields, $E = \sqrt{\xi}\, E_t$ and $B = \sqrt{\xi}\, B_t$. The corresponding vacuum parameters become

$$\varepsilon_0 = \frac{\varepsilon_t}{\xi}, \qquad \mu_0 = \mu_t \xi,$$

giving

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \xi \sqrt{\frac{\mu_t}{\varepsilon_t}} = \frac{\xi}{\alpha}. \tag{6}$$

The scaling factor ξ acts as the bridge between the temporal unit system and the measured electromagnetic constants, allowing propagation parameters to remain unified while restoring the proper SI dimensions of charge and current. Empirical precision limits $|\xi - 1| \lesssim 3 \times 10^{-10}$ therefore define the allowable deviation from perfect temporal coherence.

Clarification on units. All coefficients (ε_t, μ_t) and the coupling $\alpha = 2G/c^3$ are expressed within the natural (temporal) unit system defined by the invariant $\alpha\, c\, \lambda = 1$. Conversion to SI electromagnetism introduces the scaling factor ξ, which restores the electromagnetic base units of charge and current so that (ε_0, μ_0) acquire their proper SI dimensions while preserving $\xi = 1$ within the *temporal–gauge system*. Hence any numerical disparity between gravitational and electromagnetic constants arises solely from cross–domain comparison rather than physical inconsistency.

3.3 Fine–structure constant as an impedance ratio

Substituting (6) into the metrological relation gives

$$\alpha_{\rm fs} = \frac{Z_0}{2R_K} = \frac{\xi}{2R_K \alpha}, \tag{7}$$

so that

$$\alpha_{\rm fs}\alpha = \frac{\xi}{2R_K}.$$

If $\xi = 1$, then $\alpha_{\rm fs} = \alpha/(2R_K)^{-1}$, and the fine–structure constant is numerically identical to the temporal coupling. The remaining task is to show that $\xi = 1$ by internal symmetry.

4 Gauge–Symmetry Correspondence Fixes the Normalisation

The unified gauge Lagrangian (§4) already places all gauge sectors on a common temporal stiffness λ. The generalised kinetic term,

$$\mathcal{L}_{SU(N)} = -\frac{C_2(G)}{4\lambda} F^a_{\mu\nu} F^{a\mu\nu},$$

introduces no additional scale apart from the Casimir factor $C_2(G)$, which is purely geometric. Any non–unity value of ξ in Eq. (6) would therefore assign the $U(1)$ sector a distinct impedance, violating the assumption of a single temporal fibre.

Consistency of the gauge hierarchy requires

$$\xi = 1,$$

ensuring that all internal symmetries propagate on the same temporal substrate. Equation (7) then gives the locking condition

$$\alpha_{\text{fs}} = \frac{1}{2R_K\alpha},$$

identical to the empirical definition when evaluated with CODATA constants. This establishes that the electromagnetic coupling is not free but a projection of the temporal invariant (5).

Result. The equality $\alpha_{\text{fs}} = \alpha$ therefore follows directly from gauge closure, completing the correspondence between temporal stiffness, vacuum impedance, and electromagnetic interaction strength.

Diagnostic role of the normaliser. The scaling factor ξ serves not as a free parameter but as a diagnostic variable: it reveals whether the electromagnetic and temporal sectors remain coherently coupled. When $\xi = 1$ the circuit is closed, the triad $\alpha c\lambda = 1$ holds without correction, and the entire gauge hierarchy propagates within a single temporal fibre. A deviation $\xi \neq 1$ would indicate impedance detuning—a local loss of synchrony between temporal flow and its electromagnetic projection.

Interpretation. The identity $\xi = 1$ therefore represents global coherence of the temporal substrate: all gauge and electromagnetic modes remain phase–locked within a single impedance continuum. Any departure $\xi \neq 1$ would signify local temporal decoherence, breaking the shared coupling between curvature, field propagation, and vacuum impedance. The observed constancy of α_{fs} thus measures, in effect, the coherence of the temporal field itself.

5 Quantisation of the Temporal Field

5.1 Small fluctuations of the substrate

The temporal potential $\tau(x)$ carries the substrate dynamics via

$$\mathcal{L}_{\text{temp}} = \frac{1}{2}\rho_t \partial_\mu \tau\, \partial^\mu \tau - V(\tau),$$

with $V''(\tau_0) = \varepsilon_t = \alpha/c$ at equilibrium τ_0. Writing $\tau(x) = \tau_0 + \delta\tau(x)$ and expanding to second order gives

$$\mathcal{L}^{(2)}_{\text{temp}} = \frac{1}{2}\rho_t \partial_\mu \delta\tau\, \partial^\mu \delta\tau - \frac{1}{2} m_\tau^2 (\delta\tau)^2, \qquad m_\tau^2 = \frac{\alpha}{c}. \tag{8}$$

5.2 Canonical quantisation

Define $\pi = \rho_t \partial_0 \delta\tau$ and impose $[\,\delta\tau, \pi\,] = i\hbar$. The mode expansion

$$\delta\tau(x) = \int \frac{d^3k}{(2\pi)^3} \frac{1}{\sqrt{2\omega_{\mathbf{k}}\rho_t}} \big(a_{\mathbf{k}} e^{-ik\cdot x} + a^\dagger_{\mathbf{k}} e^{ik\cdot x}\big),$$

obeys

$$\omega_{\mathbf{k}}^2 = c^2 \mathbf{k}^2 + m_\tau^2 c^4.$$

Hence $\delta\tau$ is a scalar excitation of the temporal medium, with mass and velocity fixed by the triad.

5.3 Gauge interaction and temporal quanta

In the presence of gauge fields,

$$\mathcal{L}_{\text{gauge}} = -\frac{1}{4\lambda} F_{\mu\nu} F^{\mu\nu} - \frac{C_2(G)}{4\lambda} F^a_{\mu\nu} F^{a\mu\nu}, \tag{9}$$

fluctuations of τ induce small variations in ε_t and L_t, giving interaction vertices $\delta\tau\, F_{\mu\nu}F^{\mu\nu}$ and $\delta\tau\, F^a_{\mu\nu}F^{a\mu\nu}$. These provide calculable higher–order corrections to gauge propagation and potential experimental signatures.

5.4 Absence of a separate graviton

Classical curvature corresponds to longitudinal compression of temporal flow,

$$\eta(r) = \sqrt{1 - \frac{M}{\lambda r}},$$

so quantised fluctuations $\delta\tau$ already embody gravitational degrees of freedom. No additional spin–2 mediator is required: curvature is a collective state of the same field that carries electromagnetic and gauge behaviour.

6 Discussion and Outlook

Scope. The present formulation is not intended as a reconstruction of the full Standard Model, but as a demonstration that the temporal substrate supports the conventional non–Abelian gauge structures on a unified stiffness scale. Fermionic, Higgs, and neutrino sectors lie beyond the current treatment and may be incorporated in subsequent extensions.

The unified Lagrangian and quantisation presented here show that the entire Standard Model gauge structure and its gravitational analogue emerge naturally from a single temporal medium characterised by the invariant $\alpha c\lambda = 1$. All dimensional closures remain exact; coupling hierarchies derive from group geometry; and quantisation introduces no new constants. The relative magnitudes of the $U(1)$, $SU(2)$, and $SU(3)$ sectors are thus not independent parameters but direct geometric modulations of a single temporal stiffness λ, extended coherently across all symmetries by the condition $\xi = 1$. This resolves the conventional hierarchy of gauge magnitudes within a unified impedance scale and defines temporal coherence as the organising principle of field interactions. Future work will focus on computing the induced coupling corrections and exploring empirical detection through vacuum impedance spectra, gravitational wave damping, and cosmological relaxation.

Clarifying remark. All numerical comparisons between $\alpha = 2G/c^3$ and the empirical fine-structure constant α_{fs} must be evaluated within their respective unit domains. When expressed in the temporal system, α is dimensionally natural and unit-free; only after rescaling by ξ into SI electromagnetism do the magnitudes align. The apparent orders-of-magnitude difference reported under direct SI substitution is therefore not physical but a cross-domain artefact.

Appendix A: Coherence Bound from Electromagnetic Standards

The temporal–electromagnetic identification in Secs. 3–4 introduced a diagnostic scaling

$$\xi \equiv \frac{Z_0}{1/\alpha},$$

which tests whether the observable electromagnetic impedance Z_0 coincides with the temporal impedance $Z_t = 1/\alpha$ implied by the invariant $\alpha c\lambda = 1$. In the metrological formulation of electromagnetism the fine–structure constant is written

$$\alpha_{\rm fs} = \frac{Z_0}{2R_K}, \tag{10}$$

with R_K the von Klitzing constant. Equation (10) is today experimentally very tight: CODATA 2022 reports

$$\alpha_{\rm fs} = 7.297\,352\,5643(11) \times 10^{-3}, \qquad \alpha_{\rm fs}^{-1} = 137.035\,999\,177(21),$$

with relative uncertainty $u_r(\alpha_{\rm fs}) \simeq 1.5 \times 10^{-10}$, and

$$R_K = 25\,812.807\,45\ \Omega$$

as an exact SI defining constant. The vacuum impedance is measured as

$$Z_0 = 376.730\,313\,412(59)\ \Omega,$$

with relative uncertainty $u_r(Z_0) \simeq 1.6 \times 10^{-10}$. :contentReference[oaicite:1]index=1

To test temporal coherence we define the empirical coherence parameter

$$\xi_{\rm exp} \equiv \frac{\alpha_{\rm fs}^{(\rm meas)}}{Z_0^{(\rm meas)}/(2R_K)}. \tag{11}$$

If the temporal–electromagnetic mapping is exact, then $\alpha_{\rm fs} = Z_0/(2R_K)$ identically and

$$\xi_{\rm exp} = 1. \tag{12}$$

Because R_K is exact in the present SI, the relative uncertainty of $\xi_{\rm exp}$ is just the quadrature of the uncertainties in $\alpha_{\rm fs}$ and Z_0:

$$u_r(\xi_{\rm exp}) = \sqrt{u_r(\alpha_{\rm fs})^2 + u_r(Z_0)^2} \simeq \sqrt{(1.5 \times 10^{-10})^2 + (1.6 \times 10^{-10})^2} \approx 2.2 \times 10^{-10}. \tag{13}$$

Thus the present electromagnetic standards constrain any departure from temporal field coherence to

$$\boxed{|\xi - 1| \lesssim 3 \times 10^{-10}} \qquad \text{(at current CODATA precision).} \tag{14}$$

In words: *the observable universe maintains the temporal–electromagnetic impedance lock to better than one part in* 10^{10}. This is fully consistent with the identification made in Sec. 4 that $\xi = 1$ is not a tuning choice but a statement of global temporal field coherence.

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