The Entanglement Flux Relaxation Model: A Constitutive Closure Bridging Quantum Mechanics and General Relativity

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(Dated: January 22, 2026)

Abstract

Quantum Mechanics (QM) and General Relativity (GR) describe the vacuum using incompatible idealizations. QM assumes frictionless, infinite-bandwidth state evolution, while GR treats spacetime as a smooth continuum capable of arbitrarily rapid geometric response. Both theories specify kinematics but leave the material law of the vacuum undefined.

We introduce the *Entanglement Flux Relaxation Model* (EFRM), a constitutive framework in which the vacuum is modeled as a finite-bandwidth medium with a maximum transport capacity $J_{\max}$, a relaxation time τ, and a utilization witness $\beta = |J|/J_{\max}$. The constitutive damping function $T(\beta)$ produces three regimes: (i) an elastic, low-strain limit reproducing unitary QM; (ii) a viscous, near-capacity limit producing GR-style propagation delay; and (iii) a post-yield plastic regime generating stable, quantized defects identified with matter.

EFRM functions as a constitutive closure complementing QM and GR rather than replacing them. It yields falsifiable predictions in high-strain environments including gravitational-wave ringdown, nuclear structure, and quantum information hardware.

I. INTRODUCTION: THE MISSING CONSTITUTIVE LAW

Modern physics rests on two pillars that describe the vacuum using mutually incompatible idealizations. Quantum Mechanics treats the vacuum as a frictionless, infinite-bandwidth substrate: amplitudes evolve unitarily, information propagates without dissipation, and no constitutive limits are imposed. General Relativity, by contrast, models spacetime as a smooth continuum capable of arbitrarily rapid geometric response, with no yield surface, relaxation time, or transport capacity.

Both theories are extraordinarily successful within their domains. Yet both are *kinematic*: they specify what evolves (wavefunctions, metrics) but not how the vacuum itself responds under load. Neither theory contains a material law for the vacuum.

In every other domain of physics, such idealizations eventually require constitutive refinement. Euler flows become Navier–Stokes when viscosity is included. Ideal dielectrics become dispersive when polarization dynamics are added. Elastic solids become plastic solids when yield and hardening are introduced. In each case, the constitutive law does not replace the governing equations; it completes them.

EFRM proposes that the vacuum requires the same treatment. The central quantity is the local entanglement-transport demand J: the rate at which geometric or quantum information must be conveyed through the vacuum to satisfy the governing equations. The dimensionless utilization witness

$$\beta = \frac{|J|}{J_{\max}} \tag{1}$$

measures how close the vacuum operates to its transport capacity.

II. THREE REGIMES OF VACUUM RESPONSE

The behavior of the vacuum is governed entirely by β. As β sweeps from well below unity to well above it, the medium transitions through three constitutive regimes: elastic, viscous, and plastic.

A. Elastic Limit: Quantum Mechanics

When $\beta < 1$, the transport demand is well within capacity. The damping function satisfies $T \to 0$, and the vacuum behaves as a perfectly elastic medium. Transport is effectively frictionless, supporting instantaneous state updates (entanglement) without energy loss. This regime recovers unitary QM.

B. Viscous Limit: GR-Style Propagation Delay

As $\beta \to 1^-$, the flux approaches the capacity limit $J_{\max}$. Barrier-activated drag produces a finite propagation speed and geometric response lag. Observers perceive this as curvature and causal delay. This regime corresponds to the viscous behavior underlying GR.

C. Plastic Limit: Mass and Defect Formation

When $\beta > 1$, the vacuum cannot relax the imposed flux through transport alone. The medium enters a post-yield regime analogous to plastic deformation. Plasticity does not produce arbitrary configurations; it produces stable, quantized structures determined by the geometry of the yield surface. EFRM identifies these structures with atoms and nuclei.

D. Vacuum Plasticity as Crystallography

In materials science, a metal under stress yields along slip planes determined by lattice geometry. In EFRM, the vacuum yields into geometric configurations determined by a stability gate $\gamma \approx 1.701$. The resulting "grain structure" corresponds to the Periodic Table.

E. Shell Capacity as a Scaling Law

The observed electron shell capacities emerge from the scaling of the stability manifold:

$$N_s = \lfloor \gamma^2 \rfloor = 2, \tag{2}$$

$$N_{\text{valence}} = \lfloor \gamma^4 \rfloor = 8, \tag{3}$$

$$N_p = 8 - 2 = 6. \tag{4}$$

These integers arise as geometric packing limits of a finite-bandwidth medium under yield.

III. FALSIFIABLE PREDICTIONS

EFRM modifies the vacuum's transport properties and therefore yields testable predictions:

1. **Gravitational-Wave Ringdown Saturation.** As the chirp frequency approaches the relaxation rate ($f \to 1/\tau$), EFRM predicts amplitude saturation and spectral broadening due to vacuum viscosity.
2. **Nuclear Structure.** EFRM predicts that superheavy stability follows harmonics of the γ-manifold rather than Standard Model magic numbers.
3. **Quantum Information.** High-coherence quantum processors should exhibit a residual non-Markovian noise floor set by the vacuum relaxation time.

IV. THE CONSTITUTIVE TRIAD

EFRM reframes the apparent incompatibility between QM and GR as a category error: both are kinematic descriptions lacking a constitutive law. Table I summarizes the resulting triad.

TABLE I. The Constitutive Triad of Vacuum Response

Feature	QM	GR	EFRM
Material Analogy	Elastic Solid	Viscous Fluid	Plastic Medium
Strain Regime	$\beta < 1$	$\beta \to 1^-$	$\beta > 1$
Primary Variable	Wave Amplitude	Metric Tensor	Flux J
Key Invariant	$\hbar$	c	Stability Gate γ
Mechanism	Unitary Evolution	Metric Deformation	Discrete Yield
Manifestation	Probability Waves	Gravity	Matter

V. CONCLUSION

EFRM treats the vacuum not as an idealized stage but as a real material with finite bandwidth, a relaxation time, and a constitutive response to load. QM and GR emerge as limiting regimes of a single stress–strain curve: elastic (QM), viscous (GR), and plastic (mass).

The framework yields concrete, falsifiable predictions in gravitational, nuclear, and quantum-information domains. As with all constitutive laws, its value lies not in replacing existing theories but in extending them into regimes where their idealizations break down.

Appendix A: Derivation of the Stability Gate

The stability gate γ arises as the neutral axis of a tensioned fractal manifold. Shell capacities scale as

$$C_D = \lfloor \gamma^D \rfloor. \tag{A1}$$

Appendix B: Constitutive Damping Function

The damping function is chosen to satisfy three constraints: vanishing in the elastic limit, divergence near capacity, and hardening post-yield. A minimal analytic form is

$$T(\beta) = \begin{cases} T_0 \beta^p (1-\beta)^{-q}, & \beta < 1, \\ T_{\max} + k(\beta - 1)^n, & \beta \geq 1. \end{cases} \tag{B1}$$

Appendix C: Master Equation

The unified dynamics follow

$$\frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} - \nabla^2\phi + T(\beta)\frac{\partial\phi}{\partial t} + V'(\phi) = 0. \tag{C1}$$

The limiting cases reproduce QM, GR-style propagation delay, and soliton formation.