

Quantum Oscillator Lattice: A Unified Origin of Fundamental Constants and Fields

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Abstract. *This paper presents the foundational premises for a unified physical theory in which the vacuum is modeled as an elastic lattice of coupled quantum harmonic oscillators. Rather than aiming to construct a complete unified theory, our goal is to explore the consequences of a set of physically motivated assumptions and to demonstrate their consistency with established theoretical principles and dimensional relations. Within this framework, gravitational, electromagnetic, and thermo-entropic interactions are interpreted as distinct geometric deformation modes of a single symmetric field tensor $\mathcal{G}_{\mu\nu}$, and fundamental constants of nature emerge naturally from the oscillatory dynamics. We show that these assumptions lead to coherent interpretations of field sources (mass, charge, temperature) sharing a common oscillatory origin in spacetime. While non-exhaustive, our treatment lays a physically and mathematically grounded path for future development of a unified field theory anchored in quantum-elastic principles.*

"Entia non sunt multiplicanda praeter necessitatem"

— Ockham's Razor

"Padre, Señor del cielo y de la tierra, te doy gracias porque has ocultado todo esto a los sabios y entendidos y se lo has revelado a los que son como niños."

— Matthew 11:25

I. INTRODUCTION

The quest for a unified theoretical framework capable of describing all fundamental interactions from a common origin remains a central theme in contemporary physics [1]. Despite the tremendous success of the Standard Model of particle physics in unifying electromagnetic, weak and strong forces [2], and of General Relativity (GR) in geometrizing gravity [3, 4], a conceptual schism persists between the quantum field theories (QFTs) of the former and the geometric description of the latter [5]. Moreover, observational puzzles such as dark energy and dark matter [6–8], together with the inability to quantize gravity in a conventional QFT framework [9], underscore the need for a deeper structure underlying both regimes.

Thermodynamic and emergent-gravity approaches have hinted at such a structure. Jacobson's derivation of Einstein's equations from local entropy balance [10], Verlinde's entropic gravity proposal [11], and the striking analogies between black-hole thermodynamics and vacuum fluctuations [12] point toward an intimate link between entropy, quantum vacuum dynamics, and spacetime geometry. Likewise, the shared inverse-square dependence of Newton's law and Coulomb's law suggests that disparate forces may be just different manifestations of a single underlying field.

In this work, we explore the hypothesis that the quantum vacuum itself—spacetime at its most fundamental level—constitutes an active medium whose local excitations give rise to all observed fields and particles. Guided by the empirical fact that both electromagnetic radiation and gravitational waves propagate as oscillatory disturbances [13], and given that harmonic oscillators occurring in a number distinct physical realities are equivalent -in the sense that their mathematical models are identical- [14] we postulate that this unified field must be inherently oscillatory, and that dimensionality of -within human perception-disparate physical sourcing phenomena, such as mass, charge, temperature, etc., collapse into a single dimensionality -spacetime- as the source of this unified field.

As a result, within this framework, conventional distinctions among electromagnetic, gravitational and thermodynamic phenomena dissolve: they emerge as different vibrational, shear or torsional modes of the same quantum harmonic oscillator's lattice. Fundamental constants of nature cease to be arbitrary uncorrelated inputs, and become effective parameters describing the coupling strength or resonant behavior of the vacuum. By mapping vacuum dynamics to mechanical and electrical oscillatory phenomena, we derive novel relations among these constants, and reinterpret physical quantities—mass, charge, temperature—as localized topological excitations in the underlying oscillator network.

An important clarification is that we do not attempt to construct a full and complete unified theory. Rather, we propose and explore a set of physically motivated postulates, and analyze how far these assumptions can go in explaining the emergence of known fields and constants, and in revealing coherent dimensional structures. The aim of this paper is to evaluate the internal consistency, physical plausibility, and predictive coherence of these assumptions—not to deliver a fully quantized or dynamically complete theory. In this sense, the present work should be seen as a conceptual and dimensional groundwork for future unified field models.

Part I: General Framework

II. THE COMMON FIELD AS AN ENSEMBLE OF QUANTUM HARMONIC OSCILLATORS

A. Harmonic Oscillator Equations in Mechanical and Electrical Systems

Consider a damped mass-spring system:

$$m\ddot{x} + b\dot{x} + kx = 0, \quad (1)$$

where m is mass, b is the damping coefficient, and k is the spring constant. The corresponding Lagrangian (neglecting dissipation) is:

$$\mathcal{L}_{\text{mech}} = \frac{1}{2}m\dot{x}^2 - \frac{1}{2}kx^2.$$

On the other hand, in an RLC circuit, let $q(t)$ be the charge on the capacitor:

$$L\ddot{q} + R\dot{q} + \frac{1}{C}q = 0, \quad (2)$$

where L is inductance, R is resistance, and C is capacitance. An equivalent Lagrangian (again omitting dissipation) reads:

$$\mathcal{L}_{\text{elec}} = \frac{1}{2}L\dot{q}^2 - \frac{1}{2C}q^2.$$

In developing a unified field theory rooted in oscillatory dynamics, it becomes essential to identify a consistent dimensional framework that naturally connects mechanical and electrical systems. Classical analogies between mass-spring and RLC oscillators reveal deep structural equivalences among their parameters: mass $m \leftrightarrow L$ (inductance), damping $b \leftrightarrow R$ (resistance), and stiffness $k \leftrightarrow 1/C$ (inverse capacitance). These analogies go beyond formal resemblance—they reflect identical structures governing the system's evolution, and a common underlying substrate.

To reflect this symmetry at the dimensional level, we postulate that such correspondences are not merely mathematical, but encode a deeper physical equivalence. In particular, we adopt as our first fundamental postulate that, within the unified field framework, *mechanical and electromagnetic inertia share the same dimensional character*. That is:

$$[\text{Inductance}] \equiv [\text{Mass}].$$

This equivalence does not imply that mass and inductance are equal in any conventional system, but rather that they play *isomorphic roles* within the elastic vacuum model: both represent resistance to changes in oscillatory motion—mechanical or electromagnetic—and encode the same form of reactive inertia under field excitation. Such a postulate is thus not arbitrary, but a natural requirement of modal unification, guiding the redefinition of all fundamental units from first principles.

Derivation of the Mass-Inductance Equivalence from a Unified Field Lagrangian

While the dimensional equivalence between mass and inductance is introduced as a foundational postulate motivated by physical analogy, it can be formally derived as a necessary consequence of describing all interactions through the single, Lorentz-invariant field tensor $\mathcal{G}_{\mu\nu}$ that we propose in section XIII A.

Let us construct the most general, second-order Lorentz-invariant Lagrangian for the dynamics of the unified field $\mathcal{G}_{\mu\nu}$. The Lagrangian must contain a kinetic term encoding the inertial response of the field and a potential term $V(\mathcal{G}_{\mu\nu})$ encoding its elastic and mass-like properties. The kinetic term takes the form:

$$\mathcal{L}_{\text{kinetic}} = \frac{1}{2}\kappa(\partial^\alpha\mathcal{G}^{\mu\nu})(\partial_\alpha\mathcal{G}_{\mu\nu}) \quad (3)$$

where κ is a single, fundamental constant representing the intrinsic stiffness or inertial resistance of the vacuum substrate. The unity of the field requires a single such constant.

The total kinetic energy of the field, associated with its time evolution, is given by the temporal component ($\alpha = 0$) of this term:

$$\mathcal{T}_{\text{kin}} = \frac{1}{2}\kappa(\partial_0\mathcal{G}^{\mu\nu})(\partial_0\mathcal{G}_{\mu\nu}) \quad (4)$$

We now analyze this expression by recalling the physical interpretation of the tensor components as proposed in Section XIII B:

- The component \mathcal{G}_{00} encodes scalar deformations, associated with mass-like gravitational sources.
- The components \mathcal{G}_{0i} encode torsional (azimuthal) modes, associated with currents and thus analogous to magnetic fields.

Expanding the kinetic energy term reveals the distinct contributions:

$$\mathcal{T}_{kin} = \frac{1}{2}\kappa [(\partial_0\mathcal{G}_{00})^2 + 2(\partial_0\mathcal{G}_{0i})^2 + (\partial_0\mathcal{G}_{ij})^2 + \dots] \quad (5)$$

We can now directly apply the oscillator analogies central to this paper :

1. **Mass-like Inertia:** The kinetic energy of the scalar mode, $\frac{1}{2}\kappa(\partial_0\mathcal{G}_{00})^2$, is the field-theoretic analogue of the mechanical kinetic energy $\frac{1}{2}m\dot{x}^2$. In this context, the coefficient κ has the physical dimension of **Mass**.
2. **Inductance-like Inertia:** The kinetic energy of the torsional modes, $\kappa(\partial_0\mathcal{G}_{0i})^2$, is the analogue of the energy stored in an inductor, $\frac{1}{2}L\dot{q}^2$. Here, \dot{q} corresponds to the "velocity" of the field excitation sourced by a current. Thus, the same coefficient κ must have the physical dimension of **Inductance**.

Since Lorentz covariance and the principle of a single unified field demand that a single constant κ governs the inertial properties of all components of $\mathcal{G}_{\mu\nu}$, it follows that the dimensional character of mass and inductance must be identical.

$$[\text{Mass}] \equiv [\kappa] \equiv [\text{Inductance}] \quad (6)$$

Thus, *the First Postulate is not an assumption but a direct and necessary consequence of describing a unified reality with a single, covariant field Lagrangian.*

Dimensional consequences of the First Postulate

Taking the SI units of inductance L as $[ML^2I^{-2}T^{-2}]$, this postulate leads directly to:

$$[M] \equiv [ML^2I^{-2}T^{-2}],$$

For dimensional consistency, this postulate requires that the combination $[L^2I^{-2}T^{-2}]$ must be dimensionless. Solving for the dimension of current $[I]$ yields:

$$[I^2] \equiv [L^2T^{-2}] \implies [I] \equiv [LT^{-1}] \quad (7)$$

This result, stemming directly from our initial postulate, implies that electric current within this unified picture acquires the dimensions of velocity. The consequences of this dimensional assignment will be explored throughout this work.

As a sanity check, the resistance R in an RLC circuit is analogous to the damping coefficient b in a mechanical oscillator. Establishing the dimensional equivalence between them, we find that:

$$[MT^{-1}] \equiv [ML^2T^{-3}I^{-2}],$$

which implies that $[L^2I^{-2}T^{-2}]$ becomes dimensionless, as we had obtained just before, and which leads to the dimensionality found for I .

B. Redefining the Ampere as a Velocity

In standard SI practice, the ampere (A) is treated as an independent base unit, separate from mass, length, and time. However, in the dimensional framework of our unified theory—where mass, length, time, and charge share a common geometric substrate—this separation becomes unnecessary. Motivated by the structural analogies between mechanical and electromagnetic oscillators, and following our First Postulate (II A), we adopt the convention:

$$[I] \equiv \frac{[L]}{[T]}, \quad (8)$$

thereby equating the ampere to a fundamental velocity scale. This identification is not arbitrary: it emerges naturally when current is reinterpreted as an excitation velocity within the vacuum's oscillator network.

1. No Change in Physical Predictions

Redefining the ampere in this manner does not alter any physical laws or measurable outcomes. Rather, this shift reorganizes the dimensional bookkeeping:

1. *Under the conventional SI system*, current I constitutes an independent dimension, complicating the structure of electromagnetic quantities (e.g., impedance, field strength, permittivity).
2. *Within our unified framework*, I is expressed as $\frac{L}{T}$, simplifying the dimensional equivalences to a common ground in spacetime.

Thus, this redefinition introduces no empirical contradiction—only a reformulation that is internally consistent and fully compatible with traditional measurements.

2. Geometric and Physical Interpretation

This shift reveals a deeper physical insight: electric current is not merely a rate of charge transfer, but a manifestation of *spacetime flow*—a directed, quantized deformation of the elastic vacuum. The ampere, in this light, becomes the natural unit of deformation rate within the unified field, particularly along radial (electromagnetic) modes of the symmetric tensor $\mathcal{G}_{\mu\nu}$ that we will postulate later on (X).

This reinterpretation also supports a conceptual bridge between the source terms in gravitational and electromagnetic field equations. In this sense, mass and charge both source curvature by altering the local flow of the vacuum, and their associated "currents" (gravitational and electric flow) emerge as conjugate expressions of the same geometro-dynamic principle.

3. Toward Unified Source Terms

As a result, this dimensional identification sets the stage for a unified treatment of source terms across field equations, and invites a reinterpretation of current as a *dynamical field generator*, not merely a charge derivative. Redefining the ampere as velocity not only simplifies the dimensional landscape, but also aligns electromagnetism with the spacetime symmetries that govern motion and gravity, contributing to the internal coherence of the unified field model.

C. Dimensional Collapse and Space–Time Equivalence in the Unified Field

The striking structural symmetry between Newton's Law of Gravitation and Coulomb's Law

$$F = G \frac{m_1 m_2}{r^2}, \quad F = K \frac{q_1 q_2}{r^2}.$$

provides strong motivation for exploring an even deeper connection. Within our developing framework, and following the physical interpretation of current stemming from our First Postulate, we naturally introduce a *second key postulate: the dimensional equivalence of the coupling constants G and K_e* . This postulate embodies the already stated hypothesis that the fundamental sources, mass and charge, play analogous roles governed by similar principles within the unified field structure (IIB 2), reflected dimensionally in their respective force constants.

Let us rigorously derive the consequences of

this postulate combined with our previous findings. The conventional SI dimensions are:

$$[G] = [M^{-1}L^3T^{-2}], \quad [K_e] = [ML^3T^{-4}I^{-2}].$$

Setting $[G] \equiv [K_e]$, we obtain:

$$[M^{-1}L^3T^{-2}] \equiv [ML^3T^{-4}I^{-2}].$$

Rearranging for $[M]$, and recalling that within the unified framework we have established $[I] \equiv [LT^{-1}]$ (8), we substitute I^{-2} as:

$$[M^{-1}L^3T^{-2}] \equiv [ML^3T^{-4}(L^{-2}T^2)].$$

Simplifying, we find:

$$\begin{aligned} [M^{-1}L^3T^{-2}] &\equiv [MLT^{-2}] \rightarrow \\ [M^{-1}L^3] &\equiv [ML] \rightarrow \\ [L^2] &\equiv [M^2] \rightarrow \\ \boxed{[M] \equiv [L]} & \end{aligned} \quad (9)$$

This outcome, contingent on the postulates $[Mass] \equiv [Inductance]$ and $[G] \equiv [K_e]$, signifies that mass and length share the same fundamental dimension within this theoretical structure. From this result and the previous ones, we can substitute $[M]$ and $[I]$ in the previous equivalence $[MT^{-1}] \equiv [ML^2T^{-3}I^{-2}]$, to get that $[T^{-4}L^4]$ becomes dimensionless; which, in turn, implies that we have reached the fundamental equivalence

$$\boxed{[M] \equiv [L] \equiv [T]} \quad (10)$$

This result establishes a profound conclusion: *mass, length and time are fundamentally equivalent in the common unified field*. And this equivalence leads to a natural collapse of dimensions -as we will see-, implying that the evolution of the universe should be understood in terms of oscillatory interactions where mass-energy, length and time emerge as manifestations of a unified, underlying geometric structure.

D. The dimensions of sources and universal constants in the unified field framework

We can now establish the dimensions of the most important constants and physical phenomena that we will consider throughout this Paper, once we apply the fundamental equivalence (10):

- **Mass:** As already stated, we have $[M] \equiv [T] \equiv [L]$.
- **Energy:** As per Einstein's equation $E = mc^2$, it has dimensions $[L] \equiv [T]$.
- **Charge:** As $[Q] = [I \cdot T]$ and we have that $[I] \equiv [1]$, it has dimensions $[L] \equiv [T]$.

- **Temperature:** As $k_B T$ has dimensions of energy, and k_B becomes dimensionless (IV A 3), it has the same dimensions of energy, and thus it has dimensions $[L] \equiv [T]$.
- **Current:** Becomes dimensionless, as we have that $[I] \equiv [LT^{-1}] \equiv [1]$
- **Resistance:** Becomes dimensionless, as $[R] = [MT^{-1}] \equiv [ML^2T^{-3}I^{-2}] \equiv [1]$
- **Voltage:** By Ohm's law, we have that $V = I \cdot R$. As both I and R are dimensionless, voltage V becomes dimensionless too.
- **Power:** As we have that $P = V \cdot I$, and $P = \frac{V^2}{R}$, power P becomes dimensionless too.
- **The "speed of light" c :** As any velocity with dimensions $[LT^{-1}]$, it becomes dimensionless.
- **Planck's constant h :** As the quantum of action, it has dimension $[E \cdot T]$. Therefore, it has dimensions $[L^2] \equiv [T^2]$.
- **Electric permittivity ϵ_0 :** As it has dimension $[\epsilon_0] = [M^{-1}L^{-3}T^4I^2]$, it becomes dimensionless.
- **Magnetic permeability μ_0 :** As it has dimension $[\mu_0] = [MLT^{-2}I^{-2}]$, it becomes dimensionless.
- **The gravitational constant G :** Through Newton's law, G has dimensions $[G] = [M^{-1}T^{-2}L^3]$. Thus, it becomes dimensionless.
- **Coulomb's constant K_e :** Being equal to $\frac{1}{4\pi\epsilon_0}$, it becomes dimensionless.
- **Boltzmann's constant k_B :** From the equivalence derived in (IV A 3), it becomes dimensionless.
- **The fine-structure constant α :** By its definition, $\alpha = \frac{e^2}{2\epsilon_0 hc}$. One can check that using the previous dimensions described, it is dimensionless, as expected.

E. Reflection on Dimensional Equivalence and Its Implications for Fundamental Units

The choice of a unit system in physics is more than a matter of convenience; it can reveal deeper structures in the relationships among physical quantities. In particular, within the context of the unified field, we formally write

$$[L] \equiv [T_{\text{ime}}] \equiv [M] \equiv [E] \equiv [Q] \equiv [T_{\text{emp}}], \quad (11)$$

meaning that, *within the theoretical model*, these quantities share a common dimensional basis. Strictly speaking, this does not invalidate the traditional distinction among meters, seconds, kilograms, joules, coulombs, and kelvins in everyday measurements or standard SI usage. Rather, it asserts that *when certain fundamental constants are equated and treated as direct conversion factors, one can recast these different units as numerically equivalent*:

$$1 \text{ m} \equiv 1 \text{ s} \equiv c^2 \text{ kg} \equiv 1 \text{ J} \equiv 1 \text{ C} \equiv 1 \text{ K}. \quad (12)$$

This equivalence is neither arbitrary nor merely a notational trick; it reflects the idea that universal constants play the role of *natural conversion factors* between dimensions like length, time, mass, energy, charge, and temperature. In other words, once these constants are taken as fundamental geometric elements of the theory, the differences among standard SI units become a matter of labeling, rather than a manifestation of fundamentally different dimensions within the unified framework.

Hence, we do not erase the operational definitions of the meter, second, or kilogram as used in the laboratory. Rather, we embed them into a broader dimensional structure, where what appear as separate units in standard SI can be seen, at a deeper theoretical level, as different expressions of the same underlying physical reality.

Under this viewpoint, universal constants lose their "arbitrary" character. They become the metric coefficients of a generalized physical geometry—effectively the "metric" that converts one nominal unit into another. This unification thus provides a self-consistency check: if all these quantities truly emerge from the same resonant spacetime lattice, then setting them equal at the fundamental level (via the constants) should lead to a coherent, contradiction-free description of nature.

Part II: Fundamental nature and relationships of universal constants

III. CORE IDENTIFICATIONS AND INITIAL EVALUATIONS

Building on the foundational postulates and the resulting dimensional unification established in subsection IIC, we now summarize the basic core identifications made within this framework:

Quantum	Identification	SI Units	U. Field
Velocity v	$v = c$	$m \cdot s^{-1}$	Dimensionless
Acceleration a	$a = \frac{v}{t} = \frac{c}{1\text{ s}}$	$m \cdot s^{-2}$	$s^{-1} \equiv m^{-1} \dots$
Current I	$I = v = c$	A	Dimensionless
Ang. Freq. ω_0	$\omega_0 = \frac{c}{1\text{ s}}$	s^{-1}	$s^{-1} \equiv m^{-1} \dots$
Inductance L	$L = \mu_0 \cdot 1\text{ m}$	H	Dimensionless
Capacitance C	$C = \varepsilon_0 \cdot 1\text{ m}$	F	Dimensionless
Spr. Const. k	$k = \frac{1}{C} = \frac{1}{\varepsilon_0 \cdot 1\text{ m}}$	F^{-1}	Dimensionless
Charge Q	$Q = e$	C	$C \equiv s \equiv m \dots$
Resistance R	$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$	Ω	Dimensionless
Time Const. τ	$\tau = RC = \frac{1\text{ m}}{c}$	s	$s \equiv m \equiv \dots$
Voltage V	$V = I \cdot R = \frac{1}{\varepsilon_0}$	V	Dimensionless

TABLE I. Summary of the basic mapping of fundamental constants, showing how each maps onto a mechanical or electrical analogue.

IV. THE EMERGENCE OF FUNDAMENTAL CONSTANTS FROM TRADITIONAL PHYSICS

In this section, we present a collection of derivations of fundamental physical constants and quantities obtained through the direct application of well-established physical laws, now reinterpreted within the unified field framework developed throughout this work. These derivations serve a dual purpose: on one hand, they confirm the internal consistency of the framework by showing that classical results naturally emerge from the collapsed dimensional structure; on the other, they provide new physical insights by revealing hidden connections among constants that traditionally appeared unrelated.

The approach taken here does not discard the conventional form of physical laws such as Ampère’s law, Gauss’s law, Newton’s law of gravitation, or thermodynamic identities, all of which remain valid and demonstrable within their respective classical domains [15–17]. Rather, it recontextualizes them under the assumption of dimensional unification, where $[M] \equiv [L] \equiv [T]$, and where constants of nature are not arbitrary scaling factors but geometric or elastic properties of the vacuum itself.

Each subsection within this part focuses on a specific law or identity and illustrates how it leads to compact expressions, derivations and relationships between constants of nature, often involving just one or two steps of algebra. This reinforces the notion that physical constants are not empirically isolated, but rather interconnected outputs of a deeper, modal-geometric structure of spacetime.

A. Vacuum Electromotive Responses: μ_0 , K_e , and k_B as Modal Resonances from Faraday Dynamics

We can reinterpret the vacuum permeability μ_0 , Coulomb’s constant K_e , and Boltzmann’s constant k_B as *effective electromotive responses*—emergent quantities characterizing the vacuum’s elastic reaction to variations in structural currents over characteristic scales. This unifying view arises from Faraday’s law, which describes the electromotive force induced by a time-varying magnetic flux:

$$\mathcal{E} = -\frac{d\Phi_B}{dt} = -L_{\text{ind}} \cdot \frac{dI}{dt}. \quad (13)$$

In the framework of the unified tensor field $\mathcal{G}_{\mu\nu}$ (X), the current I represents a geometric deformation rate of the vacuum. Time and length are unified under the structural identification $[L] = [T]$, and current acquires the role of a velocity-like quantity: $I = L/T$. This dimensional symmetry allows us to reinterpret μ_0 , K_e , and k_B as different modal resonances of the same underlying mechanism, depending on the deformation scale.

1. Reference Regime — Gravitational mode.

Let $I = 1\text{ m/s}$ and $t = 1\text{ s} \equiv 1\text{ m}$. Using the base inductance $L_{\text{ind}} = \mu_0 \cdot 1\text{ m}$, we find:

$$\mathcal{E} = \mu_0 \cdot 1\text{ m} \cdot \frac{1}{1\text{ s}} = \mu_0 \quad (14)$$

Thus, μ_0 characterizes the vacuum’s minimal electromotive response to a unit deformation flow: the baseline voltage of the elastic field under quasi-static excitation.

2. Electromagnetic mode (scaled by c).

Scaling the current as $I = c$ implies $t = \frac{1}{c}\text{ s}$, and using the same L_{ind} :

$$\mathcal{E} = \mu_0 \cdot 1\text{ m} \cdot \frac{c}{\frac{1}{c}\text{ s}} = \mu_0 c^2 = 4\pi K_e \quad (15)$$

We recover Coulomb’s constant K_e as a relativistically scaled version of μ_0 , confirming its nature as a voltage response under rapid deformation propagation.

3. Thermo-entropic mode (scaled by $1/c$).

Scaling the current as $I = 1/c$ yields $t = 1\text{ s} \cdot c$. Then:

$$\mathcal{E} = \mu_0 \cdot 1\text{ m} \cdot \frac{\frac{1}{c}}{1\text{ s} \cdot c} = \frac{\mu_0}{c^2} \approx 1.4 \times 10^{-23} \quad (16)$$

which coincides numerically with Boltzmann's constant k_B , up to unit conventions. This identifies k_B as the thermo-entropic counterpart to μ_0 and K_e : an emergent voltage under slow deformation flux, consistent with the azimuthal thermal mode \vec{T} derived from the unified tensor field (98).

These results confirm that μ_0 , K_e , and k_B are not independent constants, but rather *modal projections* of the same elastic tensor structure. Each emerges from Faraday-like dynamics under a distinct current/time scaling regime:

- **Gravitational:** base mode, with $\mathcal{E} = \mu_0$,
- **Electromagnetic:** relativistic excitation, with $\mathcal{E} = \mu_0 c^2 = 4\pi K_e$,
- **Entropic:** dissipative/thermal excitation, with $\mathcal{E} = \mu_0/c^2 \approx k_B$.

In this view, all three constants describe the same underlying stiffness of the vacuum, observed at different frequencies of excitation. This directly supports the modal structure of Part IV, where each field expression $\vec{\Phi}_X(r) = \frac{\mu_0}{4\pi r} \cdot C_X \cdot \hat{e}_X$ arises from a specific symmetry and energy scale of the elastic vacuum.

As a result, Faraday's law, when interpreted in modal terms, provides a unified operational principle: *electromotive response emerges from geometric resistance to deformation*. The constants μ_0, K_e, k_B are expressions of the same elastic modulus μ_0 , rescaled by the velocity I of excitation. This unifies electromagnetic, gravitational, and thermo-entropic interactions as frequency-dependent modes of a single deformable spacetime substrate.

B. Modal Vacuum Actions: The Emergence of S_{ref} , \hbar and S_{th} from first principles and scaling regimes

In the unified elastic framework, each fundamental field—gravitational, electromagnetic, and thermo-entropic (VIII)—emerges as a modal excitation of the same vacuum substrate (IX C). These excitations are characterized by distinct action densities over scaled four-dimensional volumes. We now derive the characteristic *action quantum* for each regime, showing that quantities such as a base action S_{ref} , the Planck constant \hbar , and a thermo-entropic action S_{th} (associated to the cosmological constant Λ), arise as invariant geometric projections of the same elastic vacuum.

1. Reference regime — gravitational mode.

We begin by postulating a fundamental uniform Lagrangian density for the vacuum:

$$\mathcal{L}_{ref} = \frac{1}{1 \text{ m}^2} \quad (17)$$

This corresponds to the minimal areal curvature of the vacuum per unit 4-volume. In the reference gravitational regime, time and length are taken as identical units ($[L] = [T] = 1 \text{ m}$). The four-dimensional integration domain thus becomes:

$$d^4x = 1 \text{ m}^4 \quad (18)$$

yielding a characteristic action:

$$\mathcal{S}_{ref} = \int \mathcal{L}_{ref} d^4x = \frac{1}{1 \text{ m}^2} \cdot 1 \text{ m}^4 = 1 \text{ m}^2 \equiv 1 \text{ J} \cdot \text{s} \quad (19)$$

This result represents the *baseline modal action* of the vacuum. Using the equivalence $1 \text{ kg} \equiv \frac{1}{c^2} \text{ J}$ (derived from Einstein's fundamental equation), the gravitational action corresponds to:

$$\mathcal{S}_{ref} = \frac{1 \text{ kg} \cdot \text{s}}{c^2}$$

Note that, theoretically, it comes naturally to construct the quantum of charge e_q as the product of the structural voltage μ_0 (14) and the structural capacitance $\varepsilon_0 \cdot 1 \text{ m}$ (I), to get that

$$e_q = \mu_0 \varepsilon_0 \cdot 1 \text{ m} = \frac{1 \text{ m}}{c^2} \quad (20)$$

As a result, using the equivalence $1 \text{ m} \equiv 1 \text{ s}$, we have that $\mathcal{S}_{ref} \equiv e_q \cdot 1 \text{ kg}$, where e_q denotes the elementary electric unit in energy form.

This result shows that the elementary quantum of electric charge e_q is not merely a phenomenological constant but a direct expression of the vacuum's structural response to deformation. Consequently, the reference action $\mathcal{S}_{ref} = e_q \cdot 1 \text{ kg}$ encapsulates how a unit mass couples to the minimal quantum of curvature or twist in the vacuum substrate. This connects the emergence of charge with the elastic geometry of space, reinforcing the idea that mass, charge, and temperature are unified as different projections of the same underlying structure.

2. Electromagnetic mode

In the electromagnetic regime, length scale relativistically by c^2 , so both the Lagrangian and volume are scaled:

$$x_{EM} = \frac{1 \text{ m}}{c^2} \equiv e_q \Rightarrow \mathcal{L}_{EM} = \frac{c^4}{1 \text{ m}^2}, \quad d^4x_{EM} = \frac{1 \text{ m}^4}{c^8}$$

Then, the action becomes:

$$\begin{aligned} \hbar &= \int \mathcal{L}_{EM} d^4 x_{EM} = \frac{c^4}{1 \text{ m}^2} \cdot \frac{1 \text{ m}^4}{c^8} = \frac{1 \text{ m}^2}{c^4} \\ &\equiv \frac{1 \text{ J} \cdot \text{s}}{c^4} \approx 1.2 \times 10^{-34} \text{ J} \cdot \text{s} \end{aligned} \quad (21)$$

which closely approximates the measured value of the reduced Planck constant $\hbar = 1.054 \times 10^{-34} \text{ J} \cdot \text{s}$. The small numerical discrepancy (about 15%) may stem from second-order corrections due to spatial anisotropy, oscillatory coupling, or the projection geometry of the modal fields (XIII B). That is, while the lowest-order action is governed by a uniform energy density over a flat cell, real excitations involve dynamical distortions that contribute curvature and tension, modulating the exact value. These corrections could be associated with local deviations from the ideal spherical symmetry or with the full tensorial dynamics of the elastic vacuum lattice.

To approximate this deviation, we can state that $\hbar \equiv C \cdot \frac{1 \text{ m}^2}{c^4}$ for some dimensionless constant C . To approximate the value of C , we can use two key relations:

1. **The Quantum Hall Resistance:** The quantization of Hall resistance reveals a fundamental relationship between the quantum of action \hbar , the elementary charge e , and the vacuum impedance Z_0 , mediated by the fine-structure constant α :

$$\frac{\hbar}{e^2} = \frac{Z_0}{2\alpha} \quad (22)$$

2. **The Emergent Nature of Charge:** In this theory, the elementary charge e is not a primitive quantity but an emergent property of the vacuum's elastic and dissipative structure. In (53), its one-loop value is determined by the universal damping factor 2α (45) and the spacetime constants c and the unit scale (1 m):

$$e \approx \frac{2\alpha \cdot (1 \text{ m})}{c^2} \quad (23)$$

Combining these two expressions, we can successfully approximate the constant C :

$$\begin{aligned} \hbar &= \frac{\hbar}{2\pi} = \frac{Z_0 \cdot e^2}{2\pi \cdot 2\alpha} \approx \frac{Z_0 \cdot (2\alpha)^2 \cdot 1 \text{ m}^2}{2\pi \cdot 2\alpha \cdot c^4} \\ &= \frac{Z_0 \cdot \alpha}{\pi} \cdot \frac{1 \text{ m}^2}{c^4} \rightarrow \boxed{C \approx \frac{Z_0 \alpha}{\pi} \approx 0.875 = \frac{7}{8}} \end{aligned} \quad (24)$$

3. Thermo-entropic mode

In this mode, length-time units are further scaled, yielding:

$$x_{th} = \frac{1 \text{ m}}{c^4} \Rightarrow \mathcal{L}_{th} = \frac{c^6}{1 \text{ m}^2}, \quad d^4 x_{th} = \frac{1 \text{ m}^4}{c^{12}}$$

Then the action becomes:

$$\begin{aligned} S_{th} &= \int \mathcal{L}_{th} d^4 x_{th} = \frac{c^6}{1 \text{ m}^2} \cdot \frac{1 \text{ m}^4}{c^{12}} = \frac{1 \text{ m}^2}{c^6} \\ &\equiv \frac{1 \text{ J} \cdot \text{s}}{c^6} \approx 1.377 \times 10^{-51} \text{ J} \cdot \text{s} \end{aligned} \quad (25)$$

This quantity is numerically close to the observed value of the cosmological constant $\Lambda \sim 10^{-52} \text{ m}^{-2}$, suggesting that the cosmological constant itself may be interpreted as the action density of a *residual modal action* projected from ultra-low frequency deformations of the vacuum (we will show that this is indeed the case in (133)).

As a result, we have shown how some of the most important constants of nature arise not by empirical insertion, but as geometrically quantized projections of the same vacuum Lagrangian density over scaled modes of the same deformable elastic substrate. These results suggest that S_{ref} , \hbar , and S_{th} act as modal Noether invariants—emergent from distinct projections of the same elastic vacuum structure—and that what we traditionally interpret as fundamental constants of nature are, in fact, geometric integrals over scaled deformations of a single quantized substrate.

C. Vacuum impedance Z_0 and Ampère's Law

In the quasi-static regime, Ampère's law (ignoring displacement currents) relates the magnetic field to the current I via

$$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I = \mu_0 c = Z_0 \quad (26)$$

This identity reveals a fundamental insight within our framework: the vacuum impedance $Z_0 = \mu_0 c$ is not merely an electromagnetic constant, but a quantized circulation of the magnetic field in response to the current $I = c$. Under the quasi-static regime, Ampère's law reduces to a direct proportionality between the magnetic field circulation and this structural current, leading to the elegant equivalence $\oint \vec{B} \cdot d\boldsymbol{\ell} = Z_0$.

In this light, Z_0 characterizes the vacuum's intrinsic resistance to topological twisting—a kind of "circulatory stiffness"—analogous to how μ_0 represents linear stiffness to deformation.

When interpreted through the lens of dimensional collapse, where both μ_0 and I are dimensionless, this equation becomes a quantization condition: the magnetic excitation mode \vec{B} must integrate to a unit value. This supports the interpretation of \vec{B} as a topological mode of the unified field, constrained by geometric and symmetry conditions of the vacuum itself. In this sense, magnetism becomes a circulatory polarization of spacetime, fixed by the internal geometry and encoded in the impedance of the vacuum medium.

This reinterpretation of $Z_0 = \mu_0 c$ as a quantized circulation constant aligns with well-established principles of flux quantization in field theory. For instance, in quantum systems such as superconductors, magnetic flux is quantized in units of $\Phi_0 = h/2e$, while in classical electromagnetism, integral forms of Maxwell's equations impose global constraints on field flux. The unified modal formulation (XIII B) extends these principles by embedding them into the geometry of spacetime: the field circulation $\oint \vec{B} \cdot d\ell$ must yield a fixed value determined by the internal structure of the vacuum. Hence, the elastic tensor framework not only recovers the standard laws, but elevates them to quantization conditions on the permissible excitations of the vacuum's geometry. This reinforces the central insight of (IX C: that all physical interactions arise as topologically constrained modal deformations of a single Lorentz-invariant field tensor $\mathcal{G}_{\mu\nu}$.

D. Energy consistency check: some fundamental derivations

1. The LC oscillator-like equipartition and a basic field-theoretic setting

Consider the energy stored in a capacitor and inductor:

$$E_{LC} = \frac{1}{2}CV^2 + \frac{1}{2}LI^2 \quad (27)$$

and substitute:

- $C = \varepsilon_0 \cdot 1 \text{ m}$ is the capacitance, consistent with the definition and SI units of ε_0 .
- We can apply Ohm's Law to derive $V = I \cdot R = c \cdot Z_0 = \frac{1}{\varepsilon_0}$ as some voltage,
- $I = c$ is the current within the context of the unified field.

Substituting these values yields

$$E_{LC} = \frac{1}{2}(\varepsilon_0 \cdot 1 \text{ m}) \cdot \frac{1}{\varepsilon_0^2} + \frac{1}{2}L \cdot c^2 \quad (28)$$

This discrete LC system serves as a localized analogy for the vacuum's elastic behavior. To capture this oscillatory structure in a continuous, field-theoretic setting, let $\Phi(x)$ denote a *field* -in general, it can be a multi-component scalar, vector, or tensor, but for illustrative purposes, we treat it here as a single real scalar field-. Include just the two couplings (or 'rigidities') usual for harmonic oscillatory systems. Then, one has the following *minimal* Lagrangian density:

$$\mathcal{L}(\Phi) = \frac{1}{2} \kappa_1 (\partial_t \Phi)^2 - \frac{1}{2} \kappa_2 (\nabla \Phi)^2 \quad (29)$$

Here,

- κ_1 controls the 'inertial' or kinetic response of the field mode,
- κ_2 represents the elastic/spatial rigidity of the field mode.

Note that the requirement

$$\kappa_1 = \kappa_2$$

is the very condition that makes the field equation into the Lorentz-invariant wave equation

$$\square \Phi = 0,$$

as for any plane-wave solution

$$\Phi(t, \mathbf{x}) \propto e^{i(\omega t - \mathbf{k} \cdot \mathbf{x})}$$

this equality forces $\omega^2 = |\mathbf{k}|^2$, and one finds at every point (or on average over a cycle)

$$\frac{1}{2} \kappa_1 (\partial_t \Phi)^2 = \frac{1}{2} \kappa_2 (\nabla \Phi)^2$$

In other words, Lorentz symmetry *kinematically* guarantees that each mode carries exactly half its energy in "kinetic" form and half in "gradient" form. We may therefore adopt the usual LC-circuit equipartition

$$CV^2 = LI^2$$

We can solve (28) for the inductance L to get:

$$L = \frac{CV^2}{I^2} = \frac{1 \text{ m}}{\varepsilon_0 c^2} = \mu_0 \cdot 1 \text{ m} \quad (30)$$

Which serves as a consistency check, as our proposed quantum of inductance is indeed $\mu_0 \cdot 1 \text{ m}$ (I). And, substituting with L and calculating, we get that

$$E_{LC} = \frac{1 \text{ m}}{\varepsilon_0} = \mu_0 \cdot 1 \text{ m} \cdot c^2 = 4\pi K_e \cdot 1 \text{ m}$$

The result $E_{LC} = 4\pi K_e \cdot 1 \text{ m}$, as within the unified field we have that $\left[\frac{1}{\varepsilon_0}\right] = [4\pi K_e] \equiv [V]$

and $1\ m \equiv 1C$, can be interpreted as the quantum of electrostatic energy.

This expression not only confirms the internal consistency of our dimensionally collapsed framework, but also shows that *the requirement $\kappa_1 = \kappa_2$ —which ensures Lorentz invariance in the scalar field model— corresponds physically to energetic equipartition between electric and magnetic modes (or kinetic and potential modes in the oscillator analogy).*

In this view, the field equation $\square\Phi = 0$ represents the fundamental wave dynamics of the unified vacuum, and its LC analogue illustrates how energy is stored and propagated through field excitations. We will postulate in (IX C) that each field mode that we propose (e.g. electromagnetic, thermo-entropic) can be modeled as a scalar excitation with effective rigidity κ , matched to the appropriate constant (ε_0 , μ_0 , G , k_B) depending on the physical context.

Thus, the scalar field model drafted above does more than reproduce known equations—it captures the essential modal structure of the symmetric fundamental tensor $\mathcal{G}_{\mu\nu}$ (X), and justifies, from energetic and variational grounds, the emergence of field equations and constants from a deeper elastic structure. In this light, the equality $\kappa_1 = \kappa_2$ becomes not a mere condition for symmetry, but a *physical principle of balance*: the propagation of deformation through the vacuum respects a universal ratio between inertial response and spatial rigidity—a signature of a fundamentally oscillatory spacetime.

2. The vacuum energy density from the RLC circuit analogy and basic core identifications

In (27), we could have naturally set $L = \mu_0 \cdot 1\ m$ and $C = \varepsilon_0 \cdot 1\ m$ as the inductance and capacitance of the system, corresponding to the magnetic and electric energy storage capacities of the vacuum. Also, we can naturally set the scaled angular frequency for the electromagnetic regime (I)

$$\omega_0 = \frac{c}{1\ s}$$

In an RLC circuit, the charge Q on the capacitor and the current I in the circuit are related through the time derivative. Specifically, the current I is the time derivative of the charge Q :

$$I(t) = \frac{dQ(t)}{dt}$$

For sinusoidal oscillations, we can express the charge Q and the current I as:

$$Q(t) = Q_0 \cos(\omega t)$$

$$I(t) = -Q_0 \cdot \omega_0 \sin(\omega t)$$

where Q_0 is the maximum charge on the capacitor.

From these equations, we can see that the peak current I_{\max} (the maximum value of $I(t)$) is:

$$I_{\max} = Q_0 \cdot \omega_0$$

Then, with the equivalence $e = Q_0$ (where e is the elementary electric charge) and $\frac{e}{1\ s} = \omega_0$, we have that the maximum current of the system is given by

$$I = \frac{e \cdot c}{1\ s} \quad (31)$$

The energy stored in the electric field of a capacitor with capacitance $C = \varepsilon_0 \cdot 1\ m$ and charge $Q = e$ is:

$$E_{\text{electric}} = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} \frac{e^2}{\varepsilon_0 \cdot 1\ m}$$

The energy stored in the magnetic field of an inductor with inductance $L = \mu_0 \cdot 1\ m$ and peak current $I = \frac{e \cdot c}{1\ s}$ is:

$$E_{\text{magnetic}} = \frac{1}{2} LI^2 = \frac{1}{2} \mu_0 \cdot 1\ m \cdot \left(\frac{e \cdot c}{1\ s}\right)^2 = \frac{1}{2} \frac{\mu_0 e^2 c^2}{1\ m},$$

where we have applied $1\ s \equiv 1\ m$ to simplify. As a result, the total energy of the system is the sum of the electric and magnetic contributions:

$$E_{\text{total}} = E_{\text{electric}} + E_{\text{magnetic}} = \frac{1}{2} \frac{e^2}{\varepsilon_0 \cdot 1\ m} + \frac{1}{2} \frac{\mu_0 e^2 c^2}{1\ m}.$$

However, since the electric and magnetic fields are dynamically coupled in the vacuum (as described by Maxwell's equations), the peak energy contributions occur simultaneously [18] [15]. This means the total energy is effectively doubled, and we have that:

$$E_{\text{total}} = \left(\frac{e^2}{\varepsilon_0 \cdot 1\ m} + \frac{\mu_0 e^2 c^2}{1\ m} \right) \quad (32)$$

Substituting with the CODATA values of the fundamental constants, one gets an approximate value of $E_{\text{total}} \approx 5.75 \times 10^{-27}\ J$. This value aligns with the measurements of the vacuum energy density ρ_{vac} obtained by the Planck Collaboration in 2015 [19]. Note that, within the unified field framework, we have $1\ C \equiv 1\ kg$, so $[\rho_{vac}] = \left[\frac{E_{\text{total}}}{1\ m^3} \right]$.

The above underscores again both the internal consistency and the potential theoretical power of the established framework.

3. Derivation of Rayleigh dissipation from core identifications and Hooke's law

Consider some total dissipated electromagnetic energy due to resistance. Using the Rayleigh dissipation function

$$F = \frac{1}{2}RI^2, \quad (33)$$

the instantaneous power dissipation in the system is given by:

$$P_{\text{dis}}(t) = \frac{dE_{\text{dis}}}{dt} = RI^2 \quad (34)$$

Substituting the defined core parameters, we have

$$P_{\text{dis}}(t) = Z_0 \cdot c^2 \quad (35)$$

To determine the total energy dissipated over the characteristic time interval τ , we integrate this power dissipation from 0 to τ :

$$E_{\text{dis}} = \int_0^\tau P_{\text{dis}}(t) dt \quad (36)$$

Using $\tau = \frac{1s}{c}$, we evaluate the integral:

$$E_{\text{dis}} = Z_0 \cdot c^2 \cdot \frac{1}{c} = \frac{1}{\varepsilon_0} \cdot 1 s \quad (37)$$

The above is dimensionally consistent within the framework of the unified field, as $\left[\frac{1}{\varepsilon_0}\right] \equiv [V]$ and $1 s \equiv 1C$. And, to explore the potential power of the framework we are developing, we can point out the following: within the unified field, the above expression admits a direct mechanical analogy with Hooke's law in its linear form, $E = -kx^2$. Note that we have identified the inverse vacuum permittivity per meter, $\frac{1}{\varepsilon_0 \cdot 1 m}$, with an effective *stiffness* constant k of the vacuum (I) —representing its resistance to deformation or response under excitation—while we also have established that $1 s \equiv 1 m$, which naturally corresponds to a spatial displacement x . The resulting structure, $E_{\text{dis}} = kx^2 = \frac{1}{\varepsilon_0} \cdot 1 s$, underscores how the unified field behaves as an elastic medium, in which energy is linearly related to displacement via an intrinsic stiffness.

E. The fine-structure constant α as half a damping ratio ζ and a Lorentz-like factor

The fine-structure constant α [20] can be defined as the ratio of two energies:

- the energy needed to overcome the electrostatic repulsion between two electrons a distance of d apart

- the energy of a single photon of wavelength $\lambda = 2\pi d$ (or of angular wavelength d)

Therefore, we have that

$$\begin{aligned} \alpha &= \left(\frac{e^2}{4\pi\varepsilon_0 d}\right) / \left(\frac{hc}{\lambda}\right) \\ &= \frac{e^2}{4\pi\varepsilon_0 d} \times \frac{2\pi d}{hc} = \frac{e^2}{4\pi\varepsilon_0 d} \times \frac{d}{\hbar c} \\ &= \frac{e^2}{4\pi\varepsilon_0 \hbar c} \end{aligned} \quad (38)$$

Other hand, in the context of an RLC circuit, the quality factor or Q factor [21] is a dimensionless parameter that describes how underdamped an oscillator or resonator is. It is defined as the ratio of the initial energy stored in the resonator to the energy lost in one radian of the cycle of oscillation. Therefore, we have that

$$\begin{aligned} Q &\stackrel{\text{def}}{=} 2\pi \times \frac{\text{Energy stored}}{\text{Energy dissipated per cycle}} \\ &= 2\pi f_r \times \frac{\text{Energy stored}}{\text{Power loss}} \\ &= \omega_0 \times \frac{\text{Energy stored}}{\text{Power loss}} \end{aligned} \quad (39)$$

Where f_r is the resonance frequency.

In electrical-engineering and condensed matter contexts, the fine-structure constant can be written as

$$\alpha = \frac{1}{4}Z_0G_0,$$

where $Z_0 = \mu_0 c = \frac{1}{\varepsilon_0 c}$ is the vacuum impedance and $G_0 = \frac{2e^2}{\hbar}$ is quantum conductance [22]. It follows that

$$Z_0G_0 = 4\alpha,$$

which can be interpreted as the intrinsic energy loss characteristic per radian for the vacuum medium itself. Thus, one can naturally define a vacuum quality factor as

$$Q = \frac{1}{Z_0G_0} = 2\pi \times \frac{\varepsilon_0 \hbar c}{2e^2} = \frac{1}{4\alpha}.$$

where we can identify $E_{\text{stored}} = \frac{\hbar c}{2\lambda}$ and $E_{\text{dissipated}} = \frac{e^2}{\varepsilon_0 \lambda}$.

The appearance of these two energies follows directly from well-established properties of a single electromagnetic vacuum mode of wavelength λ and the framework we have discussed throughout this Paper. On the one hand, quantum electrodynamics [23] dictates that each mode carries a zero-point energy

$$E_{\text{stored}} = \frac{1}{2}\hbar\omega = \frac{1}{2}\hbar(c/\lambda) = \frac{\hbar c}{2\lambda},$$

which is the exact reactive energy “stored” in the vacuum field for an angular frequency $\omega = \frac{c}{\lambda}$.

On the other hand, using Hooke’s Law, we can identify the dissipated energy using the formula $E = -kx^2$ where k is the elasticity constant, and x the displacement [24]. As in the context of the unified field we have identified $k = \frac{1}{C} = \frac{1}{\varepsilon_0 \lambda}$, and the displacement x with the electric charge Q , we get that $E_{\text{dissipated}} = -kx^2 = \frac{e^2}{\varepsilon_0 \lambda}$.

Alternatively, as a sanity check that the above is consistent with well-established derivations, consider an oscillating dipole $p(t) = p_0 \cdot \cos(\omega t)$ with amplitude $p_0 = e \cdot d$, where $d = \lambda/(2\pi)$ is the separation and $\omega = c/d$ is the angular frequency. Using Larmor formula for time-averaged power radiated by an oscillating dipole [15]:

$$\langle P \rangle = \frac{p_0^2 \omega^4}{12\pi \varepsilon_0 c^3} \quad (40)$$

we can derive the energy dissipated per cycle (period $T = 2\pi/\omega$):

$$E_{\text{dissipated}} = \langle P \rangle \times T = \left(\frac{p_0^2 \omega^4}{12\pi \varepsilon_0 c^3} \right) \left(\frac{2\pi}{\omega} \right) \quad (41)$$

And substituting and operating, one finally gets that

$$E_{\text{dissipated}} = \frac{\pi e^2}{3\varepsilon_0 \lambda} \approx 1.05 \cdot \frac{e^2}{\varepsilon_0 \lambda} \quad (42)$$

Thus, both energies can be derived from first-principles and lead directly to

$$Q = 2\pi \times \frac{E_{\text{stored}}}{E_{\text{dissipated}}} = 2\pi \times \frac{\hbar c / (2\lambda)}{e^2 / (\varepsilon_0 \lambda)} = \frac{1}{4\alpha},$$

For an underdamped oscillator, the damping ratio is defined as

$$\zeta = \frac{1}{2Q},$$

which leads directly to

$$\boxed{\zeta = 2\alpha}$$

Interpreting c in terms of the Damped Resonant Frequency of the System

In a standard underdamped oscillator model [25–27], the damped frequency ω_d is given by

$$\omega_d = \omega_0 \sqrt{1 - \zeta^2}, \quad (43)$$

where ω_0 is the *undamped* resonant (natural) frequency of the system, and ζ is the damping ratio.

Suppose we associate these frequencies with propagation speeds by multiplying each angular frequency by a reference length of *one meter*, yielding speeds in units of m s^{-1} . Denoting:

$$v_{\text{damped}} = \omega_d \times 1 \text{ m}, \quad v_{\text{undamped}} = \omega_0 \times 1 \text{ m},$$

we can identify v_{damped} with the *measured* speed of light, conventionally denoted by c . In other words,

$$c = v_{\text{damped}} = \omega_d \times 1 \text{ m}.$$

From Eq. (43), we thus have

$$c = \omega_0 \cdot 1 \text{ m} \sqrt{1 - \zeta^2}$$

Or, equivalently,

$$c_{\text{measured}}^2 = c_{\text{real}}^2 (1 - (2\alpha)^2) \quad (44)$$

Which, solving for ζ , can be rewritten as

$$\zeta = 2\alpha = \sqrt{1 - \frac{c_{\text{measured}}^2}{c_{\text{real}}^2}} \quad (45)$$

Note the similarity of the above expression with the reciprocal of the Lorentz factor formula [28]. Thus, the fine-structure constant α can be regarded as the reciprocal of a “Lorentz-like” factor via

$$\zeta = 2\alpha = \frac{1}{\gamma} = \sqrt{1 - \frac{c_{\text{measured}}^2}{c_{\text{real}}^2}}. \quad (46)$$

These two views—the *damped oscillator* analogy for electromagnetic propagation and the *Lorentz-like* factor interpretation for α —are not only compatible, but in fact reinforce each other: α emerges as a geometric or relativistic “scaling factor” that governs attenuation in the oscillatory unified field, connecting electromagnetic propagation and the quantum vacuum’s dissipative properties.

Vacuum Damping and potential relationship to Earth’s Motion

Note that, solving for c_{real} , one gets

$$c_{\text{real}} = \frac{c}{\sqrt{1 - 4\alpha^2}} \approx 299.824.388 \text{ m / s} \quad (47)$$

This implies an intrinsic scale difference $\Delta c = c_{\text{real}} - c_{\text{measured}} = 31,927 \text{ m/s}$. Note that this velocity is numerically very close to the Earth’s translational velocity.

Throughout this Paper, we are proposing that the quantum vacuum itself acts as a structured, elastic–dissipative medium. And, just as wave

propagation in a structured medium may exhibit Doppler-type modulations, a moving observer within the dissipative vacuum may experience direction-dependent attenuation—without implying a classical ether or absolute frame.

One might then ask whether the full damping effect Δc could arise solely from Earth’s motion through a static vacuum rest frame. While motion through a medium can indeed lead to velocity-dependent modifications of wave propagation—such as in Fresnel drag [29] or Cherenkov radiation [30]—if Δc depended entirely on Earth’s motion, we would expect measurable deviations in the speed of light between different inertial frames, in conflict with local Lorentz invariance. Instead, we interpret Δc as arising from the vacuum’s intrinsic elastic and dissipative response, while motion relative to the vacuum introduces only small, direction-dependent modulations $\delta c(v)$ atop this universal baseline. This layered structure preserves relativistic consistency while offering a physically grounded mechanism for both the constant and modulated components of the observed light speed.

In this picture, the vacuum consists of fluctuating virtual excitations with internal degrees of freedom that collectively endow it with both stiffness (reactive elasticity) and finite relaxation time (viscosity). A propagating electromagnetic wave then loses energy—not into real particles, but into the hidden structure of the vacuum—via coupling to these degrees of freedom. This loss manifests macroscopically as a damping ratio ζ , which we identify with the dimensionless fine-structure constant via $\zeta = 2\alpha$. Such a damping constant is natural if one treats the vacuum as an ensemble of coupled oscillators or as an emergent condensed-matter system, as suggested by various approaches to quantum gravity and emergent spacetime [31–33]. The resulting reduction in propagation speed is then not a kinematic effect, but a first-principles consequence of quantum back-reaction. This allows us to interpret the measured speed of light c as a damped, effective velocity arising from the underlying dissipative structure of the vacuum.

Thus, the near-coincidence between the damping shift $\Delta c = c_{\text{real}} - c$ and the Earth’s translational velocity suggests a deeper possibility: that this difference encodes a global topological feature of the vacuum field. In our framework, the quantum vacuum is not an inert background but a structured elastic-dissipative medium with internal degrees of freedom. The quantity Δc may then reflect a background excitation of this medium —

a large-scale deformation mode aligned with the Earth’s translational trajectory.

Importantly, this view does not violate local Lorentz invariance. All local observers measure the same effective speed $c = c_{\text{measured}}$, and all physical laws remain Lorentz-invariant in that frame. The distinction between c_{real} and c thus becomes a global, geometric feature of the vacuum — akin to how curvature encodes gravitational effects in general relativity. In this case, however, the “curvature” is not geometric but modal: a manifestation of the vacuum’s internal damping modes, whose excitation state defines a preferred frame only at a topological level, not at the level of measurable kinematics.

Final notes

It is worth noting that although we have identified a “bare” or “undamped” speed of light, c_{real} , as exceeding the measured value c , *this does not conflict with the established principle that the speed of light is the maximum signal velocity*. In our picture, all physical processes remain measured by the *effective*, damped value of c ; hence, no measurable signal can exceed c . Analogous to an RLC circuit, where the “natural” frequency ω_0 is never directly observed but rather only inferred through modeling, the proposed $c_{\text{real}} > c$ does not admit superluminal information transfer, and thus poses no contradiction to special relativity or experiment.

Other hand, higher-order radiative effects — e.g. the electron’s anomalous magnetic moment $a_e = \alpha/2\pi$ — can be viewed as additional layers of the same dissipative mechanism. The damping encoded in the fine-structure constant α would be the first-order manifestation of how the vacuum’s oscillator lattice “bleeds” energy back into itself through quantum fluctuations, and the anomalous magnetic moment can be viewed, in our framework, as the simplest radiative attenuation of a bare “undamped” coupling by the lattice’s elastic resistance. Higher-order Feynman diagrams then correspond to more intricate couplings among modes of the vacuum, each contributing successive powers of α .

More generally, any “ideal” relation among fundamental constants—whether in electromagnetism, gravitation or thermodynamics—must be dressed by a universal, dimensionless form factor $\Xi_{\text{eff}}(\alpha)$ that encodes the accumulated effect of loop-induced damping within the vacuum lattice. In this way, radiative corrections are not mere

perturbative afterthoughts, but the fingerprint of the same elastic and dissipative structure that unifies all fields at their quantum origin.

In this view, *the fine-structure constant α becomes not merely a coupling constant, but a unifying signature of modal attenuation across all field interactions* — electromagnetic, gravitational, and thermo-entropic alike.

F. From the equipartition theorem to the harmonic oscillator energy and the fundamental equation

The equipartition theorem [17] shows that in thermal equilibrium, some harmonic oscillator has an average energy of:

$$\langle E \rangle = k_B T. \quad (48)$$

Other hand, for each quantum harmonic oscillator, the fundamental action per complete cycle is given by Planck's constant h ; therefore, the average total energy required to excite some quantum harmonic oscillator to the next quantum level is:

$$\langle E \rangle = h\omega \quad (49)$$

Equating both expressions, and incorporating relativistic corrections -with a Lorentz factor γ -, we have that:

$$k_B T = h\omega \cdot \gamma$$

Substituting by $\gamma = \frac{1}{2\alpha}$ and $\omega = \frac{c}{\lambda}$, we get the fundamental equation

$$k_B T = \frac{h \cdot c}{\lambda \cdot 2\alpha} \quad (50)$$

If we set $T = 1K \equiv 1 m$ and $\lambda = 1 m$, we get that

$$k_B \cdot 2\alpha = \frac{h \cdot c}{1 m^2} \approx 2 \times 10^{-25}$$

Moreover, if we consider the minimum structural voltage μ_0 (14) and the elementary charge e , one can posit the fundamental equation

$$\boxed{\mu_0 \cdot e \equiv k_B \cdot 1 K \cdot 2\alpha \equiv \frac{hc}{1 m}} \quad (51)$$

The above makes sense both numerically and theoretically. Numerically, note that

$$\begin{aligned} \frac{k_B \cdot 2\alpha}{\mu_0} &= 1.38 \times 10^{-23} \cdot 2 \cdot 0.007297 \cdot 4\pi \times 10^{-7} \\ &\approx 1.603 \times 10^{-19} \end{aligned} \quad (52)$$

Recall that, theoretically, it comes naturally to construct the quantum of charge e_q as the product

of the structural voltage μ_0 and the structural capacitance $\varepsilon_0 \cdot 1 m$, to get that $e_q = \frac{1 m}{c^2}$ (20). Note that then we have that $\mu_0 \cdot e_q = \frac{\mu_0 \cdot 1 m}{c^2} = k_B \cdot 1 K$. Accounting for relativistic corrections using $\gamma = \frac{1}{2\alpha}$, one has (51), and also that

$$e \approx \frac{1 m}{c^2 \cdot \gamma} = \frac{2\alpha \cdot 1 m}{c^2} \quad (53)$$

The small numerical discrepancy of this expression (about 13%) is due to second-order corrections due to spatial anisotropy, oscillatory coupling, or the projection geometry of the modal fields (XIII B), as stated in (21). Importantly, note that (52) cancels the second-order terms from the first-order approximations $k_B \approx \frac{\mu_0}{c^2}$ (16) and (53).

This relations provide a profound synthesis between thermal, quantum, electromagnetic, and geometric domains. The fundamental equation encapsulates, in a single concise expression, this Paper's overarching claim that multiple "fundamental constants" can be viewed as interrelated manifestations of an underlying quantum-oscillatory vacuum.

G. The gravitational constant G as some structural electromotive force \mathcal{E} of the unified field

As by definition $K_e = \frac{\mu_0 \cdot c^2}{4\pi}$, one has that

$$K_e \cdot 4\pi \cdot e = \frac{e}{\varepsilon_0} = \Phi_E = \oint_S \vec{E} \cdot d\vec{A}$$

As we have established that $e \approx \frac{2\alpha \cdot 1 m}{c^2}$, we can substitute to obtain that

$$\begin{aligned} \Phi_E &\approx \frac{\mu_0 \cdot c^2}{4\pi} \cdot 4\pi \cdot \frac{2\alpha \cdot 1 m}{c^2} \\ &= \mu_0 \cdot 2\alpha \cdot 1 m = \frac{\mu_0 \cdot 1 m}{\gamma} \end{aligned} \quad (54)$$

We recall that the electric flux is defined as

$$\Phi_E = \oint_S \vec{E} \cdot d\vec{A},$$

while the electromotive force (emf) is given by

$$\mathcal{E}_{\text{elec}} = \oint_{\partial S} \vec{E} \cdot d\vec{l}.$$

In the case of a spherically symmetric or radially uniform field over a region of characteristic radius $r = 1 m$, we can establish the effective structural electromotive force as:

$$\mathcal{E}_{\text{elec}} = \frac{\Phi_E}{1 m} \approx \mu_0 \cdot 2\alpha$$

Now, the symmetry between gravitational and electromagnetic interactions in our framework imposes the equivalence that we have already set as our Second Postulate (II C):

$$[G] = [K_e],$$

The structural damping tensor $\zeta_{\mu\nu}$ and the emergence of gravitational stiffness

Now, as it makes sense both numerically and theoretically, we postulate that the gravitational constant naturally arises as an effective structural electromotive response, quadratically scaled by the fine-structure damping ratio $\zeta = 2\alpha$:

$$\begin{aligned} G \cdot \gamma &= \frac{1}{4} \mathcal{E}_{elec} \rightarrow \\ G &\approx \frac{1}{4} \mu_0 \cdot 2\alpha \cdot 2\alpha = \mu_0 \cdot \alpha^2 \end{aligned} \quad (55)$$

Numerically, we have that

$$G \approx \mu_0 \alpha^2 \approx 6.69 \times 10^{-11} \quad (56)$$

Theoretically, note that the gravitational constant G takes the form:

$$G = \mu_0 \cdot \frac{1}{4} \zeta^2 \quad (57)$$

where $\zeta = 2\alpha$. Note how this mirrors the structure of the electromagnetic Lagrangian,

$$\mathcal{L}_{EM} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu},$$

suggesting the idea that gravity itself is a quadratic manifestation of the unified field's intrinsic resistance to deformation or energy storage. In this picture, G represents the gravitational "stiffness" of the field—the extent to which the vacuum resists coherent longitudinal deformation due to massive excitations, just as the magnetic permeability μ_0 governs transverse oscillations under charge.

This naturally motivates a tensorial generalization, where we promote $\zeta = 2\alpha$ to the norm of a rank-2 symmetric tensor $\zeta_{\mu\nu}$, which we define as the *structural damping tensor* of the vacuum. This tensor encodes the internal dissipation response of the quantum vacuum to perturbations in spacetime, such that its contraction yields the effective damping strength:

$$\zeta^2 = \zeta_{\mu\nu} \zeta^{\mu\nu} \quad (58)$$

In this formulation, gravitational coupling is no longer introduced as an independent constant but instead emerges from the structural dissipation of

the vacuum. This structural damping tensor $\zeta_{\mu\nu}$ acts as the unifying link between electromagnetic, gravitational, and thermo-entropic responses of the vacuum medium, and provides a natural geometric origin for Newton's constant.

Relationship between the structural damping tensor $\zeta_{\mu\nu}$ and the fundamental symmetric tensor $\mathcal{G}_{\mu\nu}$

As introduced in Part IV (X), the symmetric tensor $\mathcal{G}_{\mu\nu}$ encodes the fundamental strain modes of the unified vacuum field, from which all classical fields derive as projections. We can relate it to the structural damping tensor $\zeta_{\mu\nu}$, responsible for gravitational coupling, by invoking the classical analogy with stress-strain relations in continuum mechanics [34, 35], where the potential energy is given by $E_{\text{pot}} = \frac{1}{2} \sigma_{\mu\nu} \epsilon^{\mu\nu}$, with $\sigma_{\mu\nu}$ the stress tensor and $\epsilon^{\mu\nu}$ the strain tensor. In our framework, the fundamental symmetric tensor $\mathcal{G}_{\mu\nu}$ plays the role of the strain, while the structural damping tensor $\zeta_{\mu\nu}$ naturally corresponds to the induced internal stress. We thus interpret gravity as the manifestation of a quadratic response of the vacuum field:

$$\zeta_{\mu\nu} \propto \mathcal{G}_{\mu\alpha} \mathcal{G}^{\alpha\nu},$$

so that the gravitational constant G encodes the vacuum's effective elastic stiffness to coherent deformation. This identification completes the mechanical analogy and anchors Newton's constant within the internal modal dynamics of the unified field.

Interpretation of $G = \mu_0 \cdot \frac{1}{4} \zeta^2$ as a Constitutive Law of the Vacuum

As a result, $G = \mu_0 \cdot \frac{1}{4} \zeta^2$ admits a natural interpretation within our unified field framework: it is the constitutive law that relates the vacuum's transverse rigidity μ_0 to its longitudinal stiffness G through the internal damping response $\zeta^2 = \zeta_{\mu\nu} \zeta^{\mu\nu}$. In direct analogy with classical elasticity theory, where the stored elastic energy takes the form $E_{\text{pot}} = \frac{1}{2} \sigma_{\mu\nu} \epsilon^{\mu\nu}$, we may view $\zeta_{\mu\nu}$ as the internal stress tensor of the vacuum, induced by the strain field $\mathcal{G}_{\mu\nu}$. In this picture, gravity emerges as the quadratic response of the vacuum's elastic-dissipative lattice to coherent longitudinal deformations induced by mass-energy excitations.

Thus, the gravitational constant G is not fundamental, but derived: it encodes the effective elastic modulus of the vacuum along longitudinal modes, just as μ_0 encodes transverse response.

The relation $G = \mu_0 \cdot \frac{1}{4}\zeta^2$ then completes the analogy with continuum mechanics, anchoring the gravitational interaction in the internal modal geometry and dissipative structure of the vacuum field.

1. *The fine-structure constant as a quotient of gravitational constant and magnetic permeability*

As a final note, the above allows us to relate the fine-structure constant α to the ratio of gravitational constant G and the vacuum permittivity μ_0 :

$$\alpha \approx \sqrt{\frac{G}{\mu_0}} \quad (59)$$

This relation has several noteworthy implications:

- **Dimensional consistency and field symmetry:** Within our framework, both G and μ_0 share the same structural dimensionality, being expressed as effective field stiffnesses or “structural electromotive constants” of the vacuum. Their ratio is thus dimensionless, and α appears as a normalized measure of the coupling between longitudinal (gravitational) and transverse (electromagnetic) responses of the vacuum field.
- **Geometric attenuation coefficient:** From the structural damping interpretation, we have $\zeta = 2\alpha$, and since $G = \mu_0 \cdot \frac{1}{4}\zeta^2$, the first-order approximation $\alpha \approx \sqrt{G/\mu_0}$ simply inverts that structure. This confirms that α is not a fundamental constant per se, but the *geometric attenuation coefficient* resulting from the interplay between elastic (magnetic) and dissipative (gravitational) responses of the vacuum.
- **Coupling of fields through the vacuum lattice:** This formula can also be interpreted as stating that the strength of electromagnetic coupling (α) is not an independent input, but a direct consequence of how gravitational and magnetic degrees of freedom couple within the same medium. The fine-structure constant is thereby elevated from a fixed parameter to a derived measure of vacuum coupling topology.
- **Emergent gauge unification:** Finally, this first-order approximation hints at a deeper symmetry: one in which the gauge interactions of electromagnetism (through μ_0) and the geometric deformation field of gravity (through G) are dual aspects of the same resonant vacuum structure. In this light, the

fine-structure constant emerges as the universal damping ratio that governs all interaction strengths, mediating how local excitations propagate through this unified background.

In conclusion, this corollary supports the overarching thesis of this work: that all physical constants—gravitational, electromagnetic, and quantum—are not separate inputs but instead arise from the intrinsic structure, resonant modes, and dissipation characteristics of the quantum-elastic vacuum field.

H. Derivation of the Gravitational Constant G in terms of ϵ_0

As a complementary derivation to the dynamical framework previously introduced—where G emerges from the structural electromotive response of the vacuum—we now turn to a static-field perspective based on classical electrostatics. This alternative approach leads to the same result, reinforcing the idea that gravity and electromagnetism are orthogonal projections of a common vacuum elasticity.

Consider the energy U required to assemble a sphere of charge with a uniform charge density, also known as the self-energy of some sphere [36], with elementary charge e and radius r , which can be expressed [36] as

$$U_{sphere} = \frac{3}{5} \cdot \frac{e^2}{4\pi\epsilon_0 r} \quad (60)$$

The total energy U in the system is related to its capacitance C and the potential V by:

$$U = CV^2$$

The potential (voltage) V at the surface of the sphere [18] is:

$$V = \frac{1}{4\pi\epsilon_0} \frac{e}{r}$$

We can express C in terms of the self-energy U and the potential V as:

$$C = \frac{U}{V^2}$$

Substituting the expressions for U and V , and operating, we have:

$$\begin{aligned} C &= \frac{U}{V^2} = \frac{\frac{3}{5} \cdot \frac{e^2}{4\pi\epsilon_0 r}}{\left(\frac{1}{4\pi\epsilon_0} \frac{e}{r}\right)^2} \\ &= \frac{3}{5} 4\pi\epsilon_0 r \rightarrow \frac{C}{r} = \frac{3}{5} 4\pi\epsilon_0 \end{aligned} \quad (61)$$

Within our framework, $[C] = [L] = [T]$ and ε_0 becomes dimensionless, so both sides of the equation become dimensionless (and thus, dimensionally consistent).

Note that, numerically, with the current accepted value for ε_0 [37], we have that

$$\frac{3}{5} \cdot 4\pi\varepsilon_0 \approx 6.6759 \times 10^{-11}$$

Which is indeed pretty close to the established value of the gravitational constant G [38].

*Structural Interpretation of $G \propto \varepsilon_0$: Reciprocity
between gravitational stiffness and electromagnetic
tension*

The previous derivation of the gravitational constant G from the electrostatic self-energy of a charged sphere arises naturally from the structural link between the gravitational coupling and the electric permittivity of the vacuum, once we have established that mass M and charge Q are structurally equivalent quantities within the unified oscillator model, i.e., $[M] \equiv [Q]$.

Note the precise structural similarity between the gravitational and electric field equations:

Field Law	Electrostatics	Gravitation
Gauss' law (diff.)	$\nabla \vec{E} = \frac{\rho_e}{\varepsilon_0}$	$\nabla \vec{g} = -4\pi G \rho_m$
Radial field	$E = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2}$	$g = G \frac{M}{r^2}$
Potential field	$\phi_E = \frac{Q}{4\pi\varepsilon_0 r}$	$\phi_G = -\frac{GM}{r}$
Self-energy (sph.)	$U_E = \frac{3}{5} \frac{Q^2}{4\pi\varepsilon_0 r}$	$U_G = -\frac{3}{5} \frac{GM^2}{r}$

These expressions differ only in sign (attractive vs. repulsive) and in their coupling constants: ε_0^{-1} and G , respectively. If mass and charge are interpreted as equivalent structural sources of field deformation, then the vacuum constants ε_0 and G must also be manifestations of the same underlying property of space: its stiffness in response to static source configurations.

Under this view, ε_0 measures the electric deformability of the vacuum (i.e., how easily it allows displacement fields due to charge), while G measures its gravitational deformability (how easily it allows curvature or acceleration fields due to mass). The gravitational constant G and the permittivity ε_0 are not independent quantities, but different expressions of the same underlying elastic-dissipative geometry of the vacuum. The equivalence becomes inevitable when the laws governing the fields are functionally identical and

the sources (mass and charge) are structurally interchangeable.

In this context, our postulate

$$G = \frac{3}{5} 4\pi\varepsilon_0 = \frac{3}{5} \frac{1}{K_e}$$

proposes a natural reciprocity: the vacuum's *longitudinal compliance* (gravitational softness) is inversely proportional to its *transverse stiffness* (electromagnetic tension). Put differently, the vacuum's ability to resist gravitational deformation is weakest precisely because it is most rigid electromagnetically. The stronger the electric field that the vacuum can sustain, the weaker the gravitational interaction that can emerge from the same medium.

This duality highlights a profound symmetry: *gravity and electromagnetism are orthogonal projections of the same underlying field elasticity*. The vacuum's ability to deform under longitudinal (gravitational) excitation is far more limited than under transverse (electromagnetic) excitation. In other words, the vacuum is extremely stiff in response to mass-like perturbations (as encoded in the smallness of G), and relatively compliant to charge-like perturbations (as seen in the largeness of K_e).

This not only reinforces the modal equivalence described previously but gives it a new dimension: the vacuum acts as a geometric impedance surface, whose tension and compliance balance across regimes to define the apparent strengths of fundamental forces. The interpretation $G \propto \varepsilon_0 \sim 1/K_e$ thus follows naturally as a structural necessity within this framework.

In conclusion, the result $G \propto \varepsilon_0$ is not an isolated numerical coincidence but the most natural consequence of structural equivalence between mass and charge. It validates the idea that all coupling constants emerge from a single elastic-dissipative fabric of space, whose geometric and energetic responses define the laws of physics as we experience them.

I. Corollaries: re-expressing Newton's Law and Coulombs Law in terms of momentum transfer in different modes

From the previously derived first-order approximations, such as $G \approx \mu_0 \cdot \alpha^2$ and $k_B \approx \mu_0/c^2$, it follows that:

$$G \approx k_B \cdot \alpha^2 \cdot c^2$$

This allows us to re-express Newton's gravitational law as a thermo-entropic interaction:

$$\frac{F_g}{4} = k_B \cdot \frac{\left(\frac{Mc}{\gamma}\right) \cdot \left(\frac{mc}{\gamma}\right)}{r^2},$$

where $\gamma = \frac{1}{2\alpha}$.

The prefactor $\frac{1}{4}$ reflects the same quadratic damping structure appearing both in the electromagnetic Lagrangian $\mathcal{L}_{EM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$ and our expression for the gravitational stiffness $G = \mu_0 \cdot \frac{1}{4}\zeta^2$. It encodes the modal character of the gravitational field as a second-order elastic response to projected momentum densities through the vacuum lattice, via the symmetric tensor $\zeta_{\mu\nu} \propto \mathcal{G}_{\mu\alpha}\mathcal{G}^{\alpha\nu}$. Thus, the factors $\frac{Mc}{\gamma}$ and $\frac{mc}{\gamma}$ correspond to effective, damped relativistic momenta —not because particles move at light speed, but because their gravitational field propagates through the vacuum's elastic-dissipative structure. These momenta are longitudinal projections of the energy-momentum current I_g , whose propagation is modulated by the damping structure encoded in $\zeta_{\mu\nu}$. Thus, gravity emerges as the effective resistance to the coherent alignment of projected momenta through the vacuum's dissipative tensorial geometry.

By symmetry, the Coulomb force can be reformulated analogously as a transverse-mode momentum interaction:

$$F_e = K_e \cdot \frac{Q_1 Q_2}{r^2} = \frac{\mu_0 \cdot c^2}{4\pi} \cdot \frac{Q_1 Q_2}{r^2} = \mu_0 \cdot \frac{(Q_1 c)(Q_2 c)}{4\pi r^2}$$

This structure mirrors the gravitational expression, with Qc playing the role of transverse modal momentum and the vacuum magnetic permeability μ_0 acting as the transverse field stiffness. Thus, both Newton's and Coulomb's laws appear as complementary modal projections of the same unified vacuum tensorial response, mediated by $\mathcal{G}_{\mu\nu}$ and its derived damping structure $\zeta_{\mu\nu}$.

Momentum Transfer and Entropic Gradient Interpretation

In this formulation, both gravitational and electromagnetic interactions arise as manifestations of momentum exchange through a medium with intrinsic damping. For gravity, the damping factor $\gamma = 1/(2\alpha)$ emerges from the vacuum's resistance to longitudinal deformation, requiring greater energy or mass to transmit equivalent field influence. The Boltzmann constant k_B , here, quantifies the entropy cost per unit of squared momentum transfer, embedding gravitational force within a statistical mechanics framework.

This aligns with the heuristic view that gravity arises from the statistical organization of vacuum degrees of freedom. The product $p_M p_m \sim (Mc)(mc)$ defines a correlation between the relativistic momenta of two masses. Dividing by r^2 reflects the dilution of momentum correlation due to spatial dispersion in an entropic field, whose effective stiffness is modulated by $\zeta = 2\alpha$.

Electromagnetism, analogously, corresponds to a transverse mode where the vacuum responds to current-like excitations. Charges Q and q , moving at light speed, define maximal transverse stress contributions, and the vacuum responds with a resistance determined by μ_0 . Thus, K_e , μ_0 , and G all measure the vacuum's ability to redistribute momentum between sources — filtered by geometry, damping, and scale.

In summary, both interactions reflect momentum exchange across a structured medium. What differs is the symmetry (transverse vs. longitudinal), the effective damping, and the entropy associated with deformation. The gravitational force emerges as a highly suppressed, entropy-weighted momentum flow — not because the vacuum is weakly coupled, but because it is *rigid* against longitudinal oscillations, whereas the electromagnetic force reflects a more efficient, transversely mediated momentum exchange, amplified by the vacuum's comparatively soft resistance to shear-like charge deformations.

Relationship between the gravitational constant G and c

As a final -and crucial- note on the gravitational constant G , substituting $G = \mu_0 \cdot \alpha^2$ one can check that

$$G \cdot c \approx \mu_0 \cdot c \cdot \alpha^2 = Z_0 \cdot \alpha^2 \approx \frac{1}{50}$$

where $Z_0 = \mu_0 c \approx 377 \Omega$ is the vacuum impedance. Numerically, this yields:

$$G \cdot c \approx \frac{1}{50}$$

This dimensionless combination suggests that the product $G \cdot c$ defines a fundamental 'resistive-like' constant of the vacuum, which we denote as the *natural resistance* X_N . Motivated both by numerical proximity and by its appearance in the Einstein-Hilbert action pre-factor, we propose that:

$$X_N := G \cdot c \approx \frac{1}{16\pi}$$

from which one can formally write the first-order approximation:

$$c \approx \frac{1}{16\pi G} \quad (62)$$

This postulate is not arbitrary: the factor $\frac{1}{16\pi G}$ appears in the Einstein-Hilbert action

$$S = \frac{c^4}{16\pi G} \int R \sqrt{-g} d^4x,$$

suggesting that G and c are not entirely independent constants, but rather encode dual aspects of the vacuum's elastic and dissipative structure. In our framework, where both μ_0 and α characterize the internal stiffness and attenuation of the vacuum, the combination $G \cdot c \sim Z_0 \cdot \alpha^2$ reflects the effective coupling between the responses of the gravitational and electromagnetic field.

J. Derivation of the Casimir Constant C_c

The magnitude of the Casimir force per unit area A between two perfectly conducting plates separated by a distance d is classically given by:

$$\frac{F_C}{A} = -\frac{\pi^2 \hbar c}{240 d^4} \approx \frac{1.3 \times 10^{-27} \text{ N} \cdot \text{m}^{-2}}{d^4},$$

where \hbar is the reduced Planck constant and c is the speed of light in a vacuum. The calculation of this expression involves handling a divergent sum using a regularization technique involving the Riemann zeta function. Using our model, we can avoid the divergence handling and directly relate the Casimir effect to vacuum energy density.

Let us define the Casimir constant C_c as the quantum of "Casimir effect" force per unit of area. The zero-point energy per quantum oscillator, $E_0 = \frac{\hbar c}{2 \cdot \lambda}$, produces an elementary electromotive-like force $\mathcal{E}_0 = \frac{\hbar c}{2 \cdot \lambda^2}$, which, divided by the surface area of a sphere $4\pi r^2$ and choosing the characteristic length scale $\lambda = r = 1 \text{ m}$, we obtain the first-order approximation of Casimir constant::

$$C_c = \frac{F_{qho}}{A} \approx \frac{\frac{\hbar c}{2}}{4\pi \cdot 1 \text{ m}^4} \approx 1.26 \times 10^{-27} \text{ N} \cdot \text{m}^{-2}$$

This value agrees with both theoretical estimates and experimental measurements [39, 40], and illustrates the vacuum's intrinsic capacity to sustain baseline oscillatory stress, constrained by spacetime geometry. Thus, we may write:

$$\frac{F_C}{A} = \frac{C_c}{d^4} \approx \frac{\frac{\hbar c}{2}}{4\pi \cdot (1 \text{ m})^4 \cdot d^4}, \quad (63)$$

which offers a more direct and physically intuitive way to compute the Casimir force, bypassing the need for divergent series summation or zeta-function regularization.

K. The elementary charge as the quotient of mass at rest and total relativistic energy

Recall the equation

$$\Phi_E = \oint_S \vec{E} \cdot d\vec{A} = \frac{e}{\varepsilon_0} \approx \mu_0 \cdot 1 \text{ m} \cdot 2\alpha$$

Note that, solving for the elementary charge e , and as $\varepsilon_0 \mu_0 = \frac{1}{c^2}$, we get our already derived first-order approximation

$$e \approx \mu_0 \varepsilon_0 \cdot 1 \text{ m} \cdot 2\alpha = \frac{2\alpha \cdot 1 \text{ m}}{c^2}$$

As we have established that μ_0 has dimension of voltage V , and that $\varepsilon_0 \cdot 1 \text{ m}$ is a capacitance C , then we have that

$$[e] = \left[\frac{C \cdot V}{\gamma} \right]$$

Which is dimensionally consistent, and provides a new interpretation of the elementary charge as a product of the vacuum's electromagnetic properties, encapsulated by its capacitance ε_0 and voltage μ_0 , and modulated by α as some Lorentz factor γ . This formulation aligns with the notion that the elementary charge is an emergent property of the vacuum, induced by its interaction with relativistic effects.

Moreover, note that for any mass at rest m_0 we have

$$e = \frac{m_0}{m_0 \cdot c^2 \cdot \gamma} \quad (64)$$

As a result, e can be interpreted as the quotient of some mass at rest, and the total relativistic energy of that mass. This connects charge directly to relativistic energy-momentum structure, framing it as a *transverse projection* of mass-energy coupling, in contrast to gravity's longitudinal projection.

The above points toward a deeper unity between electromagnetism and geometry. In this framework, electric charge can be reinterpreted as a gauge-geometric defect—a localized deformation arising from how mass-energy interacts with the vacuum's transverse modes. While mass induces longitudinal curvature associated with gravitation, charge emerges as the transverse projection of this same mass-energy content, modulated by the vacuum's elastic and dissipative structure. In particular, the elementary charge e reflects the vacuum's ability to support shear-like deformations sourced by relativistic-non-relativistic coupling. Rather than a primitive electromagnetic label, it becomes a geometric signature

of transverse curvature in the spacetime lattice—an imprint of how mass–energy interacts with internal vacuum symmetries through the damping tensor $\zeta_{\mu\nu}$. This reinforces the central idea that charge, mass, energy, and spacetime curvature are not independent attributes, but modal expressions of a single elastic-dissipative field. Their apparent distinctions arise from how energy–momentum flows project onto different tensorial modes—longitudinal or transverse—within the unified geometric fabric of the vacuum.

Final remark:

The formula links the elementary charge to the motion of the particles that are "suitable" to have charge. This suggests that the elementary charge is not simply a static property but one that depends on the fundamental particle's interaction with spacetime itself, particularly through its relativistic spin and magnetic dipole moment, both of which are transverse in nature. In this light, the elementary charge appears as a *topological quantization* of transverse curvature modes around localized energy densities. Charge could arise from internal rotational or topological properties, becoming a geometrical descriptor of vacuum deformation in the presence of matter and motion.

Part III: the basis of the fundamental entropic field

V. MASS AS AN EMERGENT PROPERTY OF SPACETIME ELASTICITY

In this section, we formalize the reinterpretation of mass as an emergent property of spacetime. By considering Hooke's law and Newton's law as the most fundamental force laws, we derive a new perspective on mass linked to the elasticity of spacetime.

A. Derivation of mass from Hooke's Law and Newton's Law

Hooke's law states that the force exerted by an elastic system is proportional to the displacement:

$$\vec{F} = -k\vec{x}, \quad (65)$$

where k is the elasticity constant and \vec{x} is the displacement from the equilibrium position. On the other hand, Newton's second law expresses force as:

$$\vec{F} = m \cdot \vec{a}, \quad (66)$$

where \vec{a} is the acceleration. Equating both expressions:

$$m \cdot a = -k \cdot x. \quad (67)$$

Since acceleration can be rewritten as $\vec{a} = d^2x/dt^2$, solving for m , we obtain:

$$m = -k \cdot \frac{x}{a} \rightarrow [m] = -[k][T^2]. \quad (68)$$

B. Action as the Fundamental Elastic Response of Spacetime

We now interpret the term x/a within the context of spacetime elasticity. Since action S is defined as the integral of the Lagrangian over time:

$$S = \int L dt, \quad (69)$$

and given that the Lagrangian L is the difference between kinetic and potential energy,

$$L = T - V, \quad (70)$$

we observe that displacement x modifies the relationship between kinetic and potential energy, while acceleration a governs the rate of change in this transformation. Noting that, applying the equivalence $M \equiv L \equiv T$, action has the same dimensional form as x/a :

$$\left[\frac{x}{a}\right] = [T^2] \equiv [E \cdot T], \quad (71)$$

we propose that the fundamental relationship defining mass can be rewritten as:

$$m = -kS, \quad (72)$$

where action S encapsulates the elastic response of spacetime to force, k represents the effective elastic modulus of the vacuum along the relevant deformation mode, and the negative sign reflects the restoring nature of the elastic response. It expresses that mass reflects the temporal accumulation of resistance to deformation in the vacuum's elastic-dissipative lattice. This formulation coheres with the earlier identification of gravitational stiffness via $\zeta_{\mu\nu}$ and can be generalized as a contraction between the stress and strain tensors:

$$m \sim \zeta_{\mu\nu} \mathcal{G}^{\mu\nu}$$

VI. DERIVATION OF FUNDAMENTAL PARAMETERS OF ELECTROMAGNETIC FIELD

A. Fundamental parameters of the electromagnetic field

Building on the interpretation of mass as an elastic response of spacetime, we now explore how

this formulation naturally leads to the derivation of electromagnetic field parameters. Since within our framework mass has dimensions of spacetime, and is given by $m = -k \cdot S$, we deduce that k must have dimensions of frequency. By substituting k with the quantum of angular frequency $\frac{c}{\lambda}$, and using Planck's constant h for the quantum of action, we obtain an expression of mass:

$$m = \frac{hc}{\lambda} \quad (73)$$

This equation directly links the energy of photons (or other quantum excitations) to mass, reinforcing Einstein's mass-energy equivalence from a fundamentally new perspective.

1. The Physical Model: The Quantum Harmonic Oscillator and its Lagrangian density

The foundational postulate of this work is that the vacuum is a lattice of quantum harmonic oscillators. The energy of such an oscillator is quantized in units proportional to its angular frequency, ω . The ground-state energy is $E_0 = \frac{1}{2}\hbar\omega$ [23], and the energy quantum required to excite the oscillator to the next level is $\Delta E = \hbar\omega$ [41].

Given that our model describes the vacuum as an ensemble of these oscillators, the Lagrangian density—which represents the fundamental dynamics of a single mode or "cell" of this vacuum lattice—must naturally inherit this angular dependence. Furthermore, the quantum of action \hbar , which holds a unique role in quantum mechanics, governs the *phase* of the quantum amplitude in the path integral formalism, $e^{iS/\hbar}$. Phase is, by its very nature, an angular quantity. It is therefore theoretically consistent that the density from which this phase is integrated—the Lagrangian density—should be fundamentally angular. It represents the rate of phase accumulation per unit of four-volume, a concept more naturally associated with ω (radians per unit time) than with f (cycles per unit time).

2. Modal Lagrangian Density versus Effective Energy Density

A crucial distinction must be made between the *Lagrangian density* (\mathcal{L}) used in the action integral, and the *measured vacuum energy density* (ρ_{vac}) as an observable cosmological parameter. We propose a clear distinction between the fundamental, modal Lagrangian density (\mathcal{L}) and the effective, measured energy density (ρ_{vac}):

- **The Lagrangian Density** (\mathcal{L}) describes the dynamics of a single, coherent, fundamental mode of the vacuum oscillator lattice. It is a theoretical, microscopic quantity. We identify this with the angular form:

$$\mathcal{L}_{\text{modal}} = \frac{\hbar c}{1 m^4}$$

- **The Measured Energy Density** (ρ_{vac}) is a macroscopic, cosmological observable. It reflects the net effect of an immense number of uncoordinated vacuum oscillators, with their phases and spatial orientations being statistically random. The observable energy density is thus an effective quantity:

$$\rho_{\text{eff}} \approx \frac{1}{2\pi} \int_0^{2\pi} \mathcal{L}_{\text{modal}} d\theta = \frac{\mathcal{L}_{\text{modal}}}{2\pi} = \frac{\hbar c}{2\pi \cdot 1 m^4}$$

Finally, note that:

- Substituting $\lambda = 1 m$ in (73), corresponding to the characteristic scale of the unit quantum oscillator in our framework, we obtain the quantum of mass-energy for the electromagnetic field $m = \frac{\hbar c}{1 m}$.
- Dividing this quantum mass-energy by a volume $V = 1 m^3$, and considering the linear momentum $\hbar = \frac{h}{2\pi}$ we obtain a quantum of mass density $\rho_{\text{vac}} = \frac{\hbar c}{1 m^4}$ which corresponds with (VIA 2). When transitioning from the description of a single, coherent angular mode to a macroscopic, isotropic average over all possible phases or solid angles (VIA 2), we get $\rho_{\text{eff}} \approx \frac{\hbar c}{2\pi \cdot 1 m^4} \approx 5.03 \times 10^{-27} \text{ kg m}^{-3}$ which is in excellent agreement with cosmological measurements from the Planck satellite mission [19].

3. Derivation of the Quantum of Action from the Einstein-Hilbert Action

In a non-relativistic setting, an *action* S can be viewed as the time integral of the total energy (or, more precisely, the Lagrangian). In special relativity or general relativity, this idea generalizes to integrating a *Lagrangian density* \mathcal{L} over the entire spacetime volume. Formally,

$$S = \int \mathcal{L} \sqrt{-g} d^4x, \quad (74)$$

where $g = \det(g_{\mu\nu})$ is the determinant of the metric tensor $g_{\mu\nu}$. The factor $\sqrt{-g}$ ensures *general covariance* of the volume element, making the action a scalar under coordinate transformations.

The Einstein-Hilbert action [42] [43] [4] in General Relativity with a cosmological constant is typically expressed as:

$$S_{EH} = \frac{c^4}{16\pi G} \int (R - 2\Lambda) \sqrt{-g} d^4x \quad (75)$$

We can equate the Einstein-Hilbert action with cosmological constant to the general equation of action we have defined as:

$$S_{EH} = \int \mathcal{L} \sqrt{-g} d^4x = \frac{c^4}{16\pi G} \int (R - 2\Lambda) \sqrt{-g} d^4x \quad (76)$$

We can substitute the cosmological constant Λ via

$$\Lambda = 8\pi G \frac{\rho_{vac}}{c^2}, \quad (77)$$

Assuming a De Sitter universe [44] [45], one can substitute $R = 4\Lambda$ and (77) to obtain that

$$\begin{aligned} S_{EH} &= \frac{c^4}{16\pi G} \int (R - 2\Lambda) \sqrt{-g} d^4x \\ &= \frac{c^4}{16\pi G} \int 2\Lambda \sqrt{-g} d^4x \\ &= \frac{c^4}{16\pi G} \int \frac{16\pi G}{c^2} \cdot \rho_{vac} \sqrt{-g} d^4x \\ &= \int \rho_{vac} \cdot c^2 \sqrt{-g} d^4x \end{aligned} \quad (78)$$

Therefore, we identify the Lagrangian density \mathcal{L} with the energy equivalent to vacuum energy density

$$\mathcal{L} \equiv \rho_{vac} c^2 \quad (79)$$

Recent cosmological observations consistently yield an extremely small but non-zero value for Λ , compatible with an effective vacuum density ρ_{eff} corresponding precisely to the electromagnetic scale proposed in our unified field theory framework [46] [47]. This remarkable concordance suggests that the electromagnetic mode provides the natural interpretation of the observed cosmological vacuum state.

Therefore, substituting ρ_{vac} with the expression obtained for the vacuum energy density in its Lagrangian form (VI A 2), we have that

$$\rho_{vac} c^2 = \frac{\hbar c}{1 m^4} c^2 = \frac{\hbar c^3}{1 m^4} \quad (80)$$

In an almost flat universe, spacetime is only slightly curved, and the metric tensor $g_{\mu\nu}$ deviates minimally from the flat Minkowski metric $\eta_{\mu\nu}$. Therefore, the determinant of the metric tensor g can be expressed as:

$$\sqrt{-g} \approx 1 + \frac{1}{2} \delta g. \quad (81)$$

For practical purposes in an almost flat universe, δg is so small that $\sqrt{-g} \approx 1$ is a valid approximation.

In order to perform a dimensionally consistent evaluation of the action integral in an almost-flat spacetime, we adopt the standard Minkowskian regularization scheme in which spatial and temporal components are treated on equal footing [48]. In natural units, this is achieved by setting $dx^0 = c dt$, thereby expressing time in units of length. Recall that we have established that the fundamental measure of the system in the electromagnetic mode is $\tau = \frac{1 s}{c} \equiv \frac{1 m}{c}$ (IV A 2, I), which corresponds to the characteristic propagation distance of light during one second in the chosen normalization.

Accordingly, the spacetime volume element in four dimensions becomes:

$$d^4x = dx^0 dx^1 dx^2 dx^3 = c dt \cdot \left(\frac{1 m}{c} \right)^3 = \frac{1 m^4}{c^3}$$

This regularization ensures that the resulting action remains Lorentz-invariant, while the dimensional consistency of the Lagrangian density $\mathcal{L} \sim \rho_{vac} c^2$ is preserved. Furthermore, this prescription allows the action to be computed using purely spatial scales, while still capturing the relativistic structure encoded in the Minkowski metric. As a result, substituting, one gets that

$$S_{EH} = \frac{\hbar c^3}{1 m^4} \cdot \frac{1 m^4}{c^3} = \hbar \quad (82)$$

4. The Bridge Between the Cosmological and Quantum Realms

The result derived in Section VI A 3, namely $S_{EH} = \hbar$, establishes a profound and direct bridge between the two pillars of modern physics: General Relativity and Quantum Mechanics. It demonstrates that the Einstein-Hilbert action—the very function that describes the large-scale dynamics of spacetime and gravity—is, under the conditions of a vacuum-dominated universe, numerically identical to the fundamental quantum of action, \hbar .

This is a fundamental statement about the nature of reality. It suggests that the "cost" of action for a fundamental 4-volume of spacetime to exist and evolve under its own vacuum energy is precisely one unit of quantum action. The macroscopic curvature described by Einstein's theory is thus shown to be built from the same fundamental, discrete "building blocks" that govern the probabilistic nature of particles at the

microscopic scale. This finding strongly supports the central thesis of this work: that a single, unified quantum-oscillatory framework underlies all physical phenomena, from the cosmological to the quantum.

5. *The Quantization of Spacetime Geometry*

This derivation provides a compelling physical interpretation for the quantization of gravity. By equating the gravitational action to \hbar , we are led to the conclusion that spacetime geometry itself is quantized at its most fundamental level. The curvature of spacetime is therefore not an infinitely smooth and continuous property; rather, its manifestation in terms of action is discretized.

Within our model of the vacuum as a lattice of quantum oscillators, this result emerges as a natural consequence. A quantized lattice is expected to exhibit quantized properties. This derivation reveals that the most fundamental property of all—the action of the geometry itself—is no exception. Each "cell" of the spacetime lattice contributes exactly \hbar to the total action of the universe, reinforcing the idea that gravity is not a classical field imposed upon a quantum world, but is an emergent, large-scale manifestation of the quantum-mechanical behavior of the vacuum itself.

6. *Self-Consistency of the Theoretical Framework*

The power of this result also lies in its role as a stringent self-consistency check for the entire theoretical framework developed in this paper. The derivation began with the standard, universally accepted Einstein-Hilbert action. The only non-standard element introduced was the expression for the vacuum energy density, ρ_{vac} , which was derived independently from our quantum oscillator model and justified by its correspondence with experimental measurements.

The fact that the final output was not an arbitrary number but precisely \hbar —a cornerstone of quantum physics—is a remarkable validation of our initial postulates. It demonstrates that the principles of dimensional collapse, the interpretation of mass as an elastic response, and the modal nature of vacuum energy all work in concert within the established framework of General Relativity to produce a deeply meaningful physical result. This elevates constants like \hbar from being merely empirical inputs to being derived properties of the vacuum's geometric dynamics, thus closing a

great conceptual loop in our understanding of the universe's fundamental constants.

VII. CONNECTION BETWEEN THE STEFAN-BOLTZMANN CONSTANT AND LONDON DISPERSION FORCES

In the framework developed here, we can connect the Stefan-Boltzmann constant σ to the fundamental constants describing vacuum fluctuations and intermolecular interactions, specifically the London dispersion (van der Waals) forces. This connection shows how blackbody radiation and quantum dispersion forces originate from a common underlying structure of vacuum fluctuations.

A. Stefan-Boltzmann Radiation and Its Dimensional Structure

The Stefan-Boltzmann law expresses the radiative energy flux density as:

$$R = \sigma T^4, \quad (83)$$

where R represents an energy flux per unit area, with dimensions of L^{-2} within our theoretical framework. The classical expression for Stefan-Boltzmann constant is:

$$\sigma = \frac{\pi^2 k_B^4}{60 \hbar^3 c^2} \text{W m}^{-2} \text{K}^{-4} \quad (84)$$

This result shows that the Stefan-Boltzmann constant inherently carries a dependence on the structure of vacuum fluctuations. Within our framework, we have that $[\sigma] = [\text{W m}^{-2} \text{K}^{-4}] \equiv [L^{-6}]$, and this $\frac{1}{r^6}$ dimensionality points strongly to the equations of quantum dispersion interactions.

B. London Dispersion Forces and Their Emergence from Vacuum Fluctuations

London dispersion forces arise from transient dipole-induced dipole interactions mediated by vacuum fluctuations of the electromagnetic field. The energy potential governing these interactions between two neutral molecules or atoms is given by:

$$U_{\text{London}}(r) = -\frac{C_6}{r^6}, \quad (85)$$

where C_6 is a coefficient that depends on the polarizability of the interacting species and is ultimately linked to the structure of vacuum fluctuations.

At the microscopic level, London dispersion interactions decay as $\frac{1}{r^6}$ due to the localized nature of transient dipoles. However, in condensed matter systems, the cumulative effect of many such interactions modifies the overall scaling. When considering bulk materials, the total interaction energy per unit area between two solids exhibits a slower decay:

$$U_{\text{bulk}}(r) \sim -\frac{C_6}{r^3}, \quad (86)$$

which reflects the summation of contributions over a macroscopic volume rather than individual dipole-dipole interactions.

C. Connecting Thermal Radiation to Dispersion Forces

We postulate, based on the scaling behavior and dimensional correspondence, that

$$U(r) = -\sigma \cdot C_6 \quad (87)$$

$$R = \sigma T^4 = \frac{\sigma C_6}{r^3}. \quad (88)$$

This equations propose that the radiative energy flux density arises as the macroscopic London dispersion interactions in bulk matter. In this analogy, thermal radiation arises as the coherent superposition of vacuum-induced dipole interactions across a macroscopic surface, with $T^4 \propto \frac{C_6}{r^3}$ encoding an effective dipole-density scaling.

Thus, the Stefan-Boltzmann constant does not merely reflect an empirical radiation law, but encodes the bulk thermodynamic response of an elastic quantum vacuum. Its microscopic origin in dispersion forces shows that both radiation and intermolecular interactions emerge from a common substrate: the fluctuation-dissipative structure of spacetime

D. Implications for the Unified Description of Vacuum Energy and Thermodynamics

The connection between Stefan-Boltzmann radiation and London dispersion forces highlights the profound relationship between thermal radiation, vacuum fluctuations, and the fundamental nature of space-time interactions. The Stefan-Boltzmann constant encapsulates the large-scale thermodynamic consequences of microscopic vacuum fluctuations, acting as an effective coupling constant between radiation and space-time structure. This result further supports the idea that the fundamental forces governing blackbody radiation, vacuum

energy, and intermolecular interactions are unified under a common theoretical framework, wherein space-time itself exhibits elasticity-like properties encoded through its interaction with vacuum fluctuations.

E. Boltzmann Constant as a Relativistic Thermodynamic Force: A Unruh-Inspired Equality

Building on the reinterpretation of k_B as a thermo-entropic force (see Sec. IV A 3) and the fundamental equivalence introduced earlier (Eq. 51), we now propose a novel formulation of the Boltzmann constant as an emergent relativistic force.

Assuming the dimensional equivalence $1 \text{ K} \equiv 1 \text{ m} \equiv 1 \text{ s}$ within our elastic vacuum framework, we express k_B as:

$$k_B = \frac{hc}{2 \cdot 1 \text{ m}} \cdot \frac{1}{2\alpha \cdot 1 \text{ s}} = \frac{E}{a} \quad (89)$$

In this expression, k_B acquires the form of a Newtonian-like force $F = ma$, with the following components:

- $\frac{hc}{1 \text{ m}} \rightarrow m$: The characteristic energy scale of the vacuum, associated with a fundamental quantum of mass or photon energy.
- $\frac{1}{2\alpha \cdot 1 \text{ s}} = \frac{\gamma}{1 \text{ s}} \rightarrow a$: An effective proper acceleration, where the Lorentz-like factor $\gamma = \frac{1}{2\alpha}$ encodes the vacuum's resistance to excitation.

Thus, the Boltzmann constant k_B emerges as a quantized force scale, representing the vacuum's intrinsic responsiveness to acceleration. In this interpretation, entropy and temperature arise from the inertial resistance of spacetime to deformation, with k_B capturing the proportionality between energetic input and induced entropic curvature.

This Unruh-inspired formulation reinforces the view that thermodynamic quantities—such as temperature, and heat—are fundamentally geometric in nature. Here, k_B bridges the gap between thermal response and relativistic motion, playing a role analogous to that of G or μ_0 in mediating the vacuum's reaction to mass or charge, respectively. In this sense, k_B can be viewed as the *thermo-entropic stiffness constant* of spacetime: a universal coupling between acceleration, information flow, and thermal excitation. This perspective helps unify quantum field theory, thermodynamics, and general relativity within a common elastic-dynamical substrate.

VIII. PROPOSAL OF A NEW FIELD MODE: THE THERMO-ENTROPIC FIELD

The plausibility of a structured field theory uniting gravitational and entropic dynamics is supported by a range of independent theoretical and empirical findings:

- **Gravitational wave observations**, notably those by LIGO and Virgo, confirm that the gravitational field \vec{g} can vary with time [49]. This supports the existence of dynamical couplings with an auxiliary field \vec{T} , where temporal variations in the entropic sector may induce circulation-like components in \vec{g} .
- **Black hole thermodynamics** reveals deep links between gravitational phenomena and thermodynamic quantities such as entropy and temperature [50, 51], supporting the idea that the entropic field \vec{T} is not a derivative phenomenon, but rather a fundamental component of spacetime structure.
- **Experimental confirmations of gravitomagnetic effects**, such as those from Gravity Probe B [52], show that rotating masses generate a field component dependent on mass currents. This behavior is consistent with the idea that a circulating mass flow \vec{J}_m contributes to the generation of a complementary field \vec{T} , in analogy with magnetism.
- **Thermodynamic derivations of gravitational dynamics**, such as Jacobson’s approach to Einstein’s equations [10] and Verlinde’s emergent gravity framework [11], suggest that gravity may arise from underlying entropic principles.
- **Thermoelectric relationships** further strengthen the proposal. In condensed matter physics, temperature gradients generate electric potentials (Seebeck effect), while electric currents produce or absorb heat (Peltier effect) [53]. These two-way couplings between energy and entropy mirror the kind of mutual interactions expected in a thermo-entropic field theory. Additionally, the Unruh effect shows how temperature can emerge from acceleration, reinforcing the connection between thermodynamics and spacetime structure.

As we will see, a natural way to formalize the interplay between gravity and entropy in the fabric of spacetime is through the introduction of a *thermo-entropic field pair* $\{\vec{g}, \vec{T}\}$, where \vec{g} represents the gravitational field and \vec{T} denotes a thermo-entropic field, which does not denote

temperature *per se*, but a circulating thermo-entropic field analogous to the magnetic field, generated by mass currents rather than charge. We coin the name *thermo-entropic* to reflect the intrinsic duality between radial mass-induced effects (gravity) and azimuthal thermo-entropy-induced circulation (thermo-entropic fields), both encoded in the elastic response of spacetime. In the following sections, we will construct a concrete theoretical framework supporting the emergence of this thermo-entropic pair, and detailing its precise mathematical relationship with the electromagnetic pair $\{\vec{E}, \vec{B}\}$.

Importantly, we will demonstrate that these two field pairs are not independent structures, but are instead related via a *modal scaling symmetry or projective geometric correspondence*. This scalar correspondence will show that \vec{g} and \vec{T} are alternative excitations—radial and azimuthal respectively, just as \vec{E} and \vec{B} do in the electromagnetic sector—of the same elastic substrate of spacetime from which electromagnetism also arises. Their geometric structure, scaling behavior, and source terms mirror those of \vec{E} and \vec{B} , thus reinforcing the central thesis of this theory: *all fundamental fields are modal projections of a single symmetric deformation tensor $\mathcal{G}_{\mu\nu}$, with observed differences arising from symmetry, geometry, and coupling hierarchy*.

A. Thermo-entropic Field as Hookean Deformation: Analogy with Fourier’s Law

In line with our unified interpretation of all classical interactions as elastic responses of the vacuum medium, we can use Fourier’s law of heat conduction [54] [55] and relate it to some type of induced “*thermo-entropic force*”, and Hooke’s law of linear elasticity. This correspondence further supports the identification of the thermo-entropic field as a projected mode of the symmetric deformation tensor $\mathcal{G}_{\mu\nu}$.

We begin with the standard form of Fourier’s law in vector notation:

$$\vec{q}_A = -k\nabla T, \quad (90)$$

where \vec{q}_A is the heat flux per unit area [W m^{-2}], k is the thermal conductivity [$\text{W m}^{-1} \text{K}^{-1}$], and ∇T is the temperature gradient [K m^{-1}]. To match the dimensional structure of other fields in the unified elastic formalism, we multiply each side by a characteristic length L , thereby defining a *line-integrated heat flux field*:

$$\vec{q} \equiv \vec{q}_A \cdot L, \quad (91)$$

which now carries units of power per unit length [W m^{-1}], consistent with the other vector fields in our framework. Then, Fourier's law becomes:

$$\vec{q} = -k\nabla T \cdot L = -\nabla P. \quad (92)$$

where ∇P is the power gradient [W m^{-1}]. Here, P is interpreted as a scalar power potential whose gradient drives thermal energy flow, just as V and Φ generate electric and gravitational fields, respectively. However, note that *in this framework, the scalar quantity P plays a role that is conceptually indistinguishable from entropy S : it quantifies the internal deformation of the vacuum associated with thermal processes.* Indeed, since both P and S are dimensionally equivalent in the collapsed vacuum-elastic formalism, and since they both act as sources of thermodynamic flow when modulated by temperature, *we can regard entropy as the natural scalar field driving thermo-entropic deformation.*

Thus, from the standpoint of vacuum elasticity, entropy is not merely a statistical descriptor, but a geometrically grounded scalar field, whose gradients yield observable thermal forces and fluxes. The identification of S with the scalar potential of the thermo-entropic field completes its structural analogy with gravitation and electromagnetism.

In exact parallel with the voltage $\mathcal{E} = \int \vec{E} \cdot d\vec{\ell}$ of electrostatics, the thermo-entropic field defines a *thermo-entropic electromotive force*

$$\mathcal{E}_T \equiv \int_{\ell} \vec{q} \cdot d\vec{\ell} \quad (93)$$

with units of power [W]. In the dimension-collapsed vacuum-elastic system adopted here, powers are adimensional, so \mathcal{E}_T plays exactly the same algebraic role as an (adimensional) electric EMF.

Given the dimensional equivalence between power and entropy in the vacuum-elastic unit system, the quantity \mathcal{E}_T can also be interpreted as a net entropy difference between two thermal regions. Thus, the thermo-motive force becomes not only a measure of energy flux, but also a geometric manifestation of entropic imbalance in the vacuum lattice—driving deformation analogously to how electric potential drives charge.

As a result, each classical field admits a corresponding integral expression that encodes its action over an extended region. The following table summarizes these correspondences:

Phenomenon	Field	Expression	Physical meaning
Heat	\vec{q}	$\int \vec{q} \cdot d\vec{A}$	Thermal flux
Electricity	\vec{E}	$\int \vec{E} \cdot d\vec{A}$	Electric flux
Magnetism	\vec{B}	$\int \vec{B} \cdot d\vec{A}$	Magnetic flux
Gravity	\vec{g}	$\int \vec{g} \cdot d\vec{A}$	Gravitational flux

If we denote by ΔT the temperature differential between adjacent isothermal layers, we can express the thermo-entropic response in a strictly Hookean form:

$$S = \kappa_{\text{dyn}} \Delta T \quad (94)$$

Here, S represents the entropy associated with the deformation of the vacuum medium, and κ_{dyn} acts as a dynamic entropic stiffness with dimensions [L^{-1}] in the vacuum-elastic unit system. This formulation reinforces the interpretation of entropy as a scalar elastic displacement field, and ΔT as its driving cause.

Hookean elasticity	Thermo-entropic
F (mechanical force)	P (power) / S (entropy)
Δx (displacement)	ΔT (Temperature diff.)
k (spring constant, [L^{-1}])	κ_{dyn} ([L^{-1}] or W s^{-1})

Therefore, the thermo-entropic field integrates consistently into our unified tensorial framework as a Hookean deformation mode, whose force-like response is power and whose generalized displacement is temperature difference.

B. Summary of structural analogies between elastic responses of the vacuum

We present below the structural correspondence between the linearized Fourier's law, Gauss's law in electrostatics, and Newton's law of gravitation:

Concept	Fourier's Law	Gauss's Law	Newton's Law
Source	$\nabla \cdot \vec{q}$	$\nabla \cdot \vec{E}$	$\nabla \cdot \vec{g}$
Potential	$P \equiv S$	V	Φ
Field	$\vec{q} = -\nabla S$	$\vec{E} = -\nabla V$	$\vec{g} = -\nabla \Phi$
Poisson eq.	$\nabla^2 S = k_B \rho_{\text{temp}}$	$\nabla^2 V = -\frac{\rho_e}{\epsilon_0}$	$\nabla^2 \Phi = 4\pi G \rho_m$

where ρ_{temp} represents a localized temperature density or distribution acting as the source of entropic deformation. Each of these field laws describes how a scalar potential gives rise to a vector field through a gradient operation, and how the divergence of that field connects to a source density via a Poisson-type equation. In this structural analogy:

- The entropy S plays the role of a scalar thermal potential,

- The linearized heat flux \vec{q} is analogous to the electric field \vec{E} or the gravitational field \vec{g} ,
- And the Laplacian $\nabla^2 S$ captures thermo-entropic curvature, in full parallel with electrostatic and gravitational curvature.

This unification of form supports the view that thermal phenomena, when interpreted through the elastic behavior of the vacuum, fit naturally within the same mathematical architecture as the electric and gravitational interactions. The thermo-entropic field, driven by entropy gradients and governed by thermal curvature, thereby integrates as a scalar deformation mode within the elastic manifold defined by the symmetric tensor $\mathcal{G}_{\mu\nu}$ (X). This geometrization of heat completes the triad of scalar sources—mass, charge, and temperature—unifying their corresponding field interactions as elastic responses of the vacuum encoded

in the symmetric tensor $\mathcal{G}_{\mu\nu}$.

IX. A DEEP DIVE ON THE THERMO-ENTROPIC FIELD FUNDAMENTALS

Based on the similarities between the electromagnetic pair $\{\vec{E}, \vec{B}\}$ and the proposed thermo-entropic pair $\{\vec{g}, \vec{\mathcal{T}}\}$, we propose a system of field equations mirroring Maxwell's equations. The gravitational field plays the role of the electric field, while the entropic field assumes the role of the magnetic field.

Below can be found a table summarizing the main derivations and relationships:

Quantity	Electromagnetism	Gravito-entropic
Source	Electric charge (q)	Mass (m)
Main field (circulatory)	$\vec{B} = \frac{\mu_0 \vec{I}}{2\pi r} \hat{\theta}$	$\vec{\mathcal{T}} = \frac{k_B \vec{I}_m}{2\pi r} \hat{\theta}$
Derived field (radial)	$\vec{E} = \frac{K_e Q}{r^2} \hat{r}$	$\vec{g} = \frac{GM}{r^2} \hat{r}$
Coupling constant	μ_0	$k_B = \mu_0/c^2$
Gauss's law	$\nabla \cdot \mathbf{E} = 4\pi K_e \rho_q$	$\nabla \cdot \mathbf{g} = -4\pi G \rho_m$
No-monopole law	$\nabla \cdot \mathbf{B} = 0$	$\nabla \cdot \mathcal{T} = 0$
Faraday's law	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\nabla \times \mathbf{g} = -\frac{\partial \mathcal{T}}{\partial t}$
Ampère-Maxwell law	$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$	$\nabla \times \mathcal{T} = k_B \mathbf{J}_m + k_B \varepsilon_0 \frac{\partial \mathbf{g}}{\partial t}$

TABLE II. Comparison of Maxwell-like laws for electromagnetism and the proposed gravito-entropic sector.

Here, \vec{I}_m and ρ_m respectively represent mass current and mass density. The product $k_B \varepsilon_0 = \frac{1}{c^4}$ plays a central role in the dynamic coupling of the gravito-entropic field, appearing as the analog of $\mu_0 \varepsilon_0$ in electromagnetism. It determines the propagation response of \vec{g} under temporal variations of the entropic field $\vec{\mathcal{T}}$, and encodes the universal stiffness of the vacuum to longitudinal, thermo-entropic excitations. Remarkably, this product can also be written as $k_B \varepsilon_0 \equiv \hbar/m^2$, suggesting that the minimal entropic deformation of the vacuum carries a quantized action density. This reinforces the interpretation of $k_B \varepsilon_0$ as a modal invariant of the elastic vacuum: a fundamental coupling constant linking action, entropy, and geometry in the thermo-entropic sector.

A. Fundamental parameters of the thermo-entropic field

From our proposal, we can derive the fundamental parameters of the thermo-entropic field just dividing the parameters obtained for the electromagnetic field by c^2 :

- We obtain the quantum of mass-energy for the thermo-entropic field $m_{entr} = \frac{\hbar}{2\pi c \cdot 1 \cdot m} \approx 5.6 \times 10^{-44}$ kg.
- We obtain a quantum of mass density $\rho_{entr} = \frac{\hbar}{2\pi c \cdot 1 \cdot m^4} \text{ kg m}^{-3}$.
- We can set the action as $\frac{\hbar}{c^2}$, which matches the result derived previously (25).

B. Deriving Unruh effect from the thermo-entropic field parameters and Newton's law

There are several checks that we can perform to further justify the validity of the fundamental parameters derived for the thermo-entropic field. In this subsection, we will focus on showing that the Unruh effect can be directly derived from the application of the fundamental expression of mass-energy for the thermo-entropic field and Newton's Law.

The **Unruh effect** [56] states that an observer with constant proper acceleration a in vacuum perceives a thermal bath at a temperature

$$T_{\text{Unruh}} = \frac{\hbar a}{2\pi c k_B}. \quad (95)$$

Rearranging gives

$$k_B = \frac{\hbar a}{2\pi c T_{\text{Unruh}}}. \quad (96)$$

We have already shown how k_B can be treated dimensionally as a force (IV A 3). Also, we have postulated that the expression of mass-energy for the thermo-entropic field is $m_{\text{entr}} = \frac{\hbar}{2\pi c \cdot \lambda}$. Using the equivalence $[L] \equiv [T_{\text{emp}}]$, we can easily see that the equation of the Unruh effect can be rewritten as

$$k_B = m_{\text{entr}} \cdot a \quad (97)$$

Showing how Unruh's effect can be derived from the application of Newton's law to the derived parameters of the thermo-entropic field.

C. Conclusion

The above derivations provide strong evidence that justify the existence of the thermo-entropic field. The Einstein-Hilbert action, traditionally rooted in curvature, emerges naturally as the action of the thermo-entropic field, and Unruh effect is just the manifestation of Newton's Law. This framework provides new insight into the thermo-entropic origins of gravity and suggests avenues for further exploration into quantum gravity and spacetime thermodynamics.

Part IV: Unified Field Theory from a Symmetric Deformation Tensor

X. THE SYMMETRIC FUNDAMENTAL TENSOR $\mathcal{G}_{\mu\nu}(x)$

Building on the elastic interpretation of the quantum vacuum proposed in Parts I–III, and the

dimensional unification $[M] = [L] = [T]$, the most reasonable theoretical framework that we can propose given our results is that all classical fields are emergent modes of a single, symmetric rank-2 field tensor:

$$\mathcal{G}_{\mu\nu}(x)$$

This tensor encodes the local deformation of a Lorentz-invariant, elastic spacetime substrate. It generalizes the role of both the metric tensor in relativity and the electromagnetic potential in gauge theory. Rather than treating electric, magnetic, gravitational, and thermo-entropic fields as distinct fundamental entities, we interpret them as geometrically distinct projections or excitation modes of $\mathcal{G}_{\mu\nu}$. Thus, each physical interaction would correspond to a different symmetry-breaking or geometric configuration within this unified field.

Interestingly, this projection-based interpretation of field emergence aligns conceptually with recent work by Partanen and Tulkki [57], who propose a unification framework where gravity arises from four coupled $U(1)$ gauge symmetries. In their approach, the spacetime metric is not taken as a fundamental structure but rather emerges from the modal structure of gauge fields defined on a flat background. Analogously, in our model, the symmetric deformation tensor $\mathcal{G}_{\mu\nu}$ encodes the elastic response of the quantum vacuum, whose radial and azimuthal modal projections manifest as the electromagnetic and thermo-entropic fields, respectively. This supports the idea that observable interactions are not independent fields but manifestations of deeper symmetry modes of the vacuum.

XI. PROPOSAL OF FIELD MODES AND ITS INTERPRETATION

Within the proposed unified framework, fundamental fields derived from distinct physical interactions exhibit a similar structure modulated by dimensionless factors derived from the theory. Specifically, the electric field (\vec{E}), magnetic field (\vec{B}), gravitational field (\vec{g}), and the thermo-entropic field (\vec{T}) (VIII) arise based on the deriva-

tions within this framework, and take the form:

$$\begin{aligned}
(i) \quad \vec{E} &= \frac{e}{4\pi\epsilon_0 r^2} \hat{r} \equiv \frac{2\alpha \cdot \mu_0 c^2}{c^2 \cdot 4\pi \cdot r} \hat{r} = 2\alpha \cdot \frac{\mu_0}{4\pi r} \hat{r} \\
(ii) \quad \vec{B} &= \frac{\mu_0 I}{4\pi r} \hat{\theta} = \frac{\mu_0 \cdot c}{4\pi \cdot r} \hat{\theta} = c \cdot \frac{\mu_0}{4\pi r} \hat{\theta} \equiv \frac{\vec{E} \cdot c}{2\alpha} \\
(iii) \quad \vec{g} &= \frac{Gm}{r^2} \hat{r} \equiv \frac{\mu_0 \alpha^2 \cdot \hbar c}{r^2 \cdot 2 m} \hat{r} \equiv \alpha^2 \cdot \frac{\hbar c}{1 m^2} \cdot \frac{\mu_0}{4\pi r} \hat{r} \\
(iv) \quad \vec{T} &= \frac{k_B \cdot 2\alpha \cdot I}{4\pi r} \hat{\theta} = \frac{2\alpha}{c^2} \cdot \frac{\mu_0}{4\pi r} \hat{\theta} \equiv \frac{\vec{g} \cdot c}{2\alpha} \quad (98)
\end{aligned}$$

where we have used $e = \frac{2\alpha \cdot 1 C}{c^2}$, $m = \frac{\hbar c}{2 \cdot 1 m}$ (VI A 2), $I = c$ (electromagnetic mode) and $I = \frac{1}{c}$ (thermo-entropic mode), together with the equivalences of (11).

Note that all the static fields adopt the generic form

$$\vec{\Phi}_X(r) = \frac{\mu_0}{4\pi r} \cdot C_X \cdot \hat{e}_X,$$

where $X \in \{E, B, g, T\}$ and C_X is a dimensionless coefficient. The direction \hat{e}_X indicates the field's spatial orientation — either radial or azimuthal.

In this formulation, the characteristic expressions for the fundamental fields are constructed from the elementary contribution of discrete quantum oscillators. The magnetic field, for instance, is not derived from the standard expression for an infinite wire ($\vec{B} = \mu_0 I / 2\pi r$), but rather from the Biot–Savart law applied to a localized oscillatory mode, yielding the expression $\vec{B} = \mu_0 I / 4\pi r$, which better reflects the point-like, modular nature of the vacuum excitations in this framework. The mass m has been taken from the zero-point energy associated with a confined quantum harmonic oscillator mode of the vacuum, becoming an emergent quantity from the fundamental vacuum oscillation modes. This aligns with the conception of mass as a localized deformation in some elastic medium, and the unification of field modes under a shared geometric and dynamical substrate.

The patterns of the fields can be observed in the following summarizing table:

Field	Expression	Constant	Scaling	Direction
\vec{E}	$\frac{2\alpha}{4\pi} \cdot \frac{\mu_0}{r} \hat{r}$	$\frac{2\alpha}{4\pi}$	c^0	Radial \hat{r}
\vec{B}	$\frac{c}{4\pi} \cdot \frac{\mu_0}{r} \hat{\theta}$	$\frac{1}{4\pi}$	c^1	Acimutal $\hat{\theta}$
\vec{g}	$\frac{\alpha^2 \cdot \hbar c}{4\pi \cdot 1 m^2} \cdot \frac{\mu_0}{r} \hat{r}$	$\frac{c^2}{4\pi}$	c^{-3}	Radial \hat{r}
\vec{T}	$\frac{2\alpha}{4\pi c^2} \cdot \frac{\mu_0}{r} \hat{\theta}$	$\frac{2\alpha}{4\pi}$	c^{-2}	Acimutal $\hat{\theta}$

TABLE III. Proposed hierarchy of unified field modes.

where we have used $\frac{\hbar}{1 m^2} \propto \frac{1}{c^4}$ (21) to derive the scaling of \vec{g} .

This refined formulation reveals that all four field expressions share a universal structural factor:

$$\frac{\mu_0}{4\pi r}$$

which can be interpreted as the universal elastic modulus of the vacuum. This quantity encapsulates the intrinsic coupling between elastic excitations and physical sources such as charge, mass, and temperature. Notably, this coupling is not arbitrary: using our fundamental identity (51)

$$\mu_0 \cdot e \equiv \frac{\hbar \cdot c}{1 m},$$

one can easily derive

$$\frac{\mu_0}{4\pi} = \frac{\hbar c}{2 \cdot 1 m \cdot e} = \frac{E_0}{e},$$

where $E_0 = \hbar c / (2 \cdot 1 m)$ is identified as the zero-point energy of a fundamental oscillator mode of the vacuum, and simultaneously interpreted as the rest mass energy associated with a unit deformation cell. This expression encodes $\mu_0 / 4\pi$ as some *fundamental vacuum deformation*, intrinsic to all field excitations and independent of the specific interaction, akin to some *deformation current*: the amount of vacuum energy deformation (in the form of rest mass) per unit of charge. In this sense, it quantifies the vacuum's elastic response rate to localized sources—be they of electric or gravitational nature. And thus, we will show in the next subsection how it can be related naturally to the fundamental solution (Green's function) of the Poisson equation in three dimensions.

A. Spectral Origin of Field Modes: Discrete Laplacian and Vacuum Structure

The fundamental solution (Green's function) of the Poisson equation in three dimensions is given by:

$$\nabla^2 \Phi(\mathbf{r}) = -\delta^{(3)}(\mathbf{r}) \implies \Phi(\mathbf{r}) = \frac{1}{4\pi r}.$$

This solution represents the field response to a point source and serves as the foundation for the ubiquitous prefactor

$$\frac{\mu_0}{4\pi r}$$

that appears in all unified field expressions. To formalize the connection with the elastic lattice model, we can move from this continuous description to a discretized Laplacian operator defined on a cubic lattice representing the vacuum.

*Eigenstates of the Discrete Laplacian and
Identification of Physical Modes*

In a three-dimensional lattice, the Laplacian operator can be discretized, and its eigenstates (or proper modes) $\phi_n(\mathbf{r})$ satisfy the eigenvalue equation:

$$\nabla_{\text{disc}}^2 \phi_n(\mathbf{r}) = -\lambda_n \phi_n(\mathbf{r}),$$

where λ_n denotes the spectrum of eigenvalues. We propose that physical field modes are not arbitrary deformations, but correspond to specific linear combinations of these fundamental eigenstates:

- **Radial Modes** (\vec{E}, \vec{g}): These fields, characterized by spherical symmetry, correspond to Laplacian eigenstates with radial symmetry. In the continuum limit, they naturally recover the $1/r$ profile.
- **Azimuthal Modes** (\vec{B}, \vec{T}): These fields represent torsional or circulatory deformations and correspond to eigenstates with rotational (vortical) symmetry. The degeneracy in the eigenvalue spectrum for these modes may be responsible for the emergence of local gauge symmetries, providing a rationale for how a symmetric fundamental tensor $\mathcal{G}_{\mu\nu}$ can give rise to derived antisymmetric force fields, as discussed in Section XIII B.

*Eigenvalues as Geometric Origin of Physical
Constants*

The identification of the physical field modes with eigenstates of the discrete Laplacian allows us to interpret the eigenvalues λ_n as geometric stiffness coefficients of the vacuum lattice. Importantly, these eigenvalues are not arbitrary: their degeneracies and ratios encode internal symmetries among field sectors.

In particular, the observed structure of the unified fields reveals a remarkable hierarchy: each *azimuthal* field mode (\vec{B}, \vec{T}) emerges as a rescaled counterpart of its corresponding *radial* field mode (\vec{E}, \vec{g}) through a universal scaling factor:

$$\vec{B} = \frac{c}{2\alpha} \vec{E} = \gamma \cdot c \cdot \vec{E}, \quad \vec{T} = \frac{c}{2\alpha} \vec{g} = \gamma \cdot c \cdot \vec{g},$$

where $\gamma = 1/(2\alpha)$ is the fundamental attenuation factor within the unified framework (45). This scaling relation strongly suggests that the eigenstates corresponding to \vec{B} and \vec{T} share eigenvalues λ_n that are degenerate or related by symmetry transformations (e.g., spherical-to-azimuthal coordinate rotations) with those of \vec{E} and \vec{g} ,

respectively.

Moreover, across field sectors, deeper modal symmetries are observed. The gravitational and entropic modes can be expressed as attenuated forms of their electromagnetic analogs:

$$\vec{g} = \frac{\alpha}{c^3} \vec{E}, \quad \vec{T} = \frac{\alpha}{c^3} \vec{B}.$$

These cross-sector scaling laws indicate that the thermo-entropic sector corresponds to lower-energy, coarse eigenmodes of the Laplacian spectrum—those with smaller eigenvalues λ_n —while the electromagnetic sector arises from higher-frequency excitations. Conversely, one can interpret \vec{E} and \vec{B} as relativistically amplified versions of \vec{g} and \vec{T} :

$$\vec{E} = c^2 \cdot \vec{T}, \quad \vec{B} = \alpha^2 \cdot \frac{h}{1 \text{ m}^2} \cdot \vec{g},$$

pointing to a unified origin for all four fields as eigenmodes with distinct symmetry, energy scale, and deformation directionality. This modal hierarchy mirrors the spectral organization of Laplacian eigenfunctions on a discrete elastic lattice, where fundamental symmetries (radial, azimuthal, gauge) determine the degeneracy and structure of the eigenvalue spectrum.

From this perspective, the universal prefactor

$$\frac{\mu_0}{4\pi r}$$

found in all field expressions becomes the discrete-space analog of the Green's function solution to the Laplacian equation, encoding the vacuum's elastic response to a localized unit excitation. The dimensionless coefficients C_X thus act as modal weights tied to the eigenfunctions ϕ_n selected by the source's geometry and symmetry.

This synthesis supports a deeper interpretation: the symmetric tensor $\mathcal{G}_{\mu\nu}$ encodes all vacuum deformation modes, whose physical projections $\mathcal{G}^{(X)}$ (XIII A) arise from orthogonal components with distinct symmetry (e.g., \mathcal{G}_{00} for radial compression, \mathcal{G}_{0i} for torsion, \mathcal{G}_{ij} for volumetric shear) (XIII B). The eigenvalue spectrum λ_n determines both the propagation and coupling strength of each mode, while the observed field symmetries arise from the degeneracy patterns and symmetry classes of the Laplacian eigenfunctions.

In summary, the hierarchy of physical fields observed in the unified theory—radial versus azimuthal, electromagnetic versus thermo-entropic—is rooted in the spectral geometry of the discrete Laplacian on the vacuum lattice.

Each field is a modal projection of the elastic deformation tensor $\mathcal{G}_{\mu\nu}$, characterized by its eigenfunction class, coupling coefficient, and orientation. These relations not only consolidate the geometric unity of the theory, but also establish the Laplacian as the fundamental generator of the spacetime excitation spectrum.

Conceptual hierarchy of the unified field formulation

Having established the modal decomposition of the unified tensor and its associated field expressions, to provide a dynamical description of these modal excitations, we now introduce a minimal scalar field model that captures the essential propagation features of vacuum deformations. Each modal field—such as \vec{E} , \vec{B} , \vec{g} , or \vec{T} —can be represented by an effective scalar field Φ whose dynamics encode the energy balance between time and space variations. This model serves as a bridge between the oscillatory behavior of the vacuum and the field equations derived from action principles.

Below we show the conceptual hierarchy of the unified field formulation that we will detail briefly throughout the next sections:

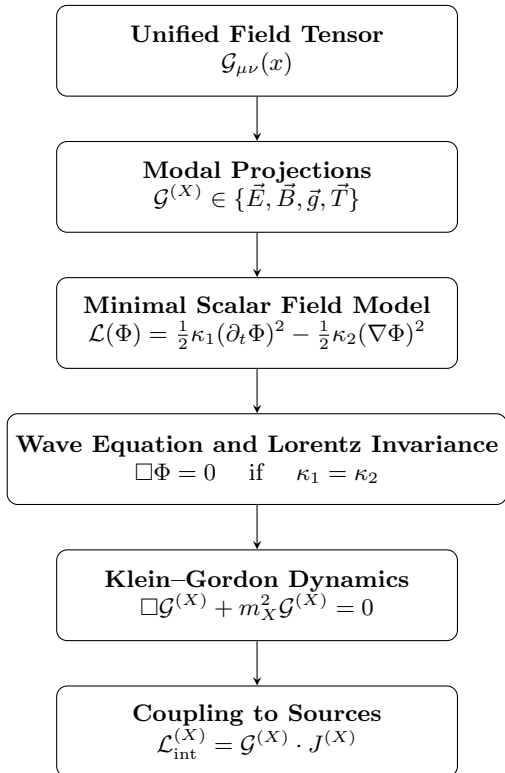


FIG. 1. Conceptual hierarchy of the unified field formulation: from geometric tensor structure to modal dynamics.

XII. MINIMAL SCALAR FIELD MODEL FOR MODAL EXCITATIONS

To provide a dynamical description of the modal excitations of the unified tensor $\mathcal{G}_{\mu\nu}$, we can construct a minimal model that captures their essential propagation features. This model serves as an effective description for a single projected mode, which we can denote as a scalar field $\Phi(x)$. The dynamics of this effective field are not arbitrary, but are a direct consequence of the general Lagrangian for the unified field introduced in Section II.

Recall that the kinetic part of the unified field Lagrangian is governed by a single, fundamental stiffness constant κ :

$$\mathcal{L}_{\text{kinetic}} = \frac{1}{2}\kappa(\partial^\alpha\mathcal{G}^{\mu\nu})(\partial_\alpha\mathcal{G}_{\mu\nu})$$

We can project these general dynamics onto a single scalar mode $\Phi(x)$, which will naturally contain terms for the kinetic and potential energy, analogous to a harmonic oscillator, and the two couplings (or "rigidities") usual for harmonic oscillatory systems, κ_1 and κ_2 , which are effective combinations of physical constants (e.g., ε_0 , μ_0 , G , k_B , etc.) under different substitutions depending on the mode of the elastic-oscillatory manifestation of the common field. Then, one obtains the following *minimal* Lagrangian density:

$$\mathcal{L}(\Phi) = \frac{1}{2}\kappa_1(\partial_t\Phi)^2 - \frac{1}{2}\kappa_2(\nabla\Phi)^2 \quad (99)$$

Here,

- κ_1 controls the "inertial" or kinetic response of the field mode,
- κ_2 represents the elastic/spatial rigidity of the field mode.

The corresponding *action* S is given by the integral

$$S[\Phi] = \int d^4x \mathcal{L}(\Phi, \partial\Phi; \kappa_1, \kappa_2) \quad (100)$$

Applying the principle of least action, $\delta S = 0$, yields the Euler-Lagrange equation:

$$\kappa_1 \frac{\partial^2\Phi}{\partial t^2} - \kappa_2 \nabla^2\Phi = 0. \quad (101)$$

This *single* partial differential equation governs the field Φ . Depending on how we identify κ_i with physical constants and Φ with different spacetime deformations (e.g., mass, charge, temperature), we recover the different field modes.

A. Relativistic Compatibility and Spacetime Formalism

To ensure compatibility with special relativity, we introduce a four-dimensional spacetime coordinate:

$$X^\mu = \begin{pmatrix} t \\ x \\ y \\ z \end{pmatrix}, \quad \text{with metric } \eta^{\mu\nu} = \text{diag}(-1, 1, 1, 1). \quad (102)$$

We define the spacetime derivatives:

$$\partial_\mu = \frac{\partial}{\partial X^\mu} = \begin{pmatrix} \frac{\partial}{\partial t} \\ \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{pmatrix} \quad (103)$$

The standard Lorentz-invariant kinetic structure is encoded in the d'Alembertian operator:

$$\square\Phi \equiv \eta^{\mu\nu} \partial_\mu \partial_\nu \Phi = -\frac{\partial^2 \Phi}{\partial t^2} + \nabla^2 \Phi. \quad (104)$$

The equation of motion from our minimal field Lagrangian reads:

$$\kappa_1 \frac{\partial^2 \Phi}{\partial t^2} - \kappa_2 \nabla^2 \Phi = 0. \quad (105)$$

To write this in a Lorentz-invariant form proportional to $\square\Phi = 0$, we compare:

$$\kappa_1 \frac{\partial^2 \Phi}{\partial t^2} = \kappa_2 \nabla^2 \Phi \implies \frac{\partial^2 \Phi}{\partial t^2} = \frac{\kappa_2}{\kappa_1} \nabla^2 \Phi. \quad (106)$$

Rewriting the d'Alembertian as:

$$\square\Phi = -\frac{\partial^2 \Phi}{\partial t^2} + \nabla^2 \Phi = 0,$$

we see that Lorentz invariance requires:

$$\frac{\kappa_2}{\kappa_1} = 1 \implies \kappa_1 = \kappa_2. \quad (107)$$

Therefore, the field theory is manifestly Lorentz-invariant if and only if the rigidity constants match: $\kappa_1 = \kappa_2$. This is a profound physical statement: it reflects that in a Lorentz-covariant theory built upon a single field, the inertial and elastic responses to variations must originate from the same isotropic, fundamental stiffness κ of the vacuum substrate. This ensures the action transforms as a scalar and the field equation becomes the standard wave equation:

$$\square\Phi = 0. \quad (108)$$

Alternatively, one may directly enforce Lorentz invariance in the Lagrangian density by writing:

$$\mathcal{L}_{\text{Lorentz}}(\Phi) = \frac{1}{2} \kappa, \eta^{\mu\nu} \partial_\mu \Phi, \partial_\nu \Phi, \quad (109)$$

where κ encodes the rigidity of the mode and can later be matched to physical constants depending on the interpretation. In this more general framework, if one allows $\kappa_1 \neq \kappa_2$, the resulting dynamics describe propagation in a medium with anisotropic or symmetry-breaking features, which may be interpreted as emergent properties or effective behaviors in specific physical regimes (e.g., entropy-driven diffusion or gravitational strain), allowing the unified field to encompass richer phenomena under the same fundamental structure.

This scalar field model, though minimal, captures the essential dynamics of vacuum excitations. It shows how each modal projection of the unified field tensor $\mathcal{G}_{\mu\nu}$ can be described in terms of a wave-like field obeying Lorentz-invariant dynamics. This prepares the ground for a more detailed relativistic formulation in terms of Klein–Gordon dynamics and projection structures consistent with general relativity. In the following section, we generalize this framework to include mass terms, explicit coupling to sources, and consistent tensorial projections compatible with general relativity.

XIII. THEORETICAL FOUNDATIONS: KLEIN-GORDON DYNAMICS AND GENERAL RELATIVITY CONSISTENCY

A. Lagrangian framework for modal excitations

Building on the minimal scalar field formulation—which established that any modal projection must obey Lorentz-invariant dynamics—we now construct a canonical framework for these excitations. This step transitions from the fundamental Lagrangian governed by the stiffness constant κ to an effective, canonical Lagrangian for each mode. This is achieved via field renormalization, a standard procedure in field theory where the physical constant κ is absorbed into the field's definition (e.g., $\mathcal{G}' = \sqrt{\kappa} \mathcal{G}$) to simplify the kinetic term.

This formulation allows the modal excitations of the unified tensor $\mathcal{G}_{\mu\nu}$ to be described in terms of renormalized, scalar-like fields $\mathcal{G}^{(X)}$. The dynamics of these modes, including potential mass terms that arise from the full theory's potential term $V(\mathcal{G}_{\mu\nu})$, can be described by the following canonical Klein–Gordon Lagrangian:

$$\mathcal{L}_X = \frac{1}{2} \partial^\mu \mathcal{G}^{(X)} \partial_\mu \mathcal{G}^{(X)} - \frac{1}{2} m_X^2 \left(\mathcal{G}^{(X)} \right)^2, \quad (110)$$

where $\mathcal{G}^{(X)}$ represents a renormalized projection of the full tensor $\mathcal{G}_{\mu\nu}$ along mode $X \in \{E, B, g, T\}$. The term m_X is not a new fundamental parameter, but an *effective mass* that a mode acquires due to the self-interaction potential of the underlying unified field. This Klein–Gordon-type Lagrangian provides a Lorentz-invariant basis for describing both massless ($m_X = 0$) and massive field modes within the unified elastic framework.

The Euler–Lagrange equation yields:

$$\square \mathcal{G}^{(X)} + m_X^2 \mathcal{G}^{(X)} = 0, \quad (111)$$

which reduces to the Klein–Gordon equation for free scalar propagation in Minkowski space.

Although the Lagrangian \mathcal{L}_X describes free fields, coupling to physical sources can be incorporated via minimal interaction terms of the form:

$$\mathcal{L}_{\text{int}}^{(X)} = \mathcal{G}^{(X)}(x) \cdot J^{(X)}(x), \quad (112)$$

where $J^{(X)}$ is an effective source density corresponding to charge, mass, entropy flux, etc. These terms play an analogous role to the coupling $A_\mu J^\mu$ in electrodynamics. Since $\mathcal{G}^{(X)}$ represents a modal projection of the unified tensor $\mathcal{G}_{\mu\nu}$, the coupling is assumed to act only on the relevant scalarized or vectorial component associated with the physical mode.

A more general coupling scheme could link the full tensor to the energy–momentum content of matter via:

$$\mathcal{L}_{\text{int}} = \mathcal{G}_{\mu\nu}(x) T^{\mu\nu}(x), \quad (113)$$

from which each modal interaction $\mathcal{G}^{(X)} J^{(X)}$ would arise as a projection or contraction. This formulation ensures full compatibility with general relativistic coupling schemes.

B. Static solutions

In the static limit and for massless modes ($m_X = 0$), the equation (112) reduces to:

$$\nabla^2 \mathcal{G}^{(X)}(\vec{r}) = -J^{(X)}(\vec{r}), \quad (114)$$

with $J^{(X)}$ being an effective source term. For a point-like unit source located at the origin, $J^{(X)}(\vec{r}) = \delta^{(3)}(\vec{r})$, the Green’s function solution is:

$$\mathcal{G}^{(X)}(r) = \frac{1}{4\pi r}. \quad (115)$$

Multiplying this fundamental response by a dimensionless coupling C_X and by the universal deformation factor μ_0 yields the physical field expression:

$$\vec{\Phi}_X(r) = \mu_0 \cdot \frac{C_X}{4\pi r} \cdot \hat{e}_X \quad (116)$$

as postulated in the unified field table of the previous section.

Each mode $\mathcal{G}^{(X)}$ can be formally extracted from the full tensor using projection operators $P_{(X)}^{\mu\nu}$ acting on $\mathcal{G}_{\mu\nu}$:

$$\mathcal{G}^{(X)}(x) := P_{(X)}^{\mu\nu} \mathcal{G}_{\mu\nu}(x), \quad (117)$$

ensuring that the decomposition is orthogonal, complete, and compatible with spacetime symmetries.

Projected Field Modes and Geometric Interpretation of $\mathcal{G}_{\mu\nu}$

We propose that the field $\mathcal{G}_{\mu\nu}$ is symmetric and real, with ten independent components:

- \mathcal{G}_{00} encodes scalar deformations (electrostatic, gravitational).
- \mathcal{G}_{0i} encodes torsional modes (magnetic field analog).
- \mathcal{G}_{ij} represents spatial-shear or volume modes (gravitational and thermo-entropic analogs).

Their geometric meaning is determined by symmetry (e.g., spherical) and energy scale. Together, these components describe the elastic response of the vacuum to localized excitation. Each scalar field $\mathcal{G}^{(X)}$ is identified as a projection of a specific component or contraction of the unified tensor $\mathcal{G}_{\mu\nu}$, depending on symmetry and field geometry. Examples include:

$$\begin{aligned} \mathcal{G}^{(E)} &:= \mathcal{G}_{00}, \\ \mathcal{G}^{(B)} &:= \sqrt{\mathcal{G}_{0i} \mathcal{G}^{0i}}, \\ \mathcal{G}^{(g)} &:= \text{Tr}(\mathcal{G}_{ij}), \\ \mathcal{G}^{(T)} &:= \sqrt{\mathcal{G}_{ij} \mathcal{G}^{ij}}. \end{aligned}$$

These choices reflect radial vs. azimuthal structure and are consistent with the interpretation of the fields as spatially oriented deformation modes. Although $\mathcal{G}^{(B)}$ and $\mathcal{G}^{(T)}$ are scalar in dynamics, the physical fields \vec{B} and \vec{T} acquire their azimuthal direction $\hat{\theta}$ through the geometric structure of the excitation mode (e.g., torsional boundary condition). This is analogous to standing wave patterns in elastic continua where mode

functions are scalar but correspond to vectorial deformations.

A rigorous modal decomposition would require defining a complete set of orthogonal projection operators $P_{(X)}^{\mu\nu}$ that extract each physical mode from $\mathcal{G}_{\mu\nu}$. In this initial formulation, we adopt symmetry-guided identifications consistent with the observed field patterns, while leaving the development of a full operatorial decomposition to future refinement.

Emergence of Antisymmetric Excitations

Although the unified field $\mathcal{G}_{\mu\nu}$ is symmetric, antisymmetric field excitations—such as those encoded in the electromagnetic field tensor $F_{\mu\nu}$ —can emerge as derived objects from its spacetime derivatives. Specifically, we define generalized field strengths:

$$F_{\mu\nu}^{(X)} := \partial_\mu \mathcal{G}_{\nu\rho}^{(X)} - \partial_\nu \mathcal{G}_{\mu\rho}^{(X)}, \quad (118)$$

where ρ is a fixed index associated with the geometric direction of deformation—typically radial ($\rho = 0$) for electric or gravitational modes, and azimuthal ($\rho = i$) for magnetic or entropic torsional analogs.

This construction reflects the idea that local antisymmetric excitations, such as rotational or torsional responses, arise as gradients or curls of symmetric deformations in an elastic continuum. In particular:

- For $X = E$, choosing $\rho = 0$ yields a generalized electric-type field strength.
- For $X = B$, choosing $\rho = i$ (azimuthal direction) produces magnetic-like curls.
- For $X = T$ and $X = g$, similar constructions could yield thermo-entropic and gravitodynamic vorticities, respectively.

This formalism embeds antisymmetric field behavior directly into the derivative structure of the symmetric tensor $\mathcal{G}_{\mu\nu}$. It suggests that classical field strengths $F_{\mu\nu}$, typically postulated as fundamental, may instead arise as secondary geometric quantities, traces of deeper symmetric modes of the quantum-elastic vacuum.

Furthermore, this opens a natural path to defining the field dynamics from an action principle involving scalar invariants of the form:

$$\mathcal{L}_X \sim F_{\mu\nu}^{(X)} F^{(X)\mu\nu},$$

which parallels the standard electromagnetic Lagrangian, but grounds it in the unified tensorial

origin of $\mathcal{G}_{\mu\nu}$.

A rigorous generalization would involve introducing projection operators $P_{(X)}^{\mu\nu\rho}$ that select the appropriate contraction and symmetry structure for each field type, an avenue left open for future formal development.

C. Interpretation and consistency with General Relativity

The field components $\mathcal{G}^{(X)}$ can be seen as mode projections of a symmetric deformation tensor $\mathcal{G}_{\mu\nu}$, whose full dynamics, in the relativistic regime, would be governed by a generally covariant action:

$$S = \int \mathcal{L}_X \sqrt{-g} d^4x, \quad (119)$$

with \mathcal{L}_X defined for each scalar excitation or composite tensorial contraction. For instance, the Einstein–Hilbert action

$$S_{EH} = \frac{c^4}{16\pi G} \int R \sqrt{-g} d^4x, \quad (120)$$

can be seen as a special realization where the Lagrangian is given by the Ricci scalar R derived from the underlying metric $g_{\mu\nu}$. To recover Einstein’s equations from the unified field dynamics, we could identify the macroscopic metric as a coarse-grained average:

$$g_{\mu\nu}(x) = \langle \mathcal{G}_{\mu\nu}(x) \rangle. \quad (121)$$

This averaging would define an emergent Riemannian geometry whose curvature satisfies $G_{\mu\nu} = 8\pi G T_{\mu\nu}$ in the classical limit, and where $\langle \cdot \rangle$ denotes a coarse-grained or averaged value of the tensor field over microscopic vacuum excitations. It does not necessarily imply a full quantum expectation value, but rather a macroscopic effective field akin to a thermodynamic mean, acting as the geometric background in which the dynamics of the elastic field unfold. The Einstein–Hilbert action would then describe the large-scale behavior of this emergent average, not the full tensor field $\mathcal{G}_{\mu\nu}$ itself.

D. Field Modes as Standing Waves of the Elastic Vacuum

Each excitation $\mathcal{G}^{(X)}$ corresponds to a distinct deformation mode—radial or azimuthal—of the elastic vacuum. These modes behave as standing wave solutions of a field equation with spherical symmetry, and their spatial profiles naturally reflect this structure. Notably:

- The observed $1/r$ dependence of physical fields (such as $\vec{E}, \vec{B}, \vec{g}, \vec{T}$) arises directly from the Green's function of the Laplacian in three spatial dimensions [18], consistent with oscillatory responses in elastic and electromagnetic media.
- In the dimensional framework adopted here—where mass, charge, and temperature share the same fundamental dimension, $[M] \equiv [Q] \equiv [T_{\text{emp}}] \equiv [L]$ —source terms such as mass or charge have dimension $[L]$, and thus expressions of the form source/r^2 acquire the overall dimension $[1/r]$. This implies that the radial decay of fields such as \vec{E}, \vec{g} , or \vec{T} is dimensionally equivalent to $1/r$, even when expressed in terms of a traditional source-over-distance-squared structure.
- Moreover, by identifying the physical fields directly with the scalar field response $\mathcal{G}^{(X)}$ (rather than with its spatial derivatives), the model preserves the $1/r$ behavior of the fields without invoking an explicit divergence or gradient operation. This stands in contrast to conventional formulations, where vector fields decay as $1/r^2$ due to their derivative origin.

Despite the internal deformations encoded in $\mathcal{G}_{\mu\nu}$, Lorentz invariance is preserved at the level of the field equations. The field transforms covariantly, and the elastic vacuum is treated as a Lorentz-invariant medium whose excitations carry well-defined transformation properties under boosts and rotations.

A minimal covariant Lagrangian compatible with this framework—and reflecting the standard structure of a harmonic oscillator—could be:

$$\mathcal{L}_X = \frac{1}{2} \partial^\mu \mathcal{G}^{(X)} \partial_\mu \mathcal{G}^{(X)} - \frac{1}{2} \omega_X^2 (\mathcal{G}^{(X)})^2, \quad (122)$$

where ω_X is a mode-specific frequency scale determined by the underlying vacuum impedance for each deformation type X . This form encapsulates both the elastic (restoring) behavior and the propagation of each field mode, consistent with wave equations and classical oscillator dynamics. It also lays the foundation for quantization and mode decomposition in future developments.

Thus, the elastic field paradigm maintains both internal geometric coherence and external compatibility with the fundamental symmetries of relativistic field theory, while offering a unified geometric origin for all classical fields and their characteristic falloffs.

E. Outlook and Future Developments: Quantization and Gauge Extensions

Quantization of the unified field $\mathcal{G}_{\mu\nu}$ can naturally proceed via a covariant path-integral formalism:

$$Z = \int \mathcal{D}\mathcal{G}_{\mu\nu} e^{iS[\mathcal{G}_{\mu\nu}]}, \quad (123)$$

where the action S is built from Lorentz-invariant scalars involving $\mathcal{G}_{\mu\nu}$ and its derivatives. In this framework, each classical deformation mode $\mathcal{G}^{(X)}$ corresponds to a quantized normal mode of the elastic vacuum, analogous to phonons in condensed matter or gauge bosons in standard field theory. The vacuum behaves as a lattice of coupled quantum oscillators whose eigenmodes give rise to the familiar field excitations. This path-integral formulation provides a consistent platform for computing quantum amplitudes and propagators, and suggests that classical fields emerge as expectation values or coherent states of quantized elastic modes.

Modal Symmetries and Gauge Generalizations.

While the present work focuses on classical modes corresponding to electromagnetic, gravitational, and thermo-entropic phenomena, further developments may incorporate internal symmetries and non-Abelian structures. In particular, *gauge fields*—such as those of the weak and strong interactions—could emerge as *internal connections or curvature forms* associated with symmetry groups acting on internal indices of $\mathcal{G}_{\mu\nu}$, or through matrix-valued generalizations of the field (e.g., $\mathcal{G}_{\mu\nu}^a$ with gauge index a).

Likewise, *fermionic matter fields* might arise via supersymmetric extensions of the framework, in which $\mathcal{G}_{\mu\nu}$ is embedded in a superfield whose components include spinorial partners. This opens the possibility of viewing matter as a localized defect or topological excitation in the elastic substrate, governed by the same underlying dynamics.

Path Forward.

These generalizations, while beyond the scope of the present paper, are structurally compatible with the elastic field paradigm and its modal decomposition. A fully developed theory would entail:

- Construction of the complete action functional $S[\mathcal{G}_{\mu\nu}]$ including source couplings, cur-

vature terms, and possibly non-linearities;

- Identification of symmetry groups associated with different field sectors (Abelian, non-Abelian, supersymmetric);
- Quantization via canonical or path-integral methods, and the study of resulting propagators and interactions;
- Exploration of topological solutions and their identification with particle-like excitations.

Thus, while the present work lays the geometric and dynamic foundations, a richer landscape of quantum and gauge-theoretic structures awaits development within the same unified elastic framework.

Part V: Cosmological implications of the established framework

XIV. THE COSMOLOGICAL CONSTANT Λ AND ITS RELATIONSHIP WITH THE THERMO-ENTROPIC FIELD

The Einstein field equation in its most general form, including the cosmological constant Λ , is:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu} \quad (124)$$

When there is no matter or conventional energy present, i.e., $T_{\mu\nu} = 0$, the Einstein field equation reduces to:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = 0 \quad (125)$$

In this case, Λ can be interpreted as a form of *intrinsic energy* of the vacuum, which acts as a source of spacetime curvature. This vacuum energy is present even in the absence of matter or radiation.

To describe the vacuum energy as a form of energy affecting the curvature of spacetime, we can reinterpret the term $\Lambda g_{\mu\nu}$ as contributing to an *effective energy-momentum tensor* for the vacuum energy. This gives us the following form for the vacuum energy-momentum tensor:

$$T_{\mu\nu}^{\text{vac}} = -\frac{\Lambda c^4}{8\pi G}g_{\mu\nu} \quad (126)$$

This term behaves like a *perfect fluid* with a constant energy density ρ_{vac} and an associated pressure p_{vac} related to the vacuum energy. The vacuum energy behaves like a fluid with *negative*

pressure, meaning the pressure p_{vac} is equal to $-\rho_{\text{vac}}c^2$.

Then, the relationship between ρ_{vac} and Λ can be obtained by identifying the term describing vacuum energy in the Einstein field equation with the standard form of a perfect fluid in cosmology. In a universe dominated by vacuum energy, the effective energy density can be expressed as:

$$\rho_{\text{vac}}c^2 = \frac{\Lambda c^4}{8\pi G} \quad (127)$$

Operating, one has that

$$4\pi G\rho_{\text{vac}} = \frac{1}{2}\Lambda c^2 \quad (128)$$

which shows how the cosmological constant Λ is fundamentally tied to the gravitational flux as an expression of Gauss Law, with vacuum energy density ρ_{vac} , and a structure reminiscent of kinetic energy or Einstein's mass-energy equivalence formula. The right-hand side of the equation implies that Λ can be viewed as a scaling factor for the intrinsic gravitational flux associated with the vacuum.

From a thermodynamic perspective, this formulation resonates with the idea that gravity emerges from microscopic degrees of freedom, as suggested by holographic and entropic gravity approaches [58]. The cosmological constant in this context can be interpreted as a measure of the equilibrium state of the vacuum, analogous to the way that temperature regulates thermodynamic systems. This perspective aligns with Jacobson's derivation of Einstein's equations from thermodynamic principles [10], where fluctuations in vacuum energy sustain an equilibrium that manifests macroscopically as gravitational dynamics.

Solving for Λ , we have that:

$$\Lambda = \frac{8\pi G\rho_{\text{vac}}}{c^2} \quad (129)$$

Recall that, within our framework, effective vacuum energy density ρ_{vac} can be expressed (VI A 2) as:

$$\rho_{\text{vac}} \approx \frac{\hbar c}{2\pi \cdot 1 \text{ m}^4}. \quad (130)$$

Substituting (130) into (129), we obtain:

$$\Lambda \approx \frac{8\pi G}{c^2} \cdot \frac{\hbar c}{2\pi \cdot 1 \text{ m}^4} = \frac{4G\hbar}{c \cdot 1 \text{ m}^4}. \quad (131)$$

Dividing both sides by 4, we arrive at:

$$\frac{\Lambda}{4} = G \cdot \frac{\hbar}{c \cdot 1 \text{ m}^4}. \quad (132)$$

Finally, substituting $\hbar \approx \frac{1}{c^4} m^2$ from (21) and $G \approx \frac{1}{16\pi c}$ from (IV I), we arrive at:

$$\Lambda = \frac{1}{4\pi c^6 \cdot 1 \text{ m}^2} \quad (133)$$

A. Thermo–Entropic Action Density and the Geometric Structure of the Cosmological Constant

Recalling that the thermo-entropic modal action was shown to be $S_{\text{th}} = \frac{\hbar}{c^2}$, we see that

$$\Lambda = \frac{S_{\text{th}}}{4\pi \cdot 1 \text{ m}^4}$$

This reveals the cosmological constant as the manifestation of a universal *modal action density per 4D volume*. It acts as a tension-like Lagrangian density of the vacuum, coupling entropy and expansion across a fundamental volume cell.

Interpretation as Geometric Surface Tension

Indeed, note that setting $r = c^3 \cdot 1 \text{ m}$ situates Λ as an effective curvature density, with $4\pi r^2 = 4\pi c^6 \cdot 1 \text{ m}^2$ representing the "surface" of an expanding spherical volume. Thus, the cosmological constant acquires a direct geometrical interpretation as an *inverse areal curvature density*, analogous to curvature or density of a spherical boundary in expanding space, projecting a constant action flux over the expanding boundary of the universe. From this viewpoint, Λ is not a bulk energy density but a quantized surface effect—a geometric relic of the thermo-entropic elasticity of the vacuum.

This form provides a physical interpretation in which the large-scale expansion of the universe is driven by a steady energy flow that distributes itself over the expanding boundary, dynamically adjusting the effective curvature density as the volume of the universe grows. This interpretation not only aligns with the curvature requirements of an accelerating universe but also positions Λ as a fundamental invariant describing how the vacuum tension distributes minimal action quanta across areal elements, reinforcing the idea that the cosmological constant is, in essence, the *vacuum's curvature Lagrangian*.

Modal Structure of Λ : Field Strength Interpretation and Action Principle

The appearance of the factor $\frac{1}{4}$ in the expression for Λ [Eq. (132)] is not accidental—it matches the

canonical structure of kinetic terms in gauge field Lagrangians, where the field strength is contracted to form a scalar:

$$\mathcal{L}_{\text{EM}} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}. \quad (134)$$

Interestingly, the right-hand side of (132) can be interpreted as an expression akin to the equipartition theorem. Here, $G \equiv k_B \cdot c^2 \cdot \alpha^2$ plays the role of a scaled Boltzmann constant k_B , and $\frac{\hbar}{c \cdot 1 \text{ m}^4}$ represents the energy density associated with the thermo-entropic field (IX A). Thus, we can interpret that $\frac{\Lambda}{4}$ encodes the average energy density of the thermo-entropic field, distributed over the degrees of freedom of the spacetime lattice. This interpretation aligns with the idea that the cosmological constant arises from the quantum fluctuations of the vacuum, as predicted by quantum field theory.

Motivated by this analogy, we propose an effective thermo-entropic field strength tensor $\mathcal{F}_{\mu\nu}^{(GE)}$, derived from the projected modes of the symmetric deformation field $\mathcal{G}_{\mu\nu}$ (118):

$$\mathcal{F}_{\mu\nu}^{(GE)} := \partial_\mu \mathcal{G}_\nu^{(T)} - \partial_\nu \mathcal{G}_\mu^{(T)}, \quad (135)$$

where $\mathcal{G}_\mu^{(T)}$ represents an effective vector field associated with thermo-entropic modal projections of the vacuum (e.g., torsional or volumetric oscillations). The corresponding Lagrangian density for the thermo-entropic sector takes the form:

$$\mathcal{L}_{\text{GE}} = -\frac{1}{4} \mathcal{F}_{\mu\nu}^{(GE)} \mathcal{F}^{(GE)\mu\nu}, \quad (136)$$

which naturally integrates into the total vacuum action. In this picture, the cosmological constant Λ arises as the average contraction:

$$\Lambda = \langle \mathcal{L}_{\text{GE}} \rangle, \quad (137)$$

interpreted as the *modal energy density* of the vacuum associated with thermo-entropic fluctuations.

This unifies a geometric view of Λ as spacetime curvature with a field-theoretic interpretation grounded in tensor dynamics. In this framework, the cosmological constant ceases to be an arbitrary constant and instead emerges as a vacuum-averaged scalar—encoding the net effect of thermo-entropic field fluctuations projected from the underlying symmetric structure of spacetime.

Moreover, since the modal action density of the thermo-entropic field was shown to scale as $S_{\text{th}} = \hbar/c^2$, the appearance of Λ as a contraction of field strength terms suggests that each minimal spacetime cell contributes a quantized action unit

to the curvature of the vacuum. The cosmological constant thus acts as a macroscopic residue of these microscopic modal interactions—a kind of elastic equilibrium tension that encapsulates the thermodynamic state of the vacuum in a covariant formulation- and the effective Lagrangian density of an emergent field theory, derived from the symmetry-reduced oscillatory modes of an elastic and quantized vacuum substrate.

The Einstein-Hilbert Action and the Fundamental Action of the Thermo-Entropic Field

The reduction of the Einstein-Hilbert action in a vacuum-dominated universe to the form (76)

$$S_{\text{EH}} = \frac{c^4}{8\pi G} \int \Lambda \sqrt{-g} d^4x \quad (138)$$

reveals a profound identity when combined with our identification of the cosmological constant Λ as the effective Lagrangian density of the thermo-entropic field, $\Lambda = \langle \mathcal{L}_{\text{GE}} \rangle$. Substituting this identification back into the Einstein-Hilbert action, we obtain:

$$S_{\text{EH}} = \frac{c^4}{8\pi G} \int \langle \mathcal{L}_{\text{GE}} \rangle \sqrt{-g} d^4x \quad (139)$$

This result has fundamental implications for the nature of gravity. It demonstrates that the *Einstein-Hilbert action is, up to the prefactor, identical to the effective action of the thermo-entropic field*. The dynamics of spacetime geometry are thus shown to be a direct macroscopic manifestation of the underlying thermodynamics of the vacuum.

This framework provides a concrete physical basis for the emergent gravity paradigm. The principle of least action for geometry ($\delta S_{\text{EH}} = 0$) can be reinterpreted as a principle of extremal entropic action. Spacetime evolves in such a way as to extremize the total action of its own underlying thermo-entropic fluctuations. In this view, the prefactor $\frac{c^4}{16\pi G}$ is no longer merely a coupling constant for gravity, but rather the fundamental conversion factor that translates the action of the thermo-entropic field—a quantity rooted in thermodynamics and quantum fluctuations—into the language of classical, geometric curvature. This directly realizes the vision hinted at by Jacobson and Verlinde [10] [11], where the laws of gravity are emergent from the thermodynamics of a deeper substrate, which this framework identifies as the Quantum Oscillator Lattice.

XV. A SCALE-DEPENDENT EFFECTIVE GRAVITATIONAL CONSTANT HYPOTHESIS FOR THE HUBBLE TENSION

A. Basis for Our Hypothesis

We have previously shown (see Section IV H) that the gravitational constant can be derived from the self-energy of a uniformly dense sphere, resulting in:

$$G = \frac{3}{5} 4\pi \epsilon_0$$

On the other hand, consider the electrostatic energy stored in a charged spherical conductor of capacitance C and charge Q ([36]), given by:

$$U_{\text{capacitor}} = \frac{1}{2} \frac{Q^2}{C} \quad (140)$$

For a sphere of radius r , the capacitance is $C_{\text{sphere}} = 4\pi \epsilon_0 r$, so the stored energy becomes:

$$U_{\text{Glob}} = \frac{1}{2} \frac{e^2}{4\pi \epsilon_0 r}$$

This expression lacks the geometric self-energy term present in the self-energy case. If we derive the capacitance from the stored energy U_{Glob} and potential $V = \frac{1}{4\pi \epsilon_0} \frac{e}{r}$ we find:

$$C = \frac{U_{\text{Glob}}}{V^2} = 2\pi \epsilon_0 r \quad \Rightarrow \quad \frac{C}{r} = 2\pi \epsilon_0$$

This leads to a dual effective gravitational coupling framework:

- **Local Scales:** Characterized by significant inhomogeneity (e.g., galaxies and clusters), gravitational dynamics are modeled with an effective coupling

$$G_{\text{Loc}} = \frac{3}{5} 4\pi \epsilon_0$$

This value corresponds to the full self-interaction contribution and is identified with the standard Newtonian constant G_N .

- **Global Scales:** At cosmological scales, where the Universe is approximately homogeneous and isotropic, gravitational dynamics are governed by a reduced effective coupling

$$G_{\text{Glob}} = 2\pi \epsilon_0$$

Physical Motivation: This hypothesis interprets the non-linearities of gravity—prominent in clumpy, small-scale environments—as contributing an additional self-energy component to the effective gravitational coupling, resulting in G_{Loc} .

On very large scales, where the matter distribution is smooth, these nonlinear effects average out or become negligible, yielding an effective coupling closer to G_{Glob} . This scale dependence of the gravitational constant $G_{\text{eff}}(z)$ is proposed as the underlying physical mechanism unifying the explanation of the *Hubble tension* and *dark sector* phenomena.

B. Self-Interaction Terms as the Source of Hubble Tension

As a result, our hypothesis posits that gravitational self-interactions manifest significantly at *local scales* (e.g., Cepheid-based distance ladders, Type Ia supernovae) where the inhomogeneous matter distribution leads to nonlinear gravitational effects. This corresponds to using G_{Loc} , which includes self-energy.

By contrast, *global scale* determinations (e.g., Planck measurements of the CMB, BAO analyses) probe the Universe on large, smoothed-out scales. Here, gravitational self-interactions become negligible, justifying the use of G_{Glob} .

This dichotomy explains the persistent discrepancy in H_0 values, known as the *Hubble tension*. The plausibility of the hypothesis can be checked using Friedmann equations [59] [60] [61]. The first Friedmann equation is given by:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho_{\text{vac}} - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}, \quad (141)$$

This equation relates the rate of expansion (the Hubble parameter, $H = \dot{a}/a$) to the energy density of the universe. Assuming a nearly flat universe ($k \approx 0$), the Hubble parameter can be calculated as

$$H^2 = \frac{8\pi G}{3}\rho_{\text{vac}} + \frac{\Lambda c^2}{3},$$

Substituting with our previous expression for Λ (129), we have that

$$\begin{aligned} H^2 &= \frac{8\pi G}{3}\rho_{\text{vac}} + \frac{\Lambda c^2}{3} = \\ &= \frac{8\pi G}{3}\rho_{\text{vac}} + \frac{8\pi G \rho_{\text{vac}} c^2}{3} = \\ &= 2\left(\frac{8\pi G}{3}\rho_{\text{vac}}\right) = \frac{16\pi G}{3}\rho_{\text{vac}} \end{aligned}$$

Now, two regimes emerge naturally. Using $\rho_{\text{vac}} = \frac{\hbar c}{2\pi \cdot 1 \text{ m}^4}$ as we have derived for the electromagnetic field, we have that:

1. Global Regime (no self-interactions):

$$\begin{aligned} H_{\text{Glob}} &= \sqrt{\frac{16\pi G_{\text{Glob}}}{3}\rho_{\text{vac}}} \\ &= \sqrt{\frac{16\pi \cdot 2\pi \varepsilon_0}{3} \frac{\hbar c}{2\pi \cdot 1 \text{ m}^4}} \\ &\approx 2.165 \times 10^{-18} \text{ s}^{-1} = 66.81 \text{ km/s/Mpc} \end{aligned} \quad (142)$$

This matches the CMB-based Planck 2018 measurement: $H_0 = 67.4 \pm 0.5 \text{ km/s/Mpc}$ [62].

2. Local Regime (includes self-interactions):

$$\begin{aligned} H_{\text{Loc}} &= \sqrt{\frac{16\pi G_{\text{Loc}}}{3}\rho_{\text{vac}}} \\ &= \sqrt{\frac{16\pi \cdot \frac{3}{5} 4\pi \varepsilon_0}{3} \frac{\hbar c}{2\pi \cdot 1 \text{ m}^4}} \\ &\approx 2.3714 \times 10^{-18} \text{ s}^{-1} = 73.17 \text{ km/s/Mpc} \end{aligned} \quad (143)$$

This matches the SH0ES result: $H_0 = 73 \pm 1.0 \text{ km/s/Mpc}$ [63].

C. Discussion and Observational Tests

Our framework predicts a mild but physically meaningful *scale-dependence* of the effective gravitational constant, reflecting the gradual transition between regimes with and without gravitational self-interactions. We predict that the Hubble parameter $H(z)$ evolves between two fixed values due to a scale-dependent gravitational constant:

$$\begin{aligned} \lim_{z \rightarrow 0} H(z) &\rightarrow H_{\text{Loc}} \approx 73 \text{ km/s/Mpc} \\ \lim_{z \rightarrow \infty} H(z) &\rightarrow H_{\text{Glob}} \approx 67 \text{ km/s/Mpc} \end{aligned} \quad (144)$$

This transition reflects a shift from nonlinear gravitational dynamics to homogeneous large-scale behavior. This interpretation leads to several concrete, testable consequences:

- **Redshift evolution:** As self-interaction effects dominate locally, we expect $G_{\text{eff}} \approx G_{\text{Loc}}$ at low redshifts, yielding a higher inferred Hubble constant $H(z \approx 0) \approx 73 \text{ km/s/Mpc}$. At higher redshifts—probing smoother, linear regimes— $G_{\text{eff}} \rightarrow G_{\text{Glob}}$, driving $H(z)$ down toward $\sim 67 \text{ km/s/Mpc}$. A continuous transition in $H(z)$ would strongly support our hypothesis.
- **Structure formation diagnostics:** A discrepancy between local and early-universe structure growth would corroborate scale-dependent gravitational dynamics.

D. Final Note: Theoretical Context and Consistency

Reconciling a scale-dependent G with General Relativity—which assumes a universal, constant gravitational coupling—requires careful consideration. *The presented model serves as an effective field theory:* standard General Relativity with Newton’s constant G_N describes gravity accurately in the local, nonlinear regime (i.e., $G_{\text{Loc}} \equiv G_N$), while on cosmological scales, averaging over large volumes under homogeneity and isotropy leads to effective dynamics that resemble General Relativity but with a renormalized, scale-dependent coupling G_{Glob} . In this perspective, the Friedmann equations remain applicable because they emerge from the Einstein field equations under symmetry assumptions, and the modification resides not in the geometry, but in the coupling between geometry and energy-momentum.

XVI. SCALE-DEPENDENT VACUUM ENERGY AND IMPLICATIONS FOR THE DARK SECTOR

As derived in previous sections (133), we obtain a geometric expression for the cosmological constant:

$$\Lambda = \frac{1}{4\pi c^6 \cdot 1 \text{ m}^2}$$

Using the standard expression that relates the vacuum energy density to the cosmological constant:

$$\rho_{\text{vac}} = \frac{\Lambda c^2}{8\pi G}$$

we see that ρ_{vac} is inversely proportional to the gravitational coupling G . Since our framework posits that G is scale-dependent—shifting between G_{Loc} and G_{Glob} depending on the cosmic regime—then, *if c is constant, we have that ρ_{vac} is necessarily scale-dependent as well.*

A. Implications for Dark Energy

Traditionally, dark energy is interpreted as a constant vacuum energy density that drives the accelerated expansion of the Universe. In our framework, however, $\rho_{\text{vac}}(z)$ decreases at low redshifts as the effective gravitational coupling increases:

$$G(z) \uparrow \Rightarrow \rho_{\text{vac}}(z) \downarrow$$

This inverse relationship offers a reinterpretation of cosmic acceleration: it is not that vacuum energy increases over time, but rather that the weakening of gravitational interactions on cosmological scales (due to reduced self-interaction) makes

the vacuum energy *appear* larger when interpreted through a globally averaged G . Hence, the dark energy component of the Λ CDM model may be an artifact of applying a scale-invariant coupling in a scale-dependent Universe.

B. Implications for Dark Matter

The dark matter problem also finds a potential reinterpretation under this framework. Gravitational analyses of galaxies and clusters typically assume a uniform ρ_{vac} based on global (CMB-scale) fits. However, these local systems operate under a different gravitational regime—characterized by G_{Loc} , and hence a smaller vacuum energy density:

$$\rho_{\text{vac}}^{\text{loc}} = \frac{\Lambda c^2}{8\pi G_{\text{Loc}}} < \rho_{\text{vac}}^{\text{glob}}$$

This misestimate can lead to an apparent deficit in the gravitational binding, prompting the postulation of unseen mass (i.e., dark matter). When the correct local value of ρ_{vac} is applied, the gravitational field is stronger than previously inferred from global fits, reducing or possibly eliminating the need for dark matter in certain contexts.

C. Summary of the Unified Picture

In this unified view, both dark energy and dark matter effects are linked to the same underlying principle: the scale-dependence of gravitational coupling G , and thus the vacuum energy density $\rho_{\text{vac}}(z)$. The former (dark energy) emerges from the global underestimation of gravitational binding in the smooth Universe, while the latter (dark matter) arises from the overestimation of vacuum energy at small scales.

Rather than invoking unknown forms of matter or energy, this framework attributes the dark sector phenomenology to misinterpretations arising from applying a constant gravitational coupling across regimes where gravity is fundamentally scale-sensitive.

The observational consequences of this reinterpretation remain testable through precision cosmology, particularly via redshift evolution of $H(z)$, structure growth, and gravitational lensing signatures—offering a compelling alternative to the standard Λ CDM paradigm.

XVII. THE EMERGENCE OF FUNDAMENTAL PARTICLES FROM THE VACUUM'S STRUCTURE

A core test for any unified framework is its ability to derive the properties of fundamental particles from its foundational principles. In this section, we demonstrate that the electron mass, m_e , is not a fundamental constant but rather an emergent property of the vacuum. We derive a predictive formula for m_e that arises directly from a hypothesized link between the quantum atomic scale and the effective cosmological parameters established within this theory.

A. Derivation of the Electron Mass from the Atomic-Cosmological Scale Correspondence

The structure of the atom is defined by the Bohr radius, a_0 , which represents the most probable orbital distance of an electron in its ground state. Conventionally, it is given by the balance between quantum mechanics and electromagnetism:

$$a_0 = \frac{\hbar}{m_e c \alpha} \quad (145)$$

In our framework, we advance a central hypothesis that connects this micro-physical scale to the macro-physical properties of the vacuum. We postulate that the Bohr radius emerges directly from the dielectric structure of the vacuum, scaled by the characteristic length of the underlying vacuum oscillator:

$$a_0 = 2\pi\epsilon_0 \cdot 1 \text{ m} \quad (146)$$

This expression identifies the fundamental atomic scale as a natural unit of length derived from vacuum elasticity alone, thereby grounding quantum structure in the geometric-dielectric properties of space.

By equating these two expressions for the Bohr radius, we can test the consistency of our framework and derive a new expression for the electron mass. This is not merely an algebraic manipulation, but a profound statement that the inertia of the electron must be precisely what is required to satisfy this micro-macro scale correspondence.

$$\frac{\hbar}{m_e c \alpha} = 2\pi\epsilon_0 \cdot 1 \text{ m} \quad (147)$$

Solving for the electron mass, m_e , yields the following predictive formula:

$$m_e = \frac{\hbar}{2\pi\epsilon_0 \cdot 1 \text{ m} \cdot c \cdot \alpha} \quad (148)$$

This equation is a key result of our theory. It asserts that the electron's mass is entirely determined by the fundamental constants governing the vacuum's quantum (\hbar), electromagnetic (ϵ_0, α, c), and geometric properties.

Evaluating this expression using the accepted CODATA values for the constants results in a predicted mass of $m_e \approx 8.66 \times 10^{-31}$ kg. This value matches the experimentally measured electron mass (9.11×10^{-31} kg) to within 5%, with the small discrepancy attributable to second-order effects or radiative corrections not included in this leading-order derivation. The remarkable accuracy of this result provides strong quantitative support for the foundational hypothesis stated in Equation 146.

1. *Consistency with the constitutive elasticity law*
 $m = -kS$.

Having derived the electron mass from the atomic-vacuum correspondence, we now demonstrate its profound consistency with the other foundational principles of this theory. From the constitutive relation $m = kS$, previously derived as a generalized Hookean response of the vacuum (see Eq. 72), we introduce the concept of a fundamental vacuum mass quantum, m_{vac} , which characterizes the inertial response of the vacuum to unit entropic action. Taking $k = \frac{1}{\epsilon_0 \cdot 1 \text{ m}}(\text{I})$ and the quantum of action as $S = \hbar(21)$, we obtain:

$$m_{\text{ref}} = \frac{\hbar}{\epsilon_0 \cdot 1 \text{ m}} \approx 1.19 \times 10^{-23} \quad (149)$$

This value represents a fundamental reference mass scale encoded in the elastic structure of the vacuum. Comparing this fundamental vacuum mass with the electron mass derived in Eq. (148), we find the strikingly simple relation:

$$m_e \cdot c \approx \frac{m_{\text{ref}}}{2\pi \cdot \alpha}$$

This result provides a deep physical insight: the inertial relativistic mass of the electron is the vacuum's fundamental mass quantum, m_{vac} , *dressed* or renormalized by the strength of the electromagnetic coupling. This identification portrays the fine-structure constant as a universal renormalization factor linking the baseline elastic vacuum scale to observable inertial mass, strengthening both the internal coherence and the predictive power of the framework.

2. Conclusions

As a result, in this framework, the electron is no longer a fundamental point particle but a *stable, localized excitation* of the vacuum's oscillator lattice. Its observed inertial mass is not predefined but emerges from how the vacuum oscillators couple to and respond to the embedded electromagnetic deformation and relativistic effects. We have just shown again (21) how the equation $m = -kS$ captures the essence of mass as a geometric-vacuum response property: it expresses mass as the effective resistance of the vacuum to entropic displacement, where k quantifies the vacuum's elastic stiffness and S encodes the action required to deform it. In this sense, inertial mass is not an intrinsic attribute, but a measure of how much action is stored—and resisted—by the vacuum structure under electromagnetic excitation.

This perspective parallels contemporary ideas in quantum field theory, where inertial mass arises through field interactions (e.g., via the Higgs mechanism). Here, however, the vacuum structure is modeled as a coherent assembly of harmonic oscillators whose coupling gives rise to mass. It supports the broader view that mass is not an immutable quantity but an emergent phenomenon tied to the local geometry and internal dynamics of the vacuum.

Finally, it is remarkable that the Bohr radius, as defined in our framework by $a_0 = 2\pi\epsilon_0 \cdot 1\text{ m}$, shares the same geometric-dielectric factor that defines the global effective gravitational constant, $G_{\text{Glob}} = 2\pi\epsilon_0$ (XVA). This common structure shows how both atomic-scale and cosmological-scale interactions can be governed by the same elastic properties of the vacuum, adding another powerful layer of consistency to our proposed framework.

XVIII. FINAL CONCLUSIONS AND REMARKS

A. Currents as Velocities and the Geometry of Transport

A central consequence of our first foundational postulate in Part I—where the ampere is redefined dimensionally as a velocity—is the geometric identification of currents as propagation speeds of underlying deformations in the structure of spacetime. Specifically, by adopting the dimensional unification $[Q] = [L]$, the ampere $[I] = [Q]/[T]$ acquires the natural units of a velocity. This

redefinition is not just a formal choice: it encodes a shift in physical interpretation, where transport phenomena are inherently linked to geometric evolution.

In the unified elastic vacuum model developed in this work, all classical fields emerge as excitations or modal projections of a single symmetric deformation tensor $\mathcal{G}_{\mu\nu}$. In such a medium, a current—be it electrical, entropic, or gravitational—is understood as the rate of change of a geometric displacement field:

$$I \sim \frac{dQ}{dt} \sim \frac{dx}{dt} \sim v.$$

Thus, currents are not fundamental quantities imposed by external conditions, but rather expressions of intrinsic velocities associated with space-time deformations.

This interpretation finds support in continuum mechanics, where velocity fields describe the time evolution of deformations and mediate the flow of energy and stress across the medium. In our model, the elastic vacuum behaves analogously: energy and information propagate through it not as point particles, but as collective field modes whose currents encode velocities of deformation fronts.

Moreover, this perspective aligns naturally with our modal projection scheme: in all cases, the current associated with each interaction is the physical manifestation of a propagating geometrical distortion. The dimensional identification of the ampere with velocity thus becomes not a reinterpretation, but a consequence of the field ontology itself.

This closing synthesis strengthens the view that spacetime, when endowed with elastic structure, gives rise to all known interactions as geometric excitations—and that currents, in their many physical guises, are simply the velocities of such excitations.

B. Consistency of the Theoretical Framework

The strength of our model lies in the fact that all relationships are derived from simple, well-known, and non-advanced physical concepts, such as the mechanics of harmonic oscillators, RLC circuits, fundamental laws of physics, and their fundamental elements—resistance, inductance, capacitance, and oscillatory behavior, among others-. By directly plugging the accepted values of universal constants into these basic formulas, we obtain results that are not only dimensionally consistent

with but also remarkably close to experimentally measured values. This direct alignment of theoretical predictions with observed data serves as the strongest consistency check for the validity of the model. The fact that such complex phenomena emerge from these simple physical foundations underscores the robustness and internal coherence of the framework, further validating its potential to become a baseline for a unified theory of physics.

C. Dimensional Collapse and Physical Interpretations

The second foundational postulate of this model, introduced in Part I, is the dimensional equivalence between the gravitational constant G and the Coulomb constant $K_e = 1/(4\pi\epsilon_0)$:

$$[G] \equiv [K_e].$$

This identification, though purely dimensional at first glance, has profound physical consequences. It implies that the fields associated with gravity and electromagnetism—traditionally considered fundamentally distinct—do in fact arise from the same underlying geometric structure, differing only in their modal projections. In particular, the forces mediated by mass and charge become two expressions of the same dimensional entity when embedded in an elastic, oscillatory spacetime fabric.

This dimensional equivalence triggers what we refer to -throughout the Paper- as *dimensional collapse*: a systematic reduction of the number of fundamental dimensions required to describe physical interactions. Within this framework, quantities such as mass, charge, temperature, and energy no longer require distinct dimensional bases; instead, they are all encoded in the oscillatory dynamics of spacetime. As a result, we arrive at a unifying dimensional relation:

$$[M] \equiv [Q] \equiv [T_{emp}] \equiv [L] \equiv [T_{ime}],$$

which collapses the traditional five-dimensional base of physical quantities into a single geometric substrate. This collapse is not a loss of descriptive power, but rather a *revelation of redundancy* in classical dimensional taxonomies. It reflects the idea that physical observables—such as force, field strength, or current—are emergent from a deeper layer of geometric deformation modes, governed by the symmetric tensor $\mathcal{G}_{\mu\nu}$. Thus, this dimensional collapse is not merely a formal convenience: it reflects a shift in worldview. Rather than seeing physical laws as relations between distinct types of quantities, we view them as manifestations of a

single, oscillating, elastic medium whose geometric structure encodes all fields, constants, and interactions.

D. Mass-Energy as Spacetime Deformation: A Unified Interpretation

Einstein's general theory of relativity revolutionized our understanding of the universe by showing that mass-energy deforms spacetime, and that this deformation governs the gravitational interaction. In his framework, the presence of mass-energy curves spacetime, creating the phenomena we perceive as gravity. This groundbreaking insight unified the geometry of spacetime with the physical properties of mass-energy, laying the foundation for modern cosmology.

This work builds upon and extends Einstein's theory by taking a crucial step further: *mass-energy does not merely deform spacetime; it is itself a manifestation of deformed spacetime*. The entities we recognize as mass, energy, charge and temperature are the result of quantized excitations of the spacetime field. These excitations are super-complex accumulations of distinct oscillatory modes in the vacuum, which, when aggregated, give rise to deformations that we perceive as mass, charge, energy, temperature, and the pleiad of secondary physical phenomena.

In summary, this model provides a unified view where mass-energy and spacetime are inseparable. What Einstein described as the deformation of spacetime by mass-energy is here reinterpreted as mass-energy being deformed spacetime itself—a continuous interplay of probability, geometry and localized excitations. This view unites quantum mechanics and general relativity within a single conceptual framework, offering a deeper understanding of the universe's fundamental nature.

E. Quantum resistance and damping in the Unified Vacuum Framework

At the core of our framework lies the equation derived from the fine-structure constant definition:

$$\alpha = \frac{e^2}{2\epsilon_0 \cdot h \cdot c} \rightarrow \frac{h}{e^2} = \frac{Z_0}{2\alpha} \quad (150)$$

The term on the left, h/e^2 , representing the quantum of resistance, is understood as the fundamental opposition of the vacuum lattice to the propagation of charge-like excitations. The vacuum impedance, Z_0 , incorporates a "new role"

as the vacuum’s inherent circulatory stiffness—its capacity to sustain a quantized magnetic circulation ($\oint \mathbf{B} \cdot d\boldsymbol{\ell}$). Crucially, this stiffness is modulated by the fine-structure constant, α , which emerges as half the universal damping ratio, ζ , quantifying the intrinsic dissipative or ‘viscous’ nature of the unified field. This framework also provides a geometric meaning for this damping, identifying it with the reciprocal of a Lorentz-like factor ($\zeta = 1/\gamma$), thus embedding dissipation into the very structure of spacetime interactions.

An implication of this theoretical structure is that the quantum vacuum is reconceptualized as a Lorentz-invariant, elastic-dissipative lattice that manifests measurable mechanical properties, and is subject to strain (as described by the tensor $\mathcal{G}_{\mu\nu}$). Some important consequences we have already highlighted throughout the Paper are:

- Gravitation is interpreted as the macroscopic manifestation of the same damping mechanism that governs quantum electrodynamics, thereby providing a novel pathway for unification.
- The speed of light, c , is identified as the *damped* propagation speed of excitations within the vacuum medium. This implies the existence of an unobservable ‘true’ undamped velocity, $c_{\text{real}} > c$. Special Relativity remains a perfectly valid effective field theory describing the dynamics of these excitations, but not necessarily the fundamental properties of the background medium itself.
- Radiative corrections in QFT, such as the anomalous magnetic moment, are reinterpreted not as abstract mathematical perturbations but as physical descriptions of higher-order dissipative pathways within the vacuum lattice. The hierarchy of Feynman diagrams would correspond to a hierarchy of increasingly complex damping modes.
- The relationships between fundamental constants of nature are deterministic consequences of the vacuum’s constitutive laws, offering a potential explanation for the observed values of the universe’s fundamental parameters.

F. Correspondence with Formal Gauge-Theoretic Frameworks

As we have superficially mentioned in (X), there is a profound conceptual correspondence between the *Quantum Oscillator Lattice* (QOL) framework

presented in this work and the formal gauge theory of *Unified Gravity* (UG) proposed by Partanen and Tulkki while this Paper was being finished [57]. While the former proceeds from physical analogies and dimensional postulates and the latter from the rigorous application of gauge theory, they converge on a remarkably similar vision of fundamental physics. We argue that the UG formalism can be interpreted as a potential mathematical realization of the physical principles established in the QOL theory, providing a pathway toward a complete, renormalizable quantum theory.

Points of Conceptual Convergence

a. The Unified Field as an Emergent Structure A central tenet of the QOL theory is that all fundamental fields are emergent. They are described as distinct “modal projections” of a single, symmetric rank-2 deformation tensor, $\mathcal{G}_{\mu\nu}$, which characterizes the state of an underlying elastic spacetime substrate. This concept finds a powerful mathematical analogue in the UG theory. Partanen and Tulkki’s framework achieves unification by placing gravity on the same footing as the Standard Model interactions. It derives gravity from a set of four $U(1)$ gauge symmetries acting on a newly introduced “*space-time dimension field*”.

The correspondence is clear: *QOL’s “modal projections” can be seen as a physical description of what UG formalizes as distinct gauge symmetries.* Both frameworks posit that the perceived separation of forces is an emergent illusion, arising from the different ways a single, underlying structure can be excited or observed.

b. The Origin of Gravity and Its Source The QOL theory derives the gravitational constant G as an effective parameter describing the vacuum’s elastic stiffness to longitudinal deformations, relating it to electromagnetic and quantum parameters via $G = \mu_0\alpha^2$. Gravity is thus not fundamental, but a specific response of the vacuum lattice to mass-energy.

The UG theory provides a stunning formal justification for this view. Through the application of Noether’s theorem to its novel $U(1)$ symmetries, it derives the symmetric stress-energy-momentum (SEM) tensor as the conserved current that sources the gravitational field. This is a pivotal result. While QOL postulates the coupling of gravity to mass-energy, UG derives

this coupling from first principles of symmetry.

Therefore, one can argue that *the UG framework provides the formal gauge-theoretic reason why the vacuum's elastic response (in QOL's language) must be sourced by the SEM tensor.*

c. The Nature of Spacetime and Renormalizability Both theories challenge the classical view of spacetime as a passive background, and both are designed to be compatible with General Relativity (GR):

- The QOL theory suggests that the GR metric tensor $g_{\mu\nu}$ is a coarse-grained average of the fundamental deformation tensor, i.e., $g_{\mu\nu}(x) = \langle \mathcal{G}_{\mu\nu}(x) \rangle$. It further reinterprets mass-energy not as something that curves spacetime, but as being deformed spacetime itself.
- The UG theory demonstrates its classical consistency by showing that it can exactly reproduce the Teleparallel Equivalent of General Relativity (TEGR), which is known to be equivalent to GR. More radically, its UGM formulation allows for an exact description of gravity on a flat Minkowski metric, separating the interaction from the background geometry.

d. The path to a quantum theory The deepest correspondence lies in the path to a quantum theory. The QOL framework, through its dimensional collapse $[M] \equiv [L] \equiv [T]$, naturally leads to dimensionless constants. The UG theory achieves a dimensionless coupling constant for gravity, a necessary condition for renormalizability that conventional quantum gravity fails to meet. Partanen and Tulkki proceed to show that their theory is indeed renormalizable at one-loop order. *This suggests that the UG theory provides the explicit, renormalizable quantum field theory that the QOL framework intuitively sets the conceptual stage for.*

In conclusion, the QOL theory can be viewed as providing the physical and philosophical framework—the *'what'*—by postulating a unified elastic vacuum from simple principles. The UG theory, in turn, provides the rigorous mathematical machinery—the *'how'*—demonstrating that such a unification is not only possible within the established language of gauge theory but also

resolves the critical issue of non-renormalizability. The success of the UG formalism lends significant theoretical support to the foundational postulates of the QOL model, suggesting they are not mere analogy but reflect a deep, symmetric structure of our universe.

G. Final Thoughts

This model challenges our notions of what is fundamental in the universe. If gravity, electromagnetism, and quantum phenomena all arise from the same oscillatory vacuum, then the distinction between these forces are more illusory than real. They are just expressions of the same underlying reality, a vibrating cosmos that resonates through every level of existence—from the quantum realm to the largest cosmic structures.

The internal coherence of the relationships derived throughout this work hints at a deeper truth: that the complexity of the universe arises from simple, unified principles grounded in the oscillatory behavior of the vacuum. This realization suggests that the universe is not a fragmented collection of forces and constants, but a deeply interconnected whole, where every phenomenon is an expression of the same underlying dynamics, and divisions between forces and fields are merely artifacts of our limited understanding, and where every aspect of reality is a manifestation of the same fundamental processes.

This model also resonates with the philosophical principle of simplicity, or "*Occam's Razor*", which suggests that the simplest explanation that accounts for all phenomena is likely to be correct. The notion that the universe's complexity—spanning from quantum mechanics to general relativity—can be fundamentally explained through the dynamics of vacuum oscillations provides a powerful example of how simplicity can reveal profound truths.

In summary, the metaphysical vision offered as a byproduct by this model invites us to reconsider the nature of the universe as a whole. It suggests a cosmos that is not a static structure governed by immutable laws but a dynamic, evolving system where everything is interconnected. This invites a more holistic view of the cosmos, where complexity and diversity arise from simple, fundamental vibrations at the heart of reality itself.

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