Part A4 - **Electromagnetic Origin of Mass and Gravity**

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Abstract

This work investigates an electromagnetic origin of inertial mass and gravity based on the electromagnetic torus model developed in Parts A1–A3. The model proposes that matter consists of localized electromagnetic structures containing two complementary energy contributions: positive energy and negative binding energy.

Inertial mass is associated with the sum of their absolute magnitudes, while gravitational interaction results from two opposing scalar-field effects. Positive energy generates a repulsive contribution, whereas binding energy generates attraction. Both scalar fields originate from the same electromagnetic structure and act upon the same receiving matter, but propagate independently without direct mutual interaction. Their disturbances are assumed to propagate at the speed of light.

A minimum-energy variational formulation leads to Poisson-type equations for the static field distributions. For localized sources, the resulting scalar potentials exhibit an inverse-distance dependence. The spatial overlap of these fields consequently produces an inverse-square interaction under the proposed source–receiver couplings.

The resulting gravitational force depends on the difference between the attractive and repulsive energy contributions. For a universal relative binding-energy parameter, the model reproduces the mathematical form of Newton's gravitational law and establishes a relationship between the gravitational constant, the scalar-field coupling coefficient, and the internal energy distribution of matter.

The analysis identifies the conditions required for agreement with gravitational measurements, particularly the universality of free fall. It also establishes the remaining theoretical requirements, including the electromagnetic origin of the scalar fields, their coupling mechanisms, and the independent determination of the model parameters.

The proposed framework offers a unified physical interpretation of inertia and gravity as two distinct manifestations of the same underlying electromagnetic energy structure.

1. Introduction

Mass, inertia, and gravity are fundamental properties of matter. Inertial mass determines the resistance of a body to acceleration, while gravitational interaction governs the mutual attraction between material bodies. Although Newtonian mechanics and general relativity provide successful mathematical descriptions of these phenomena, the present work explores a different question: whether mass and gravity can be understood as consequences of the electromagnetic structure of matter.

Parts A1–A3 of this series develop the concept of an electromagnetic torus as a possible fundamental constituent of matter. The torus is described as a localized, dynamically organized electromagnetic structure in which electric and magnetic fields, the displacement field P, and internal energy circulation establish a coherent configuration. Its stability depends on the balance between positive energy and negative binding energy.

The present article extends this concept from the internal structure of an individual torus to the macroscopic properties of matter. Its central hypothesis is that the two energy contributions responsible for the existence and stability of the torus also determine its inertial and gravitational behavior.

1.1. Two Energy Contributions

The model distinguishes between positive energy W_p and negative binding energy W_v:

$$W_p > 0, \qquad W_v < 0.$$

Positive energy is associated with the dynamical electromagnetic organization of the torus, while negative binding energy represents the contribution responsible for maintaining its localized structure.

The two contributions play different roles in inertia and gravity.

In the proposed description of inertial mass, both contributions are taken into account through their absolute magnitudes:

$$\boxed{mc^2 = W_p + |W_v|.}$$

The inertial response is then described by Newton's second law, F=ma. The energy relation above is a hypothesis of the torus model rather than a direct consequence of the standard mass–energy relation.

Gravitational interaction is different. The positive energy contribution is proposed to generate a repulsive effect, whereas the binding-energy contribution generates an attractive effect. The observed gravitational attraction is interpreted as the resultant of these two opposing contributions.

Thus, inertia depends on the combined magnitudes of the two energy contributions, while gravity depends on their opposing interactions between bodies.

1.2. Two Independent Scalar Fields

The internal electromagnetic structure of an individual torus is characterized by spatially organized vector fields. A macroscopic body, however, consists of many toruses with different positions and orientations. Their individual magnetic moments need not produce a corresponding macroscopic magnetic moment.

The present model proposes that the positive and binding-energy contributions nevertheless generate two scalar fields extending into the surrounding space.

These fields are assumed to have independent dynamics. They are linked through the electromagnetic structure of their common source, but they do not interact directly during propagation. Their physical effects combine when they act upon another torus or material body.

Because both fields are proposed to originate from electromagnetic processes, the model

assumes that changes in their configurations propagate at the speed of light, c. This assumption is consistent with the observed propagation speed of gravitational disturbances, although the existence and dynamics of the two proposed scalar fields remain to be established independently.

The spatial organization of each field is considered separately. In the static limit, a minimum-energy formulation is used to investigate conditions under which the fields acquire a long-range 1/r dependence.

1.3. Energy Minimization and Gravitational Interaction

The physical interpretation of the two fields is based on a common principle: a system tends toward energetically favorable configurations under its constraints.

For positive interaction energy, separation can reduce the energy of the combined system, producing a repulsive force. For negative binding interaction energy, approaching bodies can increase the magnitude of their negative interaction energy, thereby lowering the total energy and producing attraction.

The two processes are therefore interpreted as opposite manifestations of energy minimization.

The proposed fields are treated as spatially distributed rather than concentrated at mathematical points. Their interaction is investigated through the overlap of their scalar-field configurations.

A variational description provides a route to the Poisson equation in the static limit. For localized sources, the resulting long-range potential has a leading 1/r dependence, from which an inverse-square force law follows under an appropriate source-field coupling.

The attractive and repulsive contributions are calculated separately and combined only at the level of the resulting interaction. The opposite signs of their couplings and the possibility of a common coupling coefficient are explicit hypotheses to be examined rather than assumed consequences of the variational calculation.

1.4. Objective and Scope

The objective of Part A4 is to investigate whether the electromagnetic torus model can provide a consistent physical framework for both inertial mass and gravitational interaction.

The analysis focuses on four questions:

1. How can positive energy and negative binding energy contribute to inertial mass?
2. Under what conditions can these energy contributions generate two independently propagating scalar fields?
3. Can the spatial interaction of these fields reproduce the inverse-square gravitational law?
4. What quantitative relations and experimental constraints follow from the proposed connection between energy, mass, and gravity?

The detailed internal structure, formation, and stability of the electromagnetic torus are addressed in Parts A1–A3 and are not repeated here.

The present article therefore concentrates on the transition from localized electromagnetic structure to macroscopic physical behavior. It develops the proposed scalar-field description, examines its mathematical consequences, and identifies the conditions required for agreement with established gravitational observations.

The resulting framework is intended as a testable hypothesis concerning the electromagnetic origin of inertia and gravity, rather than as a completed derivation of these phenomena from Maxwell's equations. [1, 2, 3, 4, 5, 6]

2. Electromagnetic Torus as the Origin of Matter

2.1. Matter as an Organized Electromagnetic Structure

The electromagnetic torus model proposes that matter consists of localized and dynamically stable electromagnetic structures. Rather than treating elementary particles as dimensionless points, the model describes them as spatially organized configurations of electromagnetic fields and energy flow.

The formation, internal geometry, and stability of these structures are examined in Parts A1–A3. The present article adopts their essential results and investigates how the same structures may account for mass, inertia, and gravity.

An individual torus contains electric and magnetic fields together with the displacement field P. Their spatial organization and phase relationships establish a coherent electromagnetic system in which energy circulates within a confined geometry.

The torus is not considered a static distribution of electromagnetic energy. It is a dynamic structure maintained by continuous internal motion and energy redistribution. Its stability depends on the ability of its internal fields to preserve a coherent configuration while responding to disturbances.

In this interpretation, the electromagnetic torus represents a possible fundamental constituent of matter.

2.2. Positive Energy and Binding Energy

The internal organization of a torus involves two complementary energy contributions.

The first is positive energy, denoted by

$$W_p > 0.$$

This contribution is associated with the dynamical organization and motion of the internal electromagnetic structure, particularly the displacement field P.

The second is negative binding energy, denoted by

$$W_v < 0.$$

Binding energy represents the tendency of the electromagnetic structure to maintain spatial confinement and resist processes that would disrupt its coherent organization.

The two energy contributions have different physical roles. Positive energy supports internal motion and energy circulation, while binding energy contributes to the persistence of the localized configuration.

A stable torus requires a compatible balance between these contributions. In the proposed model, the magnitude of binding energy exceeds the positive energy contribution:

$$|W_v| > W_p.$$

This condition characterizes the assumed binding-dominated internal state. It does not require the two contributions to have nearly equal magnitudes.

Both contributions originate from the same electromagnetic structure and are therefore physically associated at their source. Nevertheless, their external effects are treated separately in the present model.

2.3. From Individual Toruses to Macroscopic Matter

A macroscopic body contains an enormous number of electromagnetic toruses. Their individual structures may differ in orientation, position, phase, and local electromagnetic environment.

Each torus possesses an organized magnetic structure and may be associated with a magnetic moment. However, the magnetic moments of different toruses need not be aligned. Their vector contributions can

therefore partially or completely cancel at the macroscopic level.

The scalar energy contributions behave differently.

Positive energy and the magnitude of binding energy are scalar quantities. Their contributions can accumulate throughout a material body even when the corresponding vector fields exhibit substantial cancellation.

For a body consisting of N toruses, the simplest additive approximation is

$$W_p = \sum_{i=1}^{N} W_{p,i},$$

$$|W_v| = \sum_{i=1}^{N} |W_{v,i}|.$$

These expressions refer to the individual energy contributions before accounting for possible changes caused by interactions, structural rearrangements, and additional binding between toruses.

The energy structure of a macroscopic body therefore depends not only on the number of constituent toruses but also on their organization and mutual interactions.

This distinction provides the starting point for describing macroscopic energy fields without requiring a corresponding macroscopic magnetic moment.

2.4. From Internal Energy to External Scalar Fields

The electromagnetic structure of an individual torus is described by vector fields and internal energy flow. At larger distances, however, the present model proposes that its two energy contributions also act as sources of scalar fields extending into the surrounding space.

Positive energy generates a positive scalar field, while binding energy generates a separate binding scalar field.

Both scalar fields are associated with the same torus at their origin. Their dynamics are nevertheless assumed to be independent during propagation. Neither field directly modifies the other while travelling through space.

The fields interact with matter at their destination, where their physical effects combine.

In the proposed description, the positive scalar field contributes a repulsive interaction, whereas the binding scalar field contributes an attractive interaction.

The two interactions are associated with the same general principle of energy minimization. Separation may reduce a positive interaction energy, while approach may reduce a negative binding interaction energy.

The spatial dependence and quantitative consequences of these interactions are developed in subsequent sections.

The model assumes that disturbances of both fields propagate at the speed of light, consistent with their proposed electromagnetic origin. The independent scalar-field dynamics and their coupling to matter constitute additional hypotheses that require physical and experimental validation.

2.5. The Connection to Mass and Gravity

The same two energy contributions appear in two different macroscopic phenomena.

For inertial mass, the model proposes that both contributions enter through their absolute magnitudes:

$$\boxed{mc^2 = W_p + |W_v|.}$$

The inertial response of a body is then described by Newton's second law:

F=ma.

The proposed energy expression specifies how the model assigns inertial mass to the internal electromagnetic structure of matter. It is not

obtained merely by applying the conventional mass–energy relation to a negative binding-energy term.

For gravitational interaction, the contributions act in opposite directions.

The positive scalar field generates repulsion, while the binding scalar field generates attraction. The resulting gravitational force is determined by their combined action on another material body.

Consequently, mass and gravity are proposed to originate from the same internal electromagnetic energy structure, although they depend on different combinations of its contributions.

This distinction provides the conceptual foundation for the scalar-field formulation developed in the following sections. [1, 2, 3, 4, 5]

3. Positive Energy and Negative Binding Energy

3.1. Two Complementary Energy Contributions

The electromagnetic torus contains two energy contributions with different physical roles. Positive energy supports the internal dynamics of the electromagnetic structure, while negative binding energy contributes to its localization and stability.

The two contributions are denoted by:

$$W_p > 0$$

$$W_v < 0$$

Positive energy is associated primarily with the dynamical electromagnetic organization of the torus and the motion of the displacement field P. Binding energy is associated with the electromagnetic organization responsible for maintaining the coherent structure.

In the proposed model, a stable torus requires the magnitude of binding energy to exceed its positive energy contribution:

$$|W_v| > W_p$$

This condition expresses the binding-dominated character of the localized structure. It does not imply that the two energy contributions must be nearly equal.

The distinction between the two contributions becomes particularly important when considering interactions between separate toruses or macroscopic bodies.

3.2. Positive Energy and Repulsive Interaction

Consider two spatially separated bodies, each generating a positive scalar energy field.

Their respective field distributions extend into the surrounding space and overlap. In the proposed model, this overlap contributes positive interaction energy to the combined system.

When the bodies approach one another, the overlap increases and the interaction energy rises. Conversely, increasing their separation reduces the interaction energy.

The energetically favorable response is therefore separation.

This behavior can be represented by a positive interaction-energy function:

$$U_p(d) = +KI_p(d)$$

Here, d is the separation between the bodies, K is a positive coupling coefficient, and $I_p(d)$ is a positive overlap function that decreases with increasing distance.

The corresponding radial force is:

$$F_p(d) = -\frac{dU_p}{dd}$$

Since the overlap decreases with distance,

$$\frac{dI_p}{dd} < 0$$

the force becomes:

$$F_p(d) > 0$$

The positive sign indicates repulsion.

Thus, repulsion is interpreted as the mechanical consequence of reducing positive interaction energy through separation.

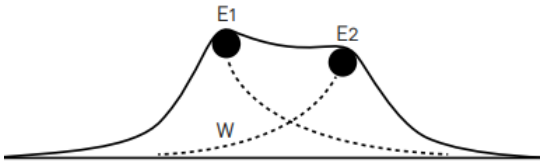


Figure 1. Overlap of positive scalar energy fields. *Two positive energy distributions extend from separate sources and overlap in the surrounding space. Within the proposed interaction model, increasing overlap raises the positive interaction energy. Separation reduces this contribution and is therefore energetically favorable.*

3.3. Negative Binding Energy and Attractive Interaction

Binding energy has the opposite energetic role.

Each torus possesses a negative binding-energy contribution associated with the maintenance of its localized electromagnetic structure. The present model proposes that this contribution also generates an external scalar binding field.

When two such fields overlap, their interaction contributes negative energy to the combined system.

As the bodies approach, the magnitude of the negative interaction energy increases. The total energy consequently decreases.

The energetically favorable response is therefore approach rather than separation.

The interaction can be represented as:

$$U_v(d) = -KI_v(d)$$

where $I_v(d)$ is a positive overlap function that decreases with increasing distance.

The corresponding force is:

$$F_v(d) = -\frac{dU_v}{dd}$$

Therefore:

$$F_v(d) = K\frac{dI_v}{dd}$$

Since the overlap decreases with distance:

$$F_v(d) < 0$$

The negative sign indicates attraction.

The physical interpretation is that approaching bodies can reduce the total energy by increasing the magnitude of their negative binding interaction.

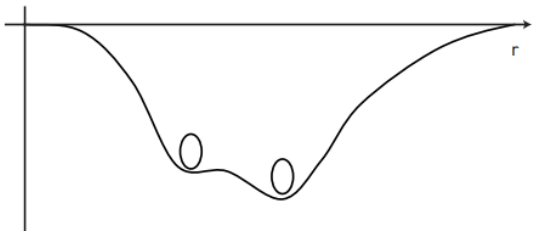


Figure 2. Negative binding-energy configuration of two interacting bodies. *Two bodies are associated with negative scalar binding-energy distributions. Their approach increases the magnitude of the negative interaction energy, producing a deeper combined energy configuration. Attraction is interpreted as the tendency toward this lower-energy state.*

3.4. A Common Principle of Energy Minimization

The preceding descriptions indicate that attraction and repulsion need not require fundamentally different principles of motion.

Both can be expressed through the relation between interaction energy and force:

$$F_d = -\frac{dU}{dd}$$

For positive interaction energy, increasing separation can reduce the energy of the system.

For negative binding interaction energy, decreasing separation can reduce the energy of the system.

The two effects therefore represent opposite consequences of the same energetic principle.

For an illustrative symmetric model, the interaction energies can be written as:

$$U_p(d) = +KI(d)$$

$$U_v(d) = -KI(d)$$

The corresponding forces are:

$$F_p(d) = -KI'(d)$$

$$F_v(d) = +KI'(d)$$

If the common overlap function decreases with distance, the forces have opposite signs and equal magnitudes for equal source strengths.

This mathematical symmetry is a useful starting point for the proposed theory. However, equal coupling coefficients and the opposite signs of the interactions remain physical hypotheses. Energy minimization alone does not determine them.

3.5. Energy Density and Binding-Energy Sign

A distinction must be made between the magnitude of an energy density and the sign of its contribution to the energy balance.

In conventional electromagnetism, the local electric and magnetic field-energy densities are nonnegative:

$$u_E = \frac{\varepsilon_0 E^2}{2}$$

$$u_B = \frac{B^2}{2\mu_0}$$

The proposed negative binding-energy contribution does not require either of these Maxwellian densities to become negative.

Instead, the model introduces a signed effective binding-energy contribution describing the energetic role of binding.

Let ρ_p and ρ_v denote nonnegative magnitudes of the corresponding energy densities:

$$\rho_p \geq 0$$

$$\rho_v \geq 0$$

Their signed contributions are:

$$w_p = +\rho_p$$

$$w_v = -\rho_v$$

The associated energies are:

$$W_p = \int \rho_p \, dV$$

$$W_v = -\int \rho_v \, dV$$

This notation preserves positive density magnitudes while distinguishing the opposite energetic roles of the two contributions.

The negative binding-energy contribution is an effective quantity of the proposed model. Its precise relation to the internal electromagnetic energy and to the work performed during binding must be established by the underlying torus dynamics.

3.6. Finite Geometry and the Lower Bound of Binding Energy

Idealized point-source interaction laws can become singular when the distance between sources approaches zero.

For example, a negative interaction energy proportional to the inverse separation would decrease without bound if the sources were mathematical points and unrestricted approach were allowed.

Electromagnetic toruses, however, possess finite spatial dimensions and internal structural constraints.

Their geometry limits the configurations that can be reached without deformation or structural transformation.

The interaction energy must therefore be considered together with the finite spatial distribution of its sources.

As an illustrative regularized interaction, consider:

$$U_v(d) = -\backslash dfracC\sqrt{d^2 + a^2}$$

Here, a represents a finite characteristic length.

At large separation, the interaction approaches an inverse-distance dependence.

At zero separation, its limiting value is finite:

$$U_v(0) = -\backslash dfracCa$$

This example shows that an attractive long-range interaction need not imply a divergent energy at short distances.

The regularization is illustrative rather than a derived geometric law for toruses. A complete stability argument must also account for possible internal deformations and other degrees of freedom.

3.7. From Energy Contributions to Gravitational Interaction

Positive energy and negative binding energy are proposed to generate two distinct scalar fields.

Both fields originate from the same electromagnetic structure, but their propagation and spatial dynamics are treated independently.

Their effects combine when they interact with another torus or material body.

The positive field contributes repulsion:

$$F_p > 0$$

The binding field contributes attraction:

$$F_v < 0$$

The resulting interaction is determined by the sum:

$$F_g = F_p + F_v$$

In the proposed description, ordinary gravitational attraction occurs when the magnitude of the binding contribution exceeds the repulsive contribution.

The spatial dependence of the two forces is not established by their signs alone. It depends on the field equations, source distributions, and coupling mechanisms.

The following sections therefore examine whether the independently evolving scalar fields can produce long-range interaction energies proportional to inverse separation and consequently an inverse-square force law.

The central hypothesis is that gravity represents the resultant of two opposing energetic interactions originating from the same electromagnetic structure that gives matter its inertial properties. [1, 2, 3, 4, 5]



Figure 3. Attractive and repulsive effects of scalar energy fields. *The negative binding-energy field attracts a particle toward a lower-energy configuration, whereas the positive energy field repels it toward a region of lower positive interaction energy. Both effects follow the principle of energy minimization but produce forces in opposite directions.*

4. Inertial Mass and Energy Contributions

4.1. Inertial Mass as a Property of Electromagnetic Structure

In the electromagnetic torus model, inertial mass is not considered an independent property assigned to a structureless particle. It is associated with the energy contained in the organized electromagnetic structure of matter.

Every torus contains positive energy and negative binding energy. Both contributions

are essential to its internal organization, although they perform different structural functions.

The model proposes that both contributions participate in the inertial response of the complete torus.

Their contributions to inertial mass are therefore taken through their absolute magnitudes:

$$mc^2 = W_p + |W_v|$$

The corresponding mass is:

$$m = \frac{W_p + |W_v|}{c^2}$$

This expression is a central hypothesis of the model. It assumes that both positive energy and the magnitude of negative binding energy contribute positively to inertia.

The signed energy balance remains a separate quantity:

$$W_s = W_p + W_v$$

Because binding energy is negative, the signed balance differs from the sum determining inertial mass.

The distinction between the signed energy balance and the energy contributions to inertial mass becomes particularly important when electromagnetic toruses interact or merge. Changes in binding energy may modify the proposed inertial mass while also producing energy exchange, mechanical work, or radiation. A complete energy-conservation analysis must account for all these contributions. The present model therefore treats the sum of absolute energy magnitudes as a hypothesis for inertial mass, while requiring the signed energy balance and any energy transferred to the surroundings to satisfy an independently established conservation law.

This distinction is important. The proposed inertial relation does not follow automatically from the standard relativistic mass–energy relation, in which binding energy enters total energy with its physical sign.

4.2. The Inertial Response to Acceleration

A material body resists changes in its state of motion. Newton's second law describes this response through the relation between applied force, inertial mass, and acceleration:

$$F = ma$$

Substituting the proposed torus-based expression for inertial mass gives:

$$F = \frac{W_p + |W_v|}{c^2}, a$$

The equation expresses the central idea of the model: both energy contributions participate in determining the inertia of matter.

Positive energy and binding energy are not required to interact directly through their external scalar fields for this relation to hold. Their common origin in the electromagnetic structure of each torus provides the proposed connection at the source.

The detailed microscopic mechanism by which the internal electromagnetic organization responds to acceleration is not derived here. The analysis instead adopts the proposed energy–mass relation and applies Newtonian mechanics to investigate its macroscopic consequences.



Figure 4. Conceptual deformation of scalar fields during acceleration. *Acceleration of the electromagnetic torus produces a temporary asymmetry in the surrounding positive and binding scalar fields. As changes propagate at the speed of light, both fields progressively adjust to the changing motion of their source. Their combined response is proposed as a physical mechanism contributing to inertia.*

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4.3. Inertial Mass of a Macroscopic Body

A macroscopic body contains a large number of electromagnetic toruses.

If the body consists of N toruses, its total positive energy may be expressed in the simplest additive approximation as:

$$W_p = \sum_{i=1}^{N} W_{p,i}$$

Similarly, the total magnitude of binding energy may be written as:

$$|W_v| = \sum_{i=1}^{N} |W_{v,i}|$$

The corresponding inertial mass is then:

$$m = \frac{1}{c^2} \sum_{i=1}^{N} (W_{p,i} + |W_{v,i}|)$$

This approximation assumes that the energy contributions of the individual toruses can be added without separately counting the same interaction energy.

In real material structures, interactions between toruses may modify their internal energies and create additional binding contributions. Such changes must be included in the total energy accounting.

The central principle nevertheless remains unchanged: in the proposed model, inertial mass depends on the combined magnitudes of the positive and binding-energy contributions of the complete material system.

4.4. Inertia and Gravitational Interaction

The distinction between inertia and gravity becomes clear when the roles of the two energy contributions are compared.

In inertia, positive energy and the magnitude of binding energy contribute in the same direction. Both increase the proposed inertial mass.

In gravitational interaction, the two external scalar fields have opposite effects.

The positive scalar field produces a repulsive contribution, while the binding scalar field produces an attractive contribution.

Consequently, the gravitational interaction depends on the balance between two opposing forces, whereas inertial mass depends on the sum of two positive energy magnitudes.

This difference offers a possible explanation within the model for why inertia can be substantial while the resulting gravitational interaction is comparatively weak.

The quantitative relationship between these effects is developed in later sections, where the spatial distributions and coupling strengths of the two scalar fields are examined.

The proposed distinction can be summarized as follows.

Inertia:

$$mc^2 = W_p + |W_v|$$

Gravity:

$$F_g = F_p + F_v$$

The two phenomena are therefore attributed to the same underlying electromagnetic energy structure, but they reflect different combinations of its physical contributions.

4.5. Scope of the Inertial Description

The purpose of the present section is not to derive Newton's second law or the conventional mass–energy equivalence relation.

Instead, it defines how the electromagnetic torus model assigns inertial mass to the two energy contributions associated with its internal structure.

The proposed relation is intended to provide a physical interpretation of inertia within the framework of electromagnetic matter.

Its ultimate validity depends on whether the internal energy structure of the torus and its response to acceleration can independently reproduce the assumed mass relation.

The subsequent analysis concentrates on the second major consequence of the same energy structure: the formation and interaction of two independent scalar fields and their proposed role in gravity. [1, 2, 3, 6]

5. Two Independent Scalar Fields

5.1. From Electromagnetic Toruses to Scalar Fields

The electromagnetic torus contains two complementary energy contributions: positive energy and negative binding energy. Both originate from the same internal electromagnetic structure, but their physical roles are different.

The positive energy contribution is associated with the internal dynamics of the torus, particularly the displacement field P. The negative binding-energy contribution is associated with the electromagnetic organization responsible for maintaining the localized structure.

The model proposes that both contributions generate scalar fields extending into the surrounding space.

The positive scalar field is denoted by

$$\Phi_p(r,t)$$

and the binding scalar field by

$$\Phi_v(r,t)$$

These fields are not identified with the ordinary electric and magnetic vector fields. Instead, they represent two proposed scalar manifestations of the electromagnetic energy structure of matter.

An individual torus possesses an organized magnetic field and may have a magnetic moment. In macroscopic matter, however, magnetic moments can have different orientations and their vector contributions may cancel.

The scalar energy contributions do not depend on such vector alignment in the same way. Their source strengths are associated with the positive energy and the magnitude of binding energy contained in the constituent toruses.

Consequently, a macroscopic body may generate both scalar fields even when its external magnetic vector field is negligible.

This distinction provides the proposed basis for a universal gravitational interaction that does not require macroscopic magnetic alignment.

5.2. Independent Dynamics of the Two Fields

The two scalar fields originate from the same electromagnetic structure, but their propagation is assumed to be independent.

The positive scalar field does not directly alter the binding scalar field during propagation. Similarly, the binding scalar field does not directly modify the positive scalar field.

Each field responds to its own source distribution and evolves according to its own dynamical equation.

Let the source densities be

$$\rho_p(r,t) \geq 0$$

$$\rho_v(r,t) \geq 0$$

where both quantities represent nonnegative magnitudes of their respective energy distributions.

The signed binding-energy contribution remains negative, although its source density is expressed through a positive magnitude.

The simplest proposed dynamical equations are

$$\frac{1}{c^2}\frac{\partial^2\Phi_p}{\partial t^2} - \nabla^2\Phi_p = \lambda_p\rho_p$$

$$\frac{1}{c^2}\frac{\partial^2\Phi_v}{\partial t^2} - \nabla^2\Phi_v = \lambda_v\rho_v$$

Here, λ_p and λ_v are the respective source-coupling coefficients.

The equations contain no direct coupling between the two scalar fields. Each evolves independently in response to its own source.

Although the mathematical forms are similar, the coefficients need not initially be identical. Equality of the two couplings would represent an additional symmetry of the model.

These wave equations are proposed governing equations rather than consequences already derived from Maxwell's equations.

5.3. Propagation at the Speed of Light

The proposed scalar fields originate from electromagnetic structures. The model therefore assumes that changes in both fields propagate at the speed of light.

$$v_p = v_v = c$$

This assumption introduces no separate propagation speed for gravitational interaction.

In established general relativity, gravitational disturbances propagate at the speed of light, in agreement with observations of gravitational waves and their electromagnetic counterparts.

The proposed model adopts the same propagation speed for its two scalar fields while offering a different interpretation of the underlying interaction.

For a localized time-dependent source, the field observed at a distance depends on the earlier state of that source.

The propagation delay is determined by

$$\Delta t = \frac{r}{c}$$

where r is the distance between source and observation point.

A change in the positive-energy source affects the positive scalar field after the corresponding propagation delay. A change in the binding-energy source similarly affects the binding scalar field.

Because both fields propagate at the same speed, changes originating simultaneously from the same torus can reach a distant location with the same propagation delay.

Nevertheless, the two field amplitudes and their interactions with matter remain distinct.

The equality of propagation speeds does not require direct interaction between the fields during transmission.

5.4. Connection at the Source and at the Receiving Body

The independence of the two scalar fields applies to their propagation through space. It does not imply that they are unrelated at their origin or destination.

At the source, both fields arise from the same electromagnetic torus.

The positive-energy contribution and binding-energy contribution are determined by the internal organization of that structure. Any change in the torus may therefore alter both source strengths.

During propagation, the two fields evolve independently.

At a receiving torus, both fields act upon the same physical structure.

The positive scalar field is proposed to produce a repulsive contribution, whereas the binding scalar field produces an attractive contribution.

Their resulting mechanical effects are combined through force addition:

$$F_g = F_p + F_v$$

The two contributions are therefore linked through the response of matter rather than through direct field-to-field interaction in space.

The same principle applies to macroscopic bodies containing many toruses.

The total response depends on the distribution of positive and binding energy within the receiving body and on the external scalar fields generated by other bodies.

This source–propagation–receiver distinction is a central feature of the proposed model.

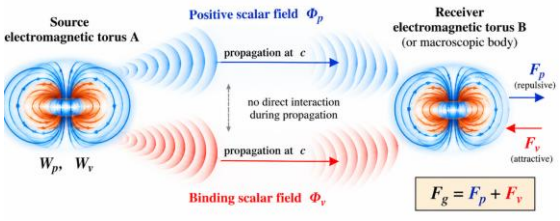


Figure 5. Independent propagation of two scalar fields between electromagnetic toruses. *An electromagnetic torus generates a positive scalar field and a binding scalar field. Both propagate independently at the speed of light. Their effects combine when they act upon another electromagnetic torus or macroscopic body. No direct interaction between the two fields is assumed during propagation.*

5.5. Static Fields and the Long-Range Approximation

For stationary sources, the scalar fields do not vary with time.

Therefore,

$$\frac{\partial^2 \Phi_p}{\partial t^2} = 0$$

$$\frac{\partial^2 \Phi_v}{\partial t^2} = 0$$

The dynamical equations then reduce to

$$\nabla^2 \Phi_p = -\lambda_p \rho_p$$

$$\nabla^2 \Phi_v = -\lambda_v \rho_v$$

These are two independent Poisson equations.

Their solutions depend on the spatial distributions of the corresponding energy sources and on the boundary conditions.

For localized sources, the scalar potentials can be expressed as

$$\Phi_p(r) = \frac{\lambda_p}{4\pi} \int \frac{\rho_p(r')}{|r - r'|} dV'$$

$$\Phi_v(r) = \frac{\lambda_v}{4\pi} \int \frac{\rho_v(r')}{|r - r'|} dV'$$

The integration extends over the source distributions.

At distances much larger than the characteristic dimensions of the source, the leading terms become

$$\Phi_p(r) \approx \frac{\lambda_p W_p}{4\pi r}$$

$$\Phi_v(r) \approx \frac{\lambda_v |W_v|}{4\pi r}$$

Both scalar potentials therefore have the same leading inverse-distance dependence.

Their gradients decrease approximately with the square of the distance.

This result provides a mathematical basis for examining an inverse-square interaction between distant bodies.

The two potentials are written with positive source magnitudes. Their different physical effects are determined by the proposed coupling of each field to matter, not by assigning a negative magnitude to the binding-field source.

The static Poisson equations and their solutions establish the spatial framework used in the subsequent analysis. They do not, by themselves, determine whether the resulting interaction is attractive or repulsive.

The following sections investigate how energy minimization, field overlap, and the proposed source–receiver couplings determine the interaction energies and forces associated with these independently propagating scalar fields. [4, 5, 6, 8]

6. Energy Minimization and Field Distribution

6.1. Energy Minimization as a Principle of Field Organization

The electromagnetic torus model proposes that positive energy and negative binding energy generate two independent scalar fields extending into the surrounding space.

Both fields originate from the same electromagnetic structure, but their spatial distributions are governed by separate dynamical processes.

The central assumption of the present analysis is that each field tends toward an energetically favorable spatial configuration under the constraints imposed by its source and boundary conditions.

This principle does not imply that positive and binding energies must cancel locally. Nor does it require direct interaction between the two fields during propagation.

Instead, each field independently establishes a spatial distribution consistent with its own energy balance.

The mathematical objective is to determine whether such a principle can produce a long-range field whose amplitude decreases inversely with distance.

The analysis begins with a general scalar field and subsequently applies the resulting equations separately to the positive and binding fields.

6.2. Energy Functional of a Scalar Field

Consider a scalar field Φ generated by a spatially distributed source density ρ.

The field is assigned the following static energy functional:

$$Ⅎ E[\Phi] = \int \left[\frac{\kappa}{2}|\nabla\Phi|^2 + \frac{\mu}{2}\Phi^2 - s\Phi\right] dV$$

Here, κ is a positive coefficient describing the energetic cost of spatial field gradients, μ describes a possible local contribution associated with field amplitude, and s denotes the effective source strength.

The source may be related to the corresponding positive energy density through:

$$s = \alpha\rho$$

where α is a coupling coefficient.

The gradient term is nonnegative:

$$\frac{\kappa}{2}|\nabla\Phi|^2 \geq 0$$

This term penalizes rapid spatial changes in the scalar field and favors smooth configurations.

The term involving μ determines whether the field has an additional local energetic cost associated with its amplitude.

The source term describes the interaction between the field and the distribution that generates it.

For κ greater than zero and μ nonnegative, the functional is convex under appropriate boundary conditions. Its stationary configuration can therefore represent a stable minimum with respect to variations of the scalar field.

The functional is introduced as a proposed effective description. Its precise coefficients and microscopic origin remain to be derived from the electromagnetic torus structure.

6.3. Derivation of the Field Equation

The equilibrium field configuration is obtained by requiring the first variation of the energy functional to vanish:

$$\delta\mathcal{E} = 0$$

Variation with respect to Φ gives:

$$\delta\mathcal{E} = \int [\kappa\nabla\Phi \cdot \nabla\delta\Phi + \mu\Phi\,\delta\Phi - s\,\delta\Phi]dV$$

Integrating the gradient term by parts, assuming that the boundary contribution vanishes, yields:

$$\delta\mathcal{E} = \int [-\kappa\nabla^2\Phi + \mu\Phi - s]\delta\Phi\ dV$$

Since the variation δΦ is arbitrary, the stationary configuration satisfies:

$$-\kappa\nabla^2\Phi + \mu\Phi = s$$

This is the governing static equation resulting from the selected energy functional.

The second variation is:

$$\delta^2\mathcal{E} = \int [\kappa|\nabla\delta\Phi|^2 + \mu|\delta\Phi|^2]dV$$

For positive κ and nonnegative μ, this expression is nonnegative, confirming stability with respect to the permitted variations.

Thus, the energy-minimization principle provides a mathematical procedure for determining the spatial distribution of the scalar field.

6.4. Poisson Equation and Long-Range Fields

For a field without an additional amplitude-dependent term, the simplest choice is:

$$\mu = 0$$

The governing equation then becomes:

$$\nabla^2\Phi = -\frac{s}{\kappa}$$

Substituting the source relation gives:

$$\nabla^2\Phi = -\frac{\alpha}{\kappa}\boldsymbol{\rho}$$

This is Poisson's equation.

Outside the effective source region, where the source density is negligible, the equation reduces to:

$$\nabla^2\Phi = 0$$

For a spherically symmetric field, the radial equation is:

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{d\Phi}{dr}\right) = 0$$

Integrating twice gives:

$$\Phi(r) = A + \frac{B}{r}$$

If the potential approaches zero at infinity, the constant A vanishes:

$$\Phi(r) = \frac{B}{r}$$

The remaining coefficient B is determined by the total source strength.

For a localized source with total magnitude Q, the far-field solution is:

$$\Phi(r) \approx \frac{\alpha Q}{4\pi\kappa r}$$

The corresponding radial gradient has magnitude:

$$\left|\frac{d\Phi}{dr}\right| \approx \frac{\alpha Q}{4\pi\kappa r^2}$$

The inverse-square dependence therefore follows mathematically from the selected energy functional, the absence of the amplitude-dependent term, and the assumption of an approximately localized source.

The inverse-distance form is a property of the resulting spatial field distribution. A physical force law additionally requires a defined coupling between the field and a receiving body.

6.5. Separate Minimization of Positive and Binding Fields

The preceding mathematical procedure can be applied independently to the two scalar fields of the electromagnetic torus model.

The positive field is described by:

$$\mathcal{E}_p = \int \left[\frac{\kappa_p}{2}\left|\nabla\Phi_p\right|^2 - s_p\Phi_p\right] dV$$

The binding field is described by:

$$\mathcal{E}_v = \int \left[\frac{\kappa_v}{2}|\nabla\Phi_v|^2 - s_v\Phi_v\right] dV$$

The two functionals contain no direct coupling term involving both fields.

Their sources are:

$$s_p = \alpha_p\rho_p$$

$$s_v = \alpha_v\rho_v$$

The corresponding Poisson equations are:

$$\nabla^2\Phi_p = -\frac{\alpha_p}{\kappa_p}\rho_p$$

$$\nabla^2\Phi_v = -\frac{\alpha_v}{\kappa_v}\rho_v$$

Both source densities represent nonnegative magnitudes of the relevant energy contributions.

The negative sign associated with binding energy does not require the binding-field gradient energy itself to be negative.

This distinction permits both field distributions to be governed by mathematically stable quadratic functionals.

For localized sources, the leading far-field solutions are:

$$\Phi_p(r) \approx \frac{\alpha_p W_p}{4\pi\kappa_p r}$$

$$\Phi_v(r) \approx \frac{\alpha_v |W_v|}{4\pi\kappa_v r}$$

Both fields exhibit an inverse-distance dependence, although their amplitudes can differ.

Their independent evolution is preserved because neither field appears in the governing equation of the other.

The repulsive or attractive character of their interaction with another body is not determined by these field equations alone. It depends on the respective source–receiver coupling and the associated interaction-energy balance.

In particular, the energy-minimization calculation does not independently establish that the two fields possess equal coupling coefficients or opposite mechanical effects. These remain additional physical hypotheses of the model.

The minimization of the two field-energy functionals determines their preferred spatial configurations. It does not, by itself, establish the signs of the mechanical interactions between separate material bodies. The gradient energy associated with each scalar field must therefore be distinguished from the interaction energy arising through its coupling to matter.

In the proposed model, positive-energy interactions are repulsive, whereas binding-energy interactions are attractive. These opposite effects are attributed to the different energetic roles of the two source–receiver couplings, while both fields retain independent and stable spatial dynamics. The mathematical forms and signs of these couplings are explicit physical assumptions, to be established from the electromagnetic structure of the torus. Their consequences for gravitational interaction are examined in Section 7.

6.6. Finite Source Geometry and Field Distribution

The inverse-distance solution represents the leading field behavior at distances much larger than the characteristic dimensions of the source.

An electromagnetic torus, however, has a finite geometry, and a macroscopic body consists of many spatially distributed toruses.

The corresponding scalar sources therefore occupy finite regions or possess spatially extended energy distributions.

For a general source distribution, the solution of Poisson's equation can be written as:

$$\Phi(r) = \frac{\alpha}{4\pi\kappa}\int \frac{\rho(r')}{|r - r'|}dV'$$

Here, r and r' denote positions in three-dimensional space, while |r-r'| represents the distance between the observation point and each source element. Integration is performed over the complete spatial distribution of the source.

At large distances, the result approaches:

$$\Phi(r) \approx \frac{\alpha Q}{4\pi\kappa r}$$

Near the source, the detailed field distribution depends on its geometry.

For a sufficiently smooth, spatially extended source, the potential can remain finite throughout the source region.

Finite source size therefore provides a natural way to avoid the singular behavior associated with ideal mathematical point sources.

The spatial distribution of the scalar field should not be confused with the geometry of the individual electromagnetic toruses. The former describes the macroscopic response of an independently evolving scalar field to the combined energy sources.

For the gravitational analysis developed in the following sections, the detailed internal geometry of the sources can be neglected when their separation is sufficiently large.

This allows the interaction between macroscopic bodies to be described using their total positive and binding-energy contributions.

The present section establishes the mathematical basis for long-range scalar fields. The following section examines the interaction between two such distributions and determines the conditions under which their opposing contributions produce an inverse-square gravitational force. [5, 12, 13, 14]

7. Field Overlap and the Origin of Gravity

7.1. Interaction Between Two Scalar Field Distributions

The preceding sections introduced two independent scalar fields associated with positive energy and negative binding energy. Both fields extend beyond their material sources and, in the static limit, are described by Poisson equations.

When two bodies are present, the scalar field generated by each body extends into the region occupied by the other. Their spatial distributions therefore overlap.

The model proposes that this overlap produces an interaction energy between the bodies.

For each scalar field, the interaction is considered independently. The positive and binding fields do not interact directly with one another during propagation.

Consider two bodies separated by a distance d. Their scalar source distributions are denoted by ρ_1 and ρ_2.

For a given field, the total source distribution is:

$$\rho = \rho_1 + \rho_2$$

Because the proposed field equations are linear, the total scalar potential is:

$$\Phi = \Phi_1 + \Phi_2$$

The spatial interaction can be characterized by an overlap integral involving the gradients of the two potentials:

$$I(d) = \int \nabla\Phi_1 \cdot \nabla\Phi_2, dV$$

This quantity measures the cross contribution of the two field gradients over space.

It differs from the direct overlap of the source densities. In particular, the gradient overlap can remain significant at large separations because the scalar potentials extend beyond the localized source regions.

The following analysis determines the distance dependence of this overlap.

7.2. Derivation of the Field-Overlap Function

For a scalar field governed by Poisson's equation, the potential generated by a localized source has the following far-field form:

$$\Phi_i(r_i) = \frac{\alpha Q_i}{4\pi\kappa r_i}$$

Here, Q_i denotes the total source strength, r_i is the distance from the corresponding source, and α and κ are the field coefficients.

Consider two sources separated by a distance d. The spatial overlap of their scalar-field gradients is defined as:

$$I(d) = \int \nabla\Phi_1 \cdot \nabla\Phi_2, dV$$

Substituting the far-field potentials gives:

$$I(d) = \frac{\alpha^2 Q_1 Q_2}{16\pi^2\kappa^2} \int \nabla\frac{1}{r_1} \cdot \nabla\frac{1}{r_2}, dV$$

For two distinct point sources, integration over all space gives the identity:

$$\int \nabla\frac{1}{r_1} \cdot \nabla\frac{1}{r_2}, dV = \frac{4\pi}{d}$$

Consequently:

$$I(d) = \frac{\alpha^2 Q_1 Q_2}{4\pi\kappa^2 d}$$

The field-gradient overlap therefore decreases inversely with the separation between the sources:

$$I(d) \propto \frac{1}{d}$$

This result establishes the spatial dependence of the overlap. It does not independently determine the sign of the mechanical interaction.

In the proposed model, the positive and binding scalar fields have independent spatial distributions. Their source–receiver interactions are assigned opposite energetic roles: positive interaction energy produces repulsion, while negative binding interaction energy produces attraction.

Accordingly, their interaction energies are represented by:

$$U_p(d) = +K_p \frac{W_{p1} W_{p2}}{d}$$

$$U_v(d) = -K_v \frac{|W_{v1}||W_{v2}|}{d}$$

The coefficients K_p and K_v incorporate the corresponding field normalization and source–receiver coupling.

The hypothesis of equal coupling strengths,

$$K_p = K_v = K$$

is adopted in the following analysis.

Thus, the inverse-distance dependence follows from the assumed scalar-field equations, while the opposite signs and equality of the interaction coefficients remain physical hypotheses of the electromagnetic torus model.

The result applies to the leading far-field approximation. For spatially extended sources, corrections depend on their geometry and energy distributions.

7.3. Positive Energy and Repulsive Interaction

The positive scalar field is proposed to produce a repulsive interaction between bodies.

Let the positive-energy source strengths of the two bodies be W_{p1} and W_{p2}.

The interaction energy is defined through the positive field-overlap contribution:

$$U_p(d) = +K\frac{W_{p1}W_{p2}}{d}$$

Here, K is a positive coefficient determined by the field normalization and source–receiver coupling.

The radial force follows from the distance derivative of the interaction energy:

$$F_p(d) = -\frac{dU_p}{dd}$$

Therefore:

$$F_p(d) = +\frac{KW_{p1}W_{p2}}{d^2}$$

The positive sign indicates repulsion.

As the bodies separate, their positive interaction energy decreases toward zero.

This behavior corresponds to the energy-minimization interpretation introduced in Section 3.

The repulsive character is a proposed property of the positive scalar-field coupling. It is not established solely by the positive sign of the local field-gradient energy.

7.4. Binding Energy and Attractive Interaction

The binding scalar field is proposed to produce attraction.

Its source strength is associated with the magnitude of negative binding energy in each body.

The corresponding interaction energy is written as:

$$U_v(d) = -K\frac{|W_{v1}||W_{v2}|}{d}$$

The negative sign represents the proposed attractive source–receiver coupling.

The radial force is:

$$F_v(d) = -\frac{dU_v}{dd}$$

Thus:

$$F_v(d) = -\frac{K|W_{v1}||W_{v2}|}{d^2}$$

The force is negative, indicating attraction.

As the separation decreases, the binding interaction energy becomes more negative. The approach of the bodies therefore corresponds to a reduction in their interaction energy.

The positive and binding fields are treated symmetrically with respect to their spatial dependence, while their interactions with matter have opposite signs.

The use of the same coupling coefficient K for both contributions is a simplifying symmetry hypothesis. It requires independent physical justification.

7.5. Gravitational Force as the Resultant of Two Interactions

The positive and binding scalar fields propagate independently. Their mechanical effects combine when they act upon the same material body.

The total radial force is:

$$F_g = F_p + F_v$$

Substituting the two contributions gives:

$$F_g(d) = \frac{K}{d^2}\left[W_{p1}W_{p2} - |W_{v1}||W_{v2}|\right]$$

The resulting interaction is attractive when:

$$|W_{v1}||W_{v2}| > W_{p1}W_{p2}$$

Under this condition, the binding contribution exceeds the repulsive contribution.

The gravitational force therefore depends on the balance between the positive and binding-energy contents of the interacting bodies.

In the model, the relative weakness of gravity may reflect the difference between two opposing interactions rather than a correspondingly weak underlying energy structure.

However, the quantitative magnitude of this difference is not determined by the inverse-square dependence alone.

It depends on the coupling coefficient and the relative energy contributions of the material sources.

7.6. Extended Sources and Finite Geometry

The preceding calculation used a point-source approximation to determine the leading long-range interaction.

Actual electromagnetic toruses have finite dimensions, and macroscopic bodies contain extended distributions of many toruses.

For spatially distributed sources, the inverse-distance interaction can be generalized as:

$$U(d) = K \int \int \frac{\rho_1(r)\rho_2(r')}{|r - r'|}, dV, dV'$$

The expression uses a simplified spatial notation. The denominator represents the three-dimensional separation between points in the two source distributions, which also depends on the relative displacement of the bodies.

For the binding field, the corresponding interaction has the opposite sign.

At large separations, the leading contribution is determined by the total source strengths:

$$U_p(d) \approx + \frac{K W_{p1} W_{p2}}{d}$$

$$U_v(d) \approx - \frac{K |W_{v1}||W_{v2}|}{d}$$

At short distances, the detailed source geometry becomes important.

For smooth, finite source distributions, the interaction energy need not diverge as the centers approach. Its behavior depends on the actual spatial distributions and any constraints on deformation or overlap.

The point-source approximation is therefore appropriate for describing long-range gravitational interaction but not necessarily for determining the forces within the internal structure of a torus.

7.7. Comparison with Newton's Gravitational Law

Newton's gravitational law for two masses separated by distance d is:

$$F_N(d) = - \frac{G m_1 m_2}{d^2}$$

The scalar-field model gives:

$$F_g(d) = - \frac{K}{d^2} \left[|W_{v1}||W_{v2}| - W_{p1} W_{p2} \right]$$

For agreement with Newton's law, the following relation must hold:

$$G m_1 m_2 = K \left[|W_{v1}||W_{v2}| - W_{p1} W_{p2} \right]$$

The model therefore reproduces the mathematical form of the inverse-square law provided that its scalar-field assumptions and coupling relations apply.

Agreement in magnitude additionally requires that the energy contributions and coupling coefficient satisfy the measured gravitational constant.

Since the proposed inertial mass is determined by the sum of the positive and binding-energy magnitudes, the relationship between gravitational and inertial mass imposes an additional quantitative constraint.

This relationship is examined in the following section.

7.8. Physical Interpretation

Within the proposed electromagnetic torus framework, gravitational attraction emerges from the competition between two independently propagating scalar-field interactions.

The positive contribution acts repulsively, while the binding contribution acts attractively.

Their spatial behavior is governed by the same type of long-range field equation. Their different mechanical effects arise from their respective couplings to matter.

The gravitational force is determined by the resultant of these contributions at the receiving body.

This interpretation connects gravitational interaction to the energy structure of matter without requiring direct interaction between the positive and binding scalar fields during propagation.

The mathematical analysis establishes how an inverse-square distance dependence follows from the proposed field equations and overlap integrals.

The electromagnetic origin of the scalar fields, the signs of their interactions, and the equality of their coupling coefficients remain physical hypotheses requiring further derivation and experimental verification.

The next section investigates the quantitative relationship between these energy contributions, inertial mass, and gravitational mass. [5, 6]

8. Gravitational and Inertial Mass

8.1. Two Expressions of the Same Energy Structure

The preceding sections proposed that inertial mass and gravitational interaction arise from the same two energy contributions of the electromagnetic torus.

Positive energy contributes to the internal dynamics of matter, while negative binding energy maintains its localized structure. Both are associated with the same material source but generate independently propagating scalar fields.

The central distinction is that inertia and gravity involve different combinations of these contributions.

In the proposed inertial description, the positive energy and the magnitude of binding energy are added:

$$m_i c^2 = W_p + |W_v|$$

In gravitational interaction, their respective scalar fields produce opposing forces.

For two bodies separated by a distance d, the resulting interaction is:

$$F_g = -\frac{K}{d^2}\left(|W_{v1}||W_{v2}| - W_{p1}W_{p2}\right)$$

Here, the negative sign denotes attraction toward the source.

The difference between the two energy combinations provides the central connection between inertial and gravitational behavior in the model.

However, the fact that both phenomena originate from the same energy structure does not automatically establish the observed equivalence of gravitational and inertial mass. That equivalence imposes an additional condition on the scalar-field coupling.

8.2. Relative Binding-Energy Dominance

To express the relationship more clearly, define the relative binding-energy dominance of a body:

$$\delta = \frac{|W_v| - W_p}{|W_v| + W_p}$$

Since the proposed stable torus is binding dominated,

$$|W_v| > W_p$$

the parameter is positive:

$$\delta > 0$$

For positive energy contributions and finite binding energy, the parameter also satisfies:

$$\delta < 1$$

The parameter δ measures the relative difference between the two contributions rather than their absolute magnitude.

From the definitions of inertial mass and δ, the positive energy can be expressed as:

$$W_p = \frac{m_i c^2}{2}(1-\delta)$$

Similarly, the magnitude of binding energy is:

$$|W_v| = \frac{m_i c^2}{2}(1+\delta)$$

These relations separate the total inertial energy scale from the relative dominance of binding energy.

The inertial mass is determined by the sum, while δ specifies how the total is distributed between the two contributions.

A body can therefore have substantial inertial mass without requiring its positive and binding-energy contributions to be nearly equal.

8.3. Gravitational Interaction in Terms of Inertial Mass

Consider two bodies with inertial masses m_1 and m_2 and energy-balance parameters δ_1 and δ_2.

Their positive energy contributions are:

$$W_{p1} = \frac{m_1 c^2}{2}(1-\delta_1)$$

$$W_{p2} = \frac{m_2 c^2}{2}(1-\delta_2)$$

Their binding-energy magnitudes are:

$$|W_{v1}| = \frac{m_1 c^2}{2}(1+\delta_1)$$

$$|W_{v2}| = \frac{m_2 c^2}{2}(1+\delta_2)$$

Substituting these expressions into the gravitational interaction law gives:

$$F_g = -\frac{Kc^4 m_1 m_2}{4d^2}[(1+\delta_1)(1+\delta_2) - (1-\delta_1)(1-\delta_2)]$$

Expanding the products yields:

$$F_g = -\frac{Kc^4 m_1 m_2}{2d^2}(\delta_1+\delta_2)$$

This equation is a central quantitative result of the proposed two-field model.

It shows that the gravitational force depends on the inertial masses of the interacting bodies and on the combined relative binding-energy dominance of their internal structures.

The corresponding effective gravitational coefficient is:

$$G_{12} = \frac{Kc^4}{2}(\delta_1+\delta_2)$$

Thus, the model permits a possible dependence of gravitational interaction strength on the internal energy composition of the interacting bodies.

Whether such dependence is physically admissible must be determined by comparison with experimental observations.

8.4. Recovery of Newton's Gravitational Law

Newton's gravitational law is:

$$F_N = -\frac{Gm_1 m_2}{d^2}$$

For the proposed model to reproduce this law with a universal gravitational constant, the effective coefficient must be independent of the material composition of the interacting bodies.

The simplest condition is that all bodies share the same value of relative binding-energy dominance:

$$\delta_1 = \delta_2 = \delta$$

Under this condition, the gravitational force becomes:

$$F_g = -\frac{Kc^4 \delta m_1 m_2}{d^2}$$

Comparison with Newton's law gives:

$$G = Kc^4$$

This relation connects the gravitational constant to the scalar-field coupling coefficient and the relative distribution of positive and binding energy.

If K and δ are universal constants, the model reproduces the Newtonian inverse-square law with a universal gravitational coefficient.

The relation does not independently determine either K or δ.

The measured value of G constrains their product, while their individual values must be established through the underlying electromagnetic structure or additional experimental information.

8.5. Gravitational Acceleration and Material Composition

A particularly important test concerns the acceleration of bodies with different internal energy compositions in the same gravitational environment.

Let body 1 be the source and body 2 the falling test body.

The magnitude of the gravitational acceleration of body 2 is obtained by dividing the interaction force by its inertial mass:

$$a_2 = \frac{|F_g|}{m_2}$$

Using the two-field interaction law gives:

$$a_2 = \frac{Kc^4 m_1}{2d^2}(\delta_1 + \delta_2)$$

The acceleration depends on the binding-energy parameter of both the source and the test body.

Therefore, two test bodies with equal inertial masses but different values of δ would generally experience different accelerations in the same external field.

For test bodies A and B near the same source, the predicted difference is:

$$a_A - a_B = \frac{Kc^4 m_1}{2d^2}(\delta_A - \delta_B)$$

This result follows directly from the proposed interaction law.

Experiments testing the universality of free fall place strong restrictions on any such material dependence.

Consequently, the model must either predict an extremely small variation of δ among different materials or identify an additional mechanism that preserves universal free-fall acceleration.

The assumption of a common δ is therefore not merely a mathematical convenience. It represents a significant physical requirement of the theory.

8.6. Gravitational Mass as an Effective Property

In Newtonian mechanics, gravitational mass is introduced through the coupling of a body to a gravitational field.

The two-field model provides a different interpretation: gravitational interaction arises from the combined attractive and repulsive scalar-field responses.

For a body with a given inertial mass, the effective gravitational coupling depends on its positive and binding-energy contents.

The interaction coefficient derived above is:

$$G_{12} = \frac{Kc^4}{2}(\delta_1 + \delta_2)$$

A noteworthy consequence is that this coefficient belongs to the interacting pair rather than automatically factorizing into a universal source property and an independent receiving-body property.

Therefore, the proposed force law does not yet establish a universally defined gravitational mass for each isolated body.

Such a definition becomes straightforward in the universal-δ limit, where the interaction takes the Newtonian form.

The distinction is relevant for interpreting the equivalence of inertial and gravitational mass.

The proposed common electromagnetic origin offers a possible conceptual connection between the two, but their quantitative equivalence depends on the coupling structure and universality conditions.

8.7. Physical Implications

The relationship between inertial mass and gravitational interaction can be summarized through two expressions.

Inertial mass:

$$m_i = \frac{W_p + |W_v|}{c^2}$$

Gravitational interaction:

$$F_g = -\frac{K}{d^2}\left(|W_{v1}||W_{v2}| - W_{p1}W_{p2}\right)$$

The first depends on the sum of two positive energy magnitudes.

The second depends on the difference between attractive and repulsive contributions involving two interacting bodies.

The resulting gravitational strength is consequently controlled by both the overall inertial-energy scale and the relative distribution of the two energy contributions.

This provides a framework in which substantial inertia can coexist with a much weaker gravitational interaction.

At the same time, the theory imposes an important requirement: the relative binding-energy dominance must be nearly universal if the gravitational acceleration of different materials is to remain consistent with observation.

The quantitative limits on this requirement, together with constraints on the coupling coefficient K and the propagation dynamics of the scalar fields, are examined in the following section. [6, 7]

9. Quantitative Constraints and Physical Tests

9.1. Quantitative Requirements of the Two-Field Model

The preceding sections developed a mathematical description in which gravitational attraction arises from two independently propagating scalar fields associated with positive energy and negative binding energy.

The model reproduces the inverse-square distance dependence of Newtonian gravity under the assumed long-range field equations and source–receiver couplings.

However, reproducing the distance dependence alone is insufficient. A physically viable theory must also reproduce the measured gravitational strength, the universality of free fall, and the observed dynamics of gravitational systems.

The proposed force law is:

$$F_g = -\frac{K}{d^2}\left(|W_{v1}||W_{v2}| - W_{p1}W_{p2}\right)$$

The corresponding inertial mass is defined by:

$$m_i c^2 = W_p + |W_v|$$

Introducing the relative binding-energy dominance:

$$\delta = \frac{|W_v| - W_p}{|W_v| + W_p}$$

allows the interaction to be expressed as:

$$F_g = -\frac{Kc^4 m_1 m_2}{2d^2}(\delta_1 + \delta_2)$$

These relations identify two central quantities requiring quantitative determination: the scalar-field coupling coefficient K and the relative binding-energy dominance δ.

Their values must ultimately follow from the electromagnetic structure of the torus and its interactions, rather than being assigned solely to reproduce the measured gravitational constant.

9.2. Gravitational Constant and Coupling Strength

For bodies sharing a universal value of δ, the model gives:

$$G = Kc^4$$

Consequently:

$$K = \frac{G}{c^4 \delta}$$

Using the measured gravitational constant and the speed of light gives approximately:

$$K = \frac{8.26 \times 10^{-45}}{\delta}\ \mathrm{N}^{-1}$$

This numerical relation constrains the combination of the coupling coefficient and the energy-balance parameter.

However, it does not determine them separately.

For every admissible value of δ, a corresponding K can reproduce the measured Newtonian gravitational constant.

The model therefore requires an independent theoretical calculation of at least one of these quantities.

One possible approach is to derive δ from the positive and binding-energy contents of a stable electromagnetic torus.

A second approach is to derive K from the normalization of the independent scalar fields and their coupling to matter.

Agreement between these independently derived quantities and the measured gravitational constant would provide a nontrivial quantitative test of the model.

Until such a derivation is available, the relation involving G should be regarded as a consistency condition rather than an independent prediction of its numerical value.

9.3. Universality of Free Fall

The universality of free fall provides a particularly sensitive test of the proposed model.

For a source body S and a test body A, the predicted gravitational acceleration is:

$$a_A = \frac{Kc^4 m_S}{2d^2}(\delta_S + \delta_A)$$

For another test body B in the same gravitational field:

$$a_B = \frac{Kc^4 m_S}{2d^2}(\delta_S + \delta_B)$$

The difference is:

$$a_A - a_B = \frac{Kc^4 m_S}{2d^2}(\delta_A - \delta_B)$$

The corresponding Eötvös parameter is defined as:

$$\eta_{AB} = \frac{2(a_A - a_B)}{a_A + a_B}$$

Substitution gives:

$$\eta_{AB} = \frac{2(\delta_A - \delta_B)}{2\delta_S + \delta_A + \delta_B}$$

Thus, the two-field model predicts a possible composition dependence of free-fall acceleration whenever different materials

possess different relative binding-energy parameters.

If the source and test bodies all have approximately the same value δ, the expression simplifies to:

$$\eta_{AB} \approx \frac{\delta_A - \delta_B}{2\delta}$$

The MICROSCOPE satellite mission tested the universality of free fall using titanium and platinum alloys.

Its final published result found no statistically significant violation, with the Eötvös parameter constrained at the level of approximately one part in 10^{15}.

This places a severe restriction on differences between the values of δ assigned to different materials.

Within the simplified universal-background approximation, the experimental result requires the relative difference between δ values for the tested materials to be extremely small.

The model must therefore explain why the positive and binding-energy contributions maintain nearly the same relative balance across materials with substantially different internal structures.

A universal δ would satisfy this requirement. However, its universality must be obtained from the proposed electromagnetic dynamics rather than imposed only to recover the observed equality of gravitational acceleration.

9.4. Tests of the Inverse-Square Law

The long-range solutions derived in Sections 6 and 7 lead to scalar potentials with an inverse-distance dependence.

Their gradients consequently generate inverse-square interactions.

For two sufficiently distant bodies, the model predicts:

$$F_g \propto \frac{1}{d^2}$$

This dependence agrees with the Newtonian gravitational law.

However, the exact inverse-square form requires that both scalar fields remain effectively long range and that their relevant coupling coefficients do not introduce additional distance dependence.

If a scalar field possesses a finite characteristic interaction range, its spatial potential may acquire an exponential attenuation factor.

A general illustrative form is:

$$\Phi(r) = \frac{A}{r} e^{-r/\mathrm{l}}$$

Here, ℓ denotes the characteristic interaction range.

The resulting force would depart from the exact inverse-square law at distances comparable to ℓ.

Precision measurements of gravitational attraction at short distances therefore constrain any such corrections.

Torsion-balance experiments have tested the inverse-square law at separations down to tens of micrometers. These measurements have found no established departure from Newtonian gravity within their reported sensitivity.

The proposed two-field model must remain consistent with these observations.

In its simplest form, both fields are assumed to possess sufficiently long interaction ranges that their leading gravitational effect remains proportional to the inverse square of distance.

Possible deviations associated with finite torus geometry or modified scalar-field dynamics must be evaluated separately.

9.5. Propagation Speed and Gravitational Disturbances

The model assumes that both scalar fields propagate changes at the speed of light.

$$v_p = v_v = c$$

The corresponding dynamical equations were introduced in Section 5.

This assumption is consistent with the observed propagation speed of gravitational disturbances.

The gravitational-wave event GW170817, observed together with the gamma-ray burst GRB 170817A, provided a particularly stringent comparison between the propagation of gravitational and electromagnetic signals.

The observations constrain their relative propagation speeds to within a few parts in 10^{15}, under the assumptions used to interpret the emission delay.

The two-field model adopts equal propagation speeds from the outset.

However, this agreement at the level of assumed propagation speed does not demonstrate that the proposed scalar fields reproduce the complete observed gravitational-wave signal.

A full dynamical theory must also determine which disturbances can propagate, how they are generated by accelerating matter, and what measurable responses they produce in detectors.

The possibility of additional scalar radiation is especially important because independently propagating scalar fields can, in general, possess radiation patterns different from those of general relativity.

Such effects must be constrained by observations of binary stars and gravitational-wave sources.

9.6. Orbital Motion and Strong-Field Tests

For weak, slowly varying gravitational fields, an inverse-square attractive force is sufficient to reproduce the leading Newtonian description of orbital motion.

However, precision observations reveal effects beyond the Newtonian approximation.

These include orbital precession, gravitational time delay, the deflection of light, and energy loss through gravitational radiation.

The Cassini spacecraft experiment measured the propagation of radio signals near the Sun and strongly constrained departures from the general-relativistic prediction for gravitational time delay.

Observations of the double pulsar PSR J0737−3039A/B have also provided stringent tests of relativistic orbital dynamics and gravitational radiation.

The static inverse-square force derived in the present model is not sufficient by itself to predict these effects.

Additional equations are needed to determine the response of electromagnetic radiation to the scalar fields, the dynamics of moving material sources, and the transport of energy by time-dependent field disturbances.

These requirements do not invalidate the static analysis, but they define the boundary between reproducing Newtonian gravity and providing a complete alternative gravitational theory.

For the present article, the inverse-square interaction is therefore treated as the first quantitative consistency test, not as a complete description of all observed gravitational phenomena.

9.7. Model Parameters and Open Quantitative Problems

The principal quantitative requirements of the model can be summarized as follows.

1. Inertial mass. The proposed energy relation is:

$$mc^2 = W_p + |W_v|$$

This relation defines inertial mass in terms of the two energy contributions of the electromagnetic torus.

2. Relative binding-energy dominance. The parameter δ expresses the relative difference between positive and binding energy:

$$\delta = \frac{|W_v| - W_p}{|W_v| + W_p}$$

Its value must be derived from the internal structure of the torus.

3. Scalar-field coupling. The coefficient K determines the strength of the proposed scalar interactions. Its absolute value has not yet been independently calculated.

4. Gravitational constant. For a universal value of δ, the model gives:

$$G = Kc^4$$

The measured gravitational constant constrains the product of K and δ, but does not determine them separately.

5. Universality of free fall. Differences in δ between materials would produce differences in gravitational acceleration. Such differences are strongly constrained by experiment.

6. Interaction range. Both scalar fields are assumed to have long-range potentials proportional to 1/r. This provides the inverse-square dependence required for Newtonian gravity.

7. Propagation speed. Changes in both fields are assumed to propagate at the speed of light:

$$v_p = v_v = c$$

This is compatible with the observed speed of gravitational disturbances.

8. Dynamical gravitational effects. The response of the scalar fields to moving sources, gravitational radiation, and relativistic orbital effects requires further investigation.

A successful calculation must satisfy two conditions simultaneously.

First, it must reproduce the measured gravitational constant without using that constant merely to assign otherwise unknown internal parameters.

Second, it must explain the near universality of free-fall acceleration across different material compositions.

The model therefore offers a quantitative starting point, but its current agreement with the Newtonian inverse-square law should be distinguished from a complete experimental validation of its underlying electromagnetic and scalar-field hypotheses. [7, 8, 9, 10, 11]

10. Discussion

The electromagnetic torus model proposes a common physical origin for inertial mass and gravity. Both phenomena are associated with the positive energy and negative binding energy of localized electromagnetic structures, but they arise through different combinations of these contributions.

Inertial mass is proposed to depend on the sum of their absolute magnitudes, whereas gravitational interaction results from the competition between two opposing scalar-field effects. The positive field produces repulsion, while the binding field produces attraction.

An important feature of the model is the independence of the two scalar fields. They originate from the same electromagnetic torus and act upon the same receiving matter, but they do not interact directly during propagation. Their effects are combined only through the response of material bodies.

The proposed mechanism interprets attraction and repulsion through a common principle of energy minimization. Separation reduces positive interaction energy, while approach reduces negative binding interaction energy. This provides a unified conceptual explanation

for the opposite mechanical effects of the two fields.

The mathematical analysis shows that the assumed scalar-field equations can produce long-range potentials proportional to inverse distance. Their spatial overlap then leads to an inverse-square force law. The proposed gravitational interaction consequently reproduces the distance dependence of Newtonian gravity.

However, the derivation depends on the assumed source–field couplings. The electromagnetic origin of the independent scalar fields, the opposite signs of their interactions, and the equality of their coupling strengths have not yet been established from the internal dynamics of the torus.

The model also introduces a quantitative relationship between the gravitational constant, scalar-field coupling, and relative binding-energy dominance:

$$G = Kc^4$$

This relation provides a useful consistency condition, but it does not independently determine the gravitational constant until the parameters are calculated from the underlying electromagnetic structure.

A particularly important requirement is the observed universality of free fall. The model permits differences in gravitational acceleration if different materials possess different relative binding-energy contributions. Experimental results therefore require the parameter δ to be nearly universal or the theory to provide another mechanism preserving the equivalence of gravitational and inertial mass.

The proposed scalar fields are assumed to propagate disturbances at the speed of light, consistent with the observed propagation of gravitational waves. Nevertheless, reproducing their propagation speed does not establish agreement with all gravitational-wave observations or with other relativistic gravitational effects.

The present framework should therefore be understood as an initial physical model connecting electromagnetic structure, mass, and gravitational interaction. Its principal contribution is the identification of a specific two-field mechanism and the mathematical conditions required for it to reproduce Newtonian gravitational behavior.

Further development must determine the coupling coefficients from torus dynamics, establish the stability and energy balance of the scalar fields, and examine their predictions for relativistic motion, gravitational radiation, and the interaction of gravity with light. [6, 7, 8, 9 10, 11]

11. Conclusions

This work develops a theoretical framework in which inertial mass and gravitational interaction originate from the electromagnetic structure of matter. Building on the electromagnetic torus model introduced in Parts A1–A3, it proposes that two complementary energy contributions—positive energy and negative binding energy—determine both the inertial properties of matter and its long-range gravitational interaction.

The central distinction is that inertia and gravity depend on these energy contributions in different ways.

Inertial mass is proposed to depend on the sum of their absolute magnitudes:

$$mc^2 = W_p + |W_v|$$

Gravitational interaction, in contrast, is attributed to the resultant of two opposing scalar-field effects. The positive energy field produces repulsion, while the binding energy field produces attraction.

Both fields originate from the same electromagnetic torus and act upon the same receiving matter. However, they are proposed to propagate independently, without direct interaction between them. Changes in both fields are assumed to propagate at the speed of light.

The analysis demonstrates that the proposed scalar-field equations can yield long-range potentials proportional to inverse distance. Under the assumed source–receiver couplings, the corresponding interaction forces follow an inverse-square dependence.

The resulting gravitational interaction is expressed as:

$$F_g = -\frac{K}{d^2}\left(|W_{v1}||W_{v2}| - W_{p1}W_{p2}\right)$$

For a universal relative binding-energy parameter, the model recovers the mathematical form of Newton's gravitational law and obtains the relation:

$$G = Kc^4$$

This relation connects gravitational strength to the scalar-field coupling and the internal energy distribution of matter.

The proposed model therefore provides a possible physical interpretation of gravity as the net result of two opposing energy interactions, while inertia reflects the combined contributions of the same underlying energy structure.

The framework also identifies clear requirements for further development. The independent scalar fields and their coupling signs must be derived from the electromagnetic dynamics of the torus. The parameters K and δ must be determined independently, and the near universality of gravitational free fall must be explained.

Additional tests are required to establish whether the proposed dynamics can reproduce relativistic gravitational effects and gravitational-wave observations.

The main contribution of Part A4 is thus a unified conceptual and mathematical framework connecting electromagnetic structure, inertial mass, and gravitational interaction. It establishes the conditions under which the proposed two-field mechanism reproduces Newtonian gravity and identifies the quantitative questions that must be resolved to assess its physical validity.

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