Electromagnetic Basis of Gravity and Inertia in Classical Systems

Walid K. Miran
https://orcid.org/0009-0002-6578-9981
B.S. Electrical Engineering, University of California, San Diego
Independent Researcher
wmiran@ucsd.edu
07/24/2025
DOI 10.5281/zenodo.15854797

ABSTRACT

This paper proposes a reinterpretation of gravity and inertia within a purely classical framework, identifying electromagnetic field energy as the sole physical basis for all observable motion in ordinary matter. It shows that the spatial structure of electromagnetic fields mirrors gravitational fields, that mass and inertia arise from electromagnetic interactions, and that relativistic effects such as time dilation and length contraction emerge from electromagnetic field energy. The framework defines a cumulative background potential based on the sum of electromagnetic fields from all constituent charges in ordinary matter, providing a mapping between electromagnetic and gravitational potentials consistent with general relativity. It explains why gravitational effects appear weak—arising from the collective influence of vast numbers of fluctuating charges—and demonstrates that this approach requires no forces beyond electromagnetism to account for classical mechanical and gravitational phenomena. While consistent with all existing observations, this reinterpretation invites future investigation into possible testable differences in strong-field regimes, quantum mechanical contexts, and interactions involving non-baryonic matter.

Keywords:

Classical mechanics, Electromagnetism, Electromagnetic field energy, General relativity, Gravity, Inertia, Length contraction, Mass–energy equivalence, Relativistic effects, Time dilation

1. MOTIVATION—CLASSICAL FOUNDATION FOR UNIFICATION

This framework is written using classical mechanics, electrodynamics, and general relativity in a form that physicists a century ago would recognize. The reason is simple: a quantum theory of gravity cannot be built without first establishing a complete classical foundation. If gravity and electromagnetism are to be unified at the quantum level, they must first be unified classically. While the framework draws occasional motivation from quantum results where useful, its formulation remains within classical physics, offering a reinterpretation of gravitational behavior based on electromagnetic field energy.

2. FIELD SYMMETRY IN CLASSICAL SPACE: ELECTROMAGNETISM AS GRAVITATIONAL ANALOG

There is an exact mapping between the spatial structure of classical electromagnetic and gravitational fields. Both radiate outward from localized sources in a spherically symmetric manner, obeying an inverse-square law, and their potentials decrease inversely with distance. Since their structures follow the same spatial rules, it becomes plausible they share a common basis.

This structural parallel holds regardless of whether the two interactions share an origin. Even without accepting the hypothesis that electromagnetism produces gravity, the correspondence remains a powerful, usable model for gravitational dynamics. The electromagnetic field is familiar, observable, and easier to analyze, while gravity is typically framed in terms of curvature and geodesics. Translating gravitational behavior into electromagnetic terms makes the physics more tangible, especially when considering relativistic effects.

3. ORDINARY MATTER AND OBSERVABLE MOTION

Ordinary matter makes up everything we directly observe in the universe: atoms, molecules, stars, planets, and living organisms. It consists of protons, neutrons, and electrons, which form atoms that combine into molecules and build macroscopic structures. Ordinary matter is the only type described by classical laws, defining the scope of both classical mechanics and the framework presented in this paper [1].

Observable motion is measurable or detectable by physical instruments—devices made of ordinary matter interacting through the electromagnetic field [2]. In classical physics, it is governed entirely by electromagnetic interactions, which mediate all forces acting on ordinary matter [2], as well as by the gravitational field, which reflects how localized energy modifies spacetime structure [3].

4. POSTULATE 1: INERTIA, MOMENTUM, AND STRESS ARE ELECTROMAGNETIC IN CLASSICAL MECHANICS

Mass is not a substance; it is a property exhibited by all localized energy [4]. In classical systems, what we call "mass" reflects how energy behaves when localized or constrained. This explains, for example, why a charged battery has greater mass than a discharged one despite containing the same amount of matter, as the additional mass corresponds to the added electromagnetic energy, not to additional particles [4].

The energy content of ordinary matter appears as motion and internal energy—such as kinetic and potential energy, thermal agitation, and vibrational modes [5]. Inertial and gravitational behavior traditionally attributed to mass is the observable effect of localized electromagnetic energy responding to external influences. In classical physics, electromagnetism is the only available interaction governing such behavior [2].

Consequently, all observable mechanical forces—such as inertia, momentum, and stress—arise from electromagnetic interactions. Contact forces, friction, pressure, tension, and collisions are all mediated by the electromagnetic forces between charged particles that compose matter [2].

This postulate asserts that the full stress-energy content of ordinary matter, as expressed by the stress-energy tensor $T^{\mu\nu}$, is electromagnetic in origin, meaning that all observable energy, momentum, and stress arise from electromagnetic fields and their interactions.

5. POSTULATE 2: ORDINARY MATTER EMITS RADIATION INDUCING RELATIVISTIC EFFECTS

In systems of ordinary matter, opposite charges do not cancel completely; their effects average out at macroscopic scales. Even when a particle is surrounded by charges producing zero net force, it does not remain still but fluctuates in position and momentum—absorbing and emitting electromagnetic energy—due to unresolved, uneven nearby fields. These fluctuations result from continuous photon exchanges and are not suppressed by net charge neutrality [6]. The energy of these fluctuations increases with the number of surrounding particles, their relative speeds—especially oscillatory motions and accelerations—and their proximity to the test particle [7]. The surrounding electromagnetic field remains active, continually driving the particle's response, producing an average confinement over time [7].

This postulate is supported by the fact that no system is truly static at the atomic level; all particles are in constant electromagnetic exchange with their environment [6]. Even electrically neutral systems, such as hydrogen molecules and helium atoms, exhibit spectral lines, emit radiation, and experience collision forces—demonstrating that electromagnetic interactions persist despite net charge zero [7].

Charge oscillations in a source mass generate energy in the surrounding field, causing fluctuations and slight shifts in nearby particle positions. These microscopic motions average out so that macroscopic motion cancels when opposing forces balance [7], yet they induce persistent relativistic effects in nearby test masses—a central claim formalized in this paper.

6. ELECTROMAGNETIC FOUNDATIONS OF MASS–ENERGY EQUIVALENCE

Mass is defined as an object's resistance to acceleration under an applied force: an object with greater mass requires greater force to produce the same change in motion [3]. Since all forces acting on ordinary matter are electromagnetic at the macroscopic level, this resistance arises from the object's electromagnetic response to external fields [2].

Moreover, because all classical equations involving mass—such as Newton's laws, kinetic energy, and momentum—are derived from measurements made with physical instruments governed by electromagnetic principles, the very form of these equations reflects electromagnetic interactions [2]. The resistance of an object to acceleration, its mechanical stiffness, and its energy content are all determined by the behavior of its electromagnetic field under external forces. In this sense, mass is operationally determined by probing an object's electromagnetic field and measuring the resulting response.

In classical mechanics, mass is operationally defined by its electromagnetic interaction properties [4]. The conceptual link between energy and inertia set the stage for Einstein's 1905 work on special relativity, where he first established the mass–energy equivalence [4]:

$$E = m\,c^2, \tag{1}$$

based entirely on the relativistic behavior of light radiation, showing that an object's mass m can be converted into electromagnetic energy E [4]. This marked a turning point, revealing that mass is a manifestation of energy, particularly electromagnetic energy.

7. SPEED OF LIGHT AND ELECTROMAGNETIC STRUCTURE OF SPACE

In classical physics, the speed of light c is not an arbitrary constant, but determined by the electromagnetic properties of the vacuum [2]. James Clerk Maxwell's unification of electricity and magnetism in the 19th century led to the realization that light is an electromagnetic wave [2]. From Maxwell's equations in vacuum, the speed of propagation of electromagnetic waves c is given by [2]:

$$c = \frac{1}{\sqrt{\varepsilon_0\,\mu_0}}, \tag{2}$$

where ε_0 is the vacuum permittivity, and μ_0 is the vacuum permeability.

Since relativistic effects depend on the propagation speed of electromagnetic waves, the structure of spacetime is tied to the electromagnetic properties of space. Therefore, spatial variations in electromagnetic field energy can modify the relativistic structure experienced by a test particle in a manner that produces effects such as time dilation, redshift, and geodesic curvature—without requiring any change in the locally measured speed of light. This perspective supports the broader thesis that electromagnetic fields are not only responsible for force interactions in ordinary matter but also for the relativistic structure of spacetime itself.

8. RELATIVISTIC EFFECTS OF ELECTROMAGNETIC FIELD ENERGY

In Newtonian mechanics, gravity is described as a force arising from mass–energy, but its origin remains unexplained. General relativity reinterprets gravity as spacetime curvature caused by energy and momentum, opening the possibility that, for ordinary matter, this energy is entirely electromagnetic in origin [3]. The electromagnetic field around any object made of ordinary matter stores energy in space. When a second object—a test mass—enters this region, it interacts with this field energy, altering its internal energy and producing relativistic effects.

These electromagnetic interactions between the charges in the test mass and the external field of the source object induce fluctuations in the test mass's internal dynamics [3]. These fluctuations include atomic vibrations, electron transitions, quantum fluctuations, and chemical bond rearrangements [6], but generally involve any internal kinetic motion [2].

Since these fluctuations involve massive constituents undergoing continuous acceleration, they produce relativistic effects [3]. The resulting time dilation and length contraction are given by [3]:

$$t = t_0\,\gamma, \tag{3}$$

and

$$L = \frac{L_0}{\gamma}, \tag{4}$$

where:

- t is the dilated time measured by an inertial observer at infinity,
- t_0 is the proper time in the rest frame of the test object,
- L is the contracted length measured by an inertial observer at infinity, and
- L_0 is the proper length in the rest frame of the test object.

The Lorentz factor γ, rearranged to express relativistic effects in terms of potential energy U gained by a test mass from a source field, takes the following form [3]:

$$\gamma = \frac{1}{\sqrt{1+\frac{2\,U}{m\,c^2}}}, \tag{5}$$

where m is the mass of the test object.

9. MODELING ELECTROMAGNETIC BACKGROUND POTENTIAL

We propose that relativistic effects emerge from the electrostatic potential energy between the constituent charges of matter. To model this, we define a net background potential energy U as the sum of the magnitudes of all pairwise electromagnetic interaction energies between charges of the source and test objects, whether attractive or repulsive. This reflects Postulate 2: relativistic effects depend on field strength, not on net force direction [3].

This formulation treats the electromagnetic background as a cumulative field energy, built from the individual fields of all particles, so that the relativistic effects produced by each particle's field add together. Since no standard expression exists for this cumulative potential, we use the following approximation:

$$U = -\sum_s \sum_t |U_{st}|, \qquad (6)$$

where:

- $s \in S$ indexes individual charges in the source object,
- $t \in T$ indexes individual charges in the test object,
- U_{st} is the electric potential energy between charge s and charge t.

This approximation illustrates the cumulative behavior. The negative sign ensures this potential behaves analogously to gravitational potential: negative-valued and decreasing with distance, consistent with an attractive interaction like gravity. In a full relativistic quantum treatment, this potential would be replaced by a field operator describing the electromagnetic field of the source, with the test object modeled as a quantum system interacting with this field.

10. MAPPING ELECTROMAGNETIC TO GRAVITATIONAL POTENTIALS

Given that Postulate 1 states the electromagnetic field alone accounts for the full contents of the stress-energy tensor $T^{\mu\nu}$, and that general relativity relates it directly to the Einstein tensor $G^{\mu\nu}$ through Einstein's field equation [3]:

$$G^{\mu\nu} = \frac{8\pi G}{c^4} T^{\mu\nu}, \qquad (7)$$

which maps energy-momentum content to spacetime curvature, the Newtonian gravitational constant G becomes the required scaling factor between electromagnetic field energy and the curvature effects we observe as gravity.

To formalize the correspondence, gravitational potential energy is assigned an equivalent electrostatic form, justified because gravitational and electromagnetic potentials share the same spatial structure. Both potentials decrease proportionally to distance from a localized source and arise from fields diminishing as the inverse square of distance. Given this parallel, it is natural to define a one-to-one mapping between them—not as a derivation but a definitional identification, aligning their forms and scaling for consistency. We therefore equate the electric and gravitational potential energies by assigning [3]:

$$U = -\frac{G M m}{r}, \qquad (8)$$

where M is the source mass, and m is the test mass.

Expressing the electromagnetic potential in terms of mass ensures that the resulting acceleration reproduces the expected gravitational behavior for a test object.

11. RECOVERING GRAVITATIONAL TIME DILATION

To demonstrate consistency with general relativity, we express the Lorentz factor γ in terms of the gravitational potential energy defined in equation (8). Substituting this into equation (5) yields:

$$\gamma = \frac{t}{t_0} = \frac{1}{\sqrt{1 - \frac{2 G M}{r c^2}}}, \qquad (9)$$

which exactly matches the expression for gravitational time dilation $\frac{t}{t_0}$ derived from the Schwarzschild metric [3].

This confirms that the proposed mapping between electromagnetic and gravitational potentials leads to results consistent with general relativity. It shows that the relativistic behavior traditionally attributed to spacetime curvature can be equivalently interpreted as arising from electromagnetic field energy when properly formulated.

12. GRAVITATIONAL MOTION FROM ELECTROMAGNETIC TIME DILATION

Gravity arises from gradients in spacetime structure: time slows and spatial intervals contract near matter, guiding all motion along curved paths [3]. As a test object approaches a source, its constituent particles gain electromagnetic energy and fluctuate more strongly. These internal motions produce relativistic effects, slowing time for each particle. Because gravitational and electromagnetic field strengths both decrease with distance according to an inverse-square law, the time dilation and length contraction gradients produced by electromagnetic fields mirror gravitational potential in general relativity [2]. The closer the object, the more electromagnetic energy it gains and the more its proper time slows and spatial length contracts. This curvature gradient bends the paths of nearby objects, consistent with gravitational theory [3].

13. ELECTRORELATIVITY

This paper coins the term electrorelativity to describe relativistic behavior arising from electromagnetic energy alone. The associated electrorelativistic effects—time dilation, length contraction, and curved motion—result from electrostatic interactions in classical systems and require no additional forces or new physics beyond electromagnetism and general relativity.

The only potentially speculative element is the choice of G as the proportionality constant, used to match the scale of standard gravitational potential. All preceding results follow directly from this paper's postulates. It remains possible that this effect is negligible outside classical systems, where additional processes may contribute to gravity. But no alternative mechanism has been identified that accounts for gravitational behavior using known physical interactions.

14. SCALING: THE APPARENT WEAKNESS OF GRAVITY

Two predictions that follow logically from the reasoning developed throughout this paper:

14.1. Prediction 1

Many readers will instinctively struggle with the idea that electromagnetic radiation alone can produce relativistic effects strong enough to drive motion on gravitational scales. The author initially shared this skepticism, influenced—like most physicists—by the deeply ingrained association of gravity with massive celestial bodies, while electromagnetic radiation is dismissed as a small-scale phenomenon confined to atoms or laboratories. But this comparison is misleading: when the electromagnetic and gravitational fields produced by the same large-scale object are compared directly, the electromagnetic field is overwhelmingly stronger. This prediction anticipates the common objection that electromagnetism is too weak to matter at large scales and highlights a broader conceptual bias: gravity is assumed to act on cosmic scales, while electromagnetism is confined to short-range interactions.

14.2. Prediction 2

Gravity is known to be approximately 10^{39} times weaker than electromagnetism [8]. This enormous difference is not anomalous but expected if gravitational effects emerge from electromagnetic radiation. A single fluctuating particle contributes minimally to curvature, but when averaged over countless particles, the cumulative effect becomes a weak yet persistent influence. Though negligible for individual particles, these interactions collectively generate a smooth large-scale gradient in field energy sufficient to mimic gravitational behavior. The resulting gravitation is so weak compared to electromagnetism that only an enormous aggregation of charged particles produces a noticeable effect. This scaling provides strong evidence that electromagnetic effects are the primary source of gravitational behavior, with any other contributions necessarily secondary.

15. ELECTROMAGNETISM GOVERNS OBSERVABLE MOTION

In classical physics, all recorded measurements of position, velocity, force, energy, and time operate through electromagnetic effects [5]. Electromagnetism is not only the mechanism of observation but also the background through which motion occurs [3]. The structure of space and time, as experienced by matter, arises from electromagnetic interaction. In this framework, gravity, inertia, and contact are not separate forces but unified responses of charged matter to the electromagnetic field under different conditions. Thus, electromagnetism defines the spacetime background and serves as the foundation for all observable motion.

16. ADDRESSING NEUTRON NEUTRALITY

As a neutral particle, the neutron may seem—at first glance—to fall outside a framework where electromagnetic fields underlie mechanical effects. However, the neutron has a nonzero, measurable magnetic moment despite having no net electric charge [5], suggesting it is not truly neutral, but a composite structure of internal charged components [1].

From this perspective, the neutron remains compatible with a theory in which all mechanical behavior arises from electromagnetic fields. Its neutrality does not imply an absence of interaction. Instead, its internal field structure continues to couple with surrounding matter, contributing to both inertia and curvature-driven motion. Here, neutrality refers only to net charge—not to the absence of electromagnetic energy.

17. THEORETICAL CONSIDERATIONS: NON-BARYONIC MATTER CONTRIBUTIONS

Neutrinos are predicted to possess a nonzero magnetic moment [9], implying a weak electromagnetic interaction, though negligible for most classical considerations. This suggests that even particles traditionally considered non-interacting may still couple to the electromagnetic field under certain conditions. While such particles may eventually be integrated into the framework proposed here, their detailed properties fall outside the present scope.

18. SCOPE AND APPLICABILITY: CLASSICAL FRAMEWORK

This paper limits its scope to classical regimes, incorporating classical mechanics, classical electrodynamics, and general relativity in baryonic matter—but outside the atomic nucleus. Phenomena occurring inside atomic nuclei or under extreme high-energy conditions fall outside the domain considered here.

Quantum electrodynamics reveals non-classical field behavior at small scales [5], and the resulting interactions may require modifications to Newtonian gravitational dynamics, as has been proposed in other contexts [10]. At quantum scales, gravitational effects reflect the quantum structure of the electromagnetic field. In that case, quantum-scale interactions would also imply a form of quantum gravity—emerging not as a separate force, but as a consequence of the quantum structure of electromagnetic fields.

Black holes are excluded from this analysis because their strong-field regimes and event horizons involve extreme high-energy conditions requiring separate treatment within general relativity [3].

The conclusions presented apply strictly to ordinary matter and to the classical behavior of objects composed of it. Within that domain, no evidence demands the existence of any force beyond electromagnetism to explain motion, interaction, or structure—including gravitational effects.

19. TESTABILITY AND FUTURE WORK

This framework is consistent with existing observations and requires no new experiments to establish its validity at this stage. Its predictions match standard gravitational behavior within classical regimes and reinterpret known relativistic effects as electromagnetic in origin. However, future work may identify conditions where it yields testable differences from standard interpretations.

Potential areas for investigation include electromagnetic contributions to strong-field systems such as galactic centers and black holes, extensions to quantum mechanical regimes, and interactions involving non-baryonic matter such as neutrinos.

20. CONCLUSION

This paper has proposed a reinterpretation of gravitational and inertial phenomena within a purely classical context, identifying electromagnetic field energy as the sole physical basis for all observable motion in ordinary matter. By framing gravity as an emergent relativistic effect of electromagnetic interactions, this framework preserves consistency with general relativity while offering a more tangible physical model tied directly to electromagnetic field structure.

The proposed theory does not claim finality or universality: its scope is explicitly classical, limited to baryonic matter outside atomic nuclei, and excludes black holes and quantum-scale interactions. Within this scope, however, it eliminates the need for a separate gravitational force, providing a unified account of inertia, contact forces, and gravitational curvature.

If correct, this approach suggests that gravity itself is not a distinct fundamental interaction but a relativistic manifestation of the electromagnetic field. The result invites further investigation into whether quantum gravitational effects might likewise emerge from the quantum structure of electromagnetic fields—a question deliberately left open for future work.

REFERENCES

[1] F. Halzen and A. D. Martin, Quarks and Leptons. New York, NY, USA: Wiley, 1984, ch. 4.

[2] J. D. Jackson, Classical Electrodynamics, 3rd ed. New York, NY, USA: Wiley, 1998.

[3] L. D. Landau and E. M. Lifshitz, The Classical Theory of Fields, 4th ed. Oxford, U.K.: Butterworth-Heinemann, 1975.

[4] A. Einstein, "Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?" Ann. Phys., vol. 18, pp. 639–641, 1905.

[5] R. P. Feynman, QED: The Strange Theory of Light and Matter. Princeton, NJ, USA: Princeton Univ. Press, 1985.

[6] Callen, H. B., & Welton, T. A. (1951). Irreversibility and Generalized Noise. *Physical Review*, 83(1), 34–40.

[7] D. J. Wineland *et al.*, "Experimental issues in coherent quantum-state manipulation of trapped atomic ions," *J. Res. Natl. Inst. Stand. Technol.*, vol. 103, no. 3, pp. 259–328, 1998. DOI: 10.6028/jres.103.019.

[8] P. A. M. Dirac, "A New Basis for Cosmology," Proc. R. Soc. Lond. A, vol. 165, no. 921, pp. 199–208, 1938.

[9] C. Broggini, C. Giunti, and A. Studenikin, "Electromagnetic properties of neutrinos," Adv. High Energy Phys., vol. 2012, Art. ID 459526.

[10] M. Milgrom, "A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis," *Astrophys. J.*, vol. 270, pp. 365–370, Jul. 1983. DOI: 10.1086/161130.