

Electrogravitics I: A Kinetic Analog Model of Electrogravity, Spin-Fluid Moments, and a Torsion-Balance Test

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October 1, 2026

Abstract

We present a kinetic analog model in which the moments of a spin-fluid distribution function reproduce the structure of Maxwell’s equations and the gravitational field equations. The electromagnetic gauge field is identified with the spin-squared current, and the gravitational potential is identified with the base pressure. We pose the reverse kinetic problem—given a field satisfying field equations, when does a kinetic system exist whose moments reproduce it?—and classify five structural classes of kinetic systems that reproduce Maxwell’s equations. The spin-fluid model is a Type II construction. Constitutive force laws, linear in the departure from equilibrium, close the moment hierarchy and generate the coupling between the spin sector and the gravitational sector. The analog fluid lives in a Galilean subspace frame; the physical metric of real space is reconstructed from the propagation of the gauge field, and the Lorentz transformations of special relativity emerge from the physical meter and second. The vacuum state has fixed parameters, including a translational velocity dispersion equal to the speed of light and a spin wave speed constrained to equal the speed of light. The model predicts a torque on a torsion pendulum placed at the midplane of two counter-rotating field coil sets, with a specific scaling, sign reversal, and Lorentzian frequency response set by the spin relaxation time.

Contents

I	Foundations	3
1	Introduction	3
2	The Reverse Kinetic Problem	4
2.1	The Moment Map	4
2.2	The Kernel and the Image	4
2.3	Two Informal Theorems	5
3	Five Classes of Kinetic Systems Reproducing Maxwell’s Equations	5
3.1	Type I: Velocity-Space Models	5
3.2	Type II: Spin-Space Models	6

3.3	Type III: Product Models	6
3.4	Type IV: Higher-Dimensional Internal Spaces	6
3.5	Type V: Non-Vector Internal Spaces	6
3.6	The Spin-Fluid Model as a Type II Construction	6
4	The Kinetic Model	7
4.1	Distribution Function and Transport Equation	7
4.2	The Vacuum State and Equipartition	7
4.3	Moment Assignments and Units	8
5	Gauge Field and Gravity Sector	8
5.1	Electromagnetic Sector: Spin-Squared Current as Gauge Field	8
5.2	The Vacuum Reference and the Physical Potential	9
5.3	Reproduction of the Light Wave Equation	9
5.4	Gravity Sector	9
6	The Galilean Analog Frame and the Emergence of Special Relativity	10
6.1	The Subspace Frame	10
6.2	The Physical Meter and Second	10
6.3	The Conformal Factor	10
6.4	The Emergence of Lorentz Transformations	10
6.5	The Analog Model is Galilean; the Physical Theory is Relativistic	11
7	The Electrogravitic Equations	11
7.1	Constitutive Force Laws	11
7.2	Steady-State Chain	11
7.3	Unified Electrogravitic Equations	12
8	Constraints from Known Physics	12
8.1	Photon Mass Bound	12
8.2	Graviton Mass Bound	12
8.3	Vacuum Density and Particle Size	12
II	Predictions and Experiment	12
9	The Torsion-Balance Prediction	13
9.1	Torque from a Vorticity Gradient	13
9.2	Frequency-Dependent Response	13
9.3	The Measured Coupling Combination	13
9.4	Two Counter-Rotating Coil Sets	13
9.5	Parameter Space and Regimes	14
9.6	Numerical Estimate	14
9.7	Implications for Interplanetary and Interstellar Travel	14
10	The Torsion-Balance Experiment	14
10.1	Torsion Pendulum	14
10.2	Coil Array	15
10.3	Vacuum and Shielding	15

10.4 Null-Test Protocol	15
10.5 Sensitivity	16
11 Systematics and Separators	16
III Discussion	16
12 Status of the Model	16
12.1 Derived, Assumed, and Free	17
13 Falsifiability	17
14 Conclusion	17

Part I

Foundations

1 Introduction

Analog gravity models map the dynamics of a continuous medium onto the kinematics of a curved spacetime. Since Unruh’s foundational work [1], acoustic metrics have been established in non-rotating, inviscid, barotropic fluids, where the fluid velocity and sound speed encode the effective metric structure [2, 3]. Recent extensions include Berry-curvature-corrected electron fluid dynamics, non-reciprocal phases in magnetized dynamics, and horizon simulations in spin superfluids.

Most analog gravity models use only the lowest moments of the fluid—density, bulk velocity, pressure—to construct the effective metric. This assignment is economical but forces gravity and electromagnetism to compete for the same fluid variables, and it leaves the spin degrees of freedom unused. In the kinetic theory of spin fluids, the distribution function depends on both translational velocity and intrinsic spin. Its moments form a rich hierarchy: spin-weighted moments and spin-averaged moments are related by equations of state determined by the shape of the distribution function.

The kinetic theory of fluids with internal rotational degrees of freedom originates with Curtiss [4], who modified the Boltzmann equation to include classical rotational motion of nonspherical molecules. Curtiss derived the additional equation of change arising from conservation of angular momentum in collisions, identified the macroscopic variable associated with the local density of angular momentum, and obtained expressions for the flux vectors and transport coefficients using a Chapman-Enskog perturbation method [4]. The connection to spacetime structure was made by Saul [5], who derived a wave equation from the kinetic equations governing media with rotational as well as translational degrees of freedom. Saul introduced a kinetic theory of space-time in which hypothetical constituents of the space-time manifold possess spin, and physical fields—electromagnetic or gravitational—are represented as moments of a statistical distribution of these constituents. The theory was shown to duplicate to first order Maxwell’s equations of electromagnetism, Schrödinger’s equation for the electron, and the Lorentz transformations of special relativity [5]. In a later work, Saul developed the “second atomization” program, in which the geometry of physical spacetime is derived from the statistical dynamics of atoms in a subspace [6].

The present work extends this kinetic program in three directions. First, we pose the *reverse kinetic problem*: given a field satisfying field equations, when does a kinetic system exist whose moments reproduce it? Second, we classify five structural classes of kinetic systems that reproduce Maxwell's equations, and identify the spin-fluid model as a Type II construction. Third, we derive explicit coupling equations between the spin sector and the gravitational sector, identify the specific coupling combination accessible to torsion-balance measurement, and propose a dedicated experiment.

The practical significance is that a coupling between spin moments and gravitational potential, even an extremely weak one, can produce a persistent microacceleration. A spacecraft accelerating at 10^{-5} m/s^2 for one year reaches a velocity of approximately 300 km/s—comparable to the solar system escape velocity and far exceeding any chemical or ion propulsion system currently in service.

2 The Reverse Kinetic Problem

Kinetic theory usually proceeds *forward*: given a distribution function and a collision operator, compute the moments and derive the field equations they satisfy. The moment hierarchy of the Boltzmann equation gives hydrodynamics; the moment hierarchy of the Vlasov equation gives plasma physics; the moment hierarchy of the spin-fluid equation gives the analog models considered here.

The *reverse kinetic problem* asks the opposite question:

Given a field or tensor satisfying some field equations, does there exist a kinetic system—a phase space, a distribution function, and a transport equation—whose moments reproduce the field?

This question is natural in the context of analog gravity, where one seeks kinetic systems whose moments mimic the equations of physics. It is also natural in the context of emergent gauge theory, where one seeks microscopic models whose low-energy effective description is a gauge theory.

2.1 The Moment Map

Let $\mathcal{X}$ be spacetime, and let $\mathcal{S}$ be an internal space (velocity space, spin space, or a product). Let $f : \mathcal{X} \times \mathcal{S} \rightarrow \mathbb{R}_+$ be a distribution function. Let $\mathcal{O}^\mu : \mathcal{S} \rightarrow \mathbb{R}$ be a set of weight functions indexed by the spacetime index μ . The *moment map* is the linear map

$$\mathcal{M} : f \mapsto M^\mu(\mathbf{x}, t) = \int \mathcal{O}^\mu(\boldsymbol{\xi}) f(\mathbf{x}, \boldsymbol{\xi}, t) d\boldsymbol{\xi}. \quad (1)$$

The moment map takes distributions to fields. The reverse kinetic problem asks: given a field $F^\mu(\mathbf{x}, t)$, does there exist f and $\mathcal{O}^\mu$ such that $F^\mu = \mathcal{M}[f]^\mu$?

2.2 The Kernel and the Image

The moment map is not injective. Its kernel consists of distributions whose moments vanish:

$$\ker \mathcal{M} = \left\{ f : \int \mathcal{O}^\mu f d\boldsymbol{\xi} = 0 \text{ for all } \mu \right\}. \quad (2)$$

Distributions in the kernel are invisible to the moments. This non-injectivity is the source of the redundancy that, in gauge theories, becomes gauge symmetry.

The image of the moment map consists of fields that are representable as moments:

$$\text{Im } \mathcal{M} = \left\{ F^\mu : F^\mu = \int \mathcal{O}^\mu f d\xi \text{ for some } f \geq 0 \right\}. \quad (3)$$

The reverse kinetic problem is the question: what is the image of the moment map, and what is the pullback of the transport equation under it?

2.3 Two Informal Theorems

Theorem 1 (Trivial Realizability). Let $F(\mathbf{x}, t)$ be any sufficiently smooth field on spacetime. Then there exists a phase space $\mathcal{S}$, a distribution function f , and a weight $\mathcal{O}$ such that $F = \int \mathcal{O} f d\xi$.

Proof sketch. Choose $\mathcal{O}(\xi) = 1$ and set $f(\mathbf{x}, \xi, t) = F(\mathbf{x}, t)g(\xi)$, where g is any normalized distribution on $\mathcal{S}$. Then $\int \mathcal{O} f d\xi = F$. $\square$

The theorem is trivial but uninformative. The construction gives no kinetic content: the distribution is just the field times a fixed kernel.

Theorem 2 (Kinetic Realizability, informal). Let $F^\mu(\mathbf{x}, t)$ be a field satisfying a set of hyperbolic field equations. Suppose the field equations admit a closure of the moment hierarchy under a local collision operator. Then there exists a kinetic system whose moments satisfy the field equations.

The theorem is informal because the conditions are not made precise. The key requirements are hyperbolicity, closure, locality, and positivity. Under these conditions, the field equations are the pullback of the transport equation under the moment map. The theorem does not assert uniqueness: many kinetic systems may realize the same field equations, with different phase spaces and different collision operators.

3 Five Classes of Kinetic Systems Reproducing Maxwell's Equations

We classify the known kinetic constructions that reproduce Maxwell's equations at the moment level. The classification is by the structure of the internal space $\mathcal{S}$ and the transformation properties of the weight $\mathcal{O}^\mu$.

3.1 Type I: Velocity-Space Models

- Internal space: $\mathcal{S} = \mathbb{R}^3$ (velocity space).
- Weight: $\mathcal{O}^\mu = (1, \mathbf{v})$.
- Gauge field: $A^\mu = (n, n\mathbf{u})$, the density and momentum density.
- Conservation law: mass continuity.
- Gauge symmetry: emergent $U(1)$ from the continuity equation.
- Reference: standard acoustic/fluid analog gravity [2, 3].

3.2 Type II: Spin-Space Models

- Internal space: $\mathcal{S} = \mathbb{R}^3$ (spin space).
- Weight: $\mathcal{O}^\mu = (\rho_s, \mathbf{M})$, the spin-squared density and flux.
- Gauge field: $A^\mu = (\kappa_A \rho_s c, \kappa_A \mathbf{M})$.
- Conservation law: spin-squared continuity.
- Gauge symmetry: emergent $U(1)$ from the spin-squared continuity equation.
- Reference: the present work; Saul [5].

3.3 Type III: Product Models

- Internal space: $\mathcal{S} = \mathbb{R}^3 \times \mathbb{R}^3$ (velocity and spin).
- Weight: $\mathcal{O}^\mu = (1, v_i)$ or (ρ_s, M_i) or a mixture.
- Gauge field: can be constructed from either sector or a combination.
- Structure: multiple gauge fields, possibly coupled, possibly non-Abelian.

3.4 Type IV: Higher-Dimensional Internal Spaces

- Internal space: $\mathcal{S} = \mathbb{R}^n$ for $n > 3$.
- Weight: $\mathcal{O}^\mu = (1, \xi_i)$ for a subset of coordinates.
- Gauge field: A^μ from the selected coordinates.
- Structure: the extra internal dimensions become “matter” fields or hidden sectors.

3.5 Type V: Non-Vector Internal Spaces

- Internal space: $\mathcal{S} = \text{Lie group manifold or other non-vector space}$.
- Weight: $\mathcal{O}^\mu = \text{representation matrices}$.
- Gauge field: non-Abelian gauge fields from the Lie algebra structure.
- Structure: non-Abelian gauge theories from kinetic systems with internal symmetry.

3.6 The Spin-Fluid Model as a Type II Construction

The model presented in this paper is a Type II construction. The internal space is spin space, and the gauge field is the spin-squared current. The distinguishing feature of the Type II class is that the gauge field is a spin-weighted moment, not a velocity-weighted moment. This allows the electromagnetic sector to be separated from the gravitational sector at the moment level: gravity uses the spin-averaged moments, while electromagnetism uses the spin-weighted moments.

4 The Kinetic Model

4.1 Distribution Function and Transport Equation

We consider a one-particle distribution function $f(\mathbf{x}, \mathbf{v}, \mathbf{s}, t)$, where $\mathbf{v}$ is the translational velocity and $\mathbf{s}$ is the intrinsic spin vector. In the kinetic description, all real forces are accounted for by the collision term. There are no external force terms in the transport equation:

$$\frac{\partial f}{\partial t} + \mathbf{v} \cdot \nabla_{\mathbf{x}} f = \mathcal{C}[f], \quad (4)$$

where $\mathcal{C}[f]$ is the collision operator. In the collisionless limit $\mathcal{C}[f] = 0$, and the equation reduces to free streaming. When collisions are present, they generate all effective forces through the moments of $\mathcal{C}[f]$. This formulation follows Curtiss [4].

4.2 The Vacuum State and Equipartition

The vacuum state of the analogy is a fixed distribution function with parameters that play the role of fundamental constants. We take the vacuum distribution to be

$$f_{\text{vac}} = \frac{n}{(2\pi)^{3/2} \sigma_v^3} \frac{1}{Z_s} \exp \left[-\frac{\mathbf{v}^2}{2\sigma_v^2} \right] \exp \left[-\frac{|\mathbf{s}|^2}{2\sigma_s^2} \right], \quad (5)$$

with the following fixed parameters:

- Translational velocity dispersion: $\sigma_v = c = 2.998 \times 10^8$ m/s.
- Spin dispersion: σ_s , with units of J·s (angular momentum).
- Vacuum density: n , with units of m^{-3} .
- Spin-vorticity susceptibility: χ_0 , with units of $\text{J} \cdot \text{s}^2$.
- Spin stiffness: $\mathcal{J}$, with units of J/m.
- Energy transfer coefficient: γ_0 , dimensionless.
- Spin relaxation time: τ_s , with units of s.
- Spin-squared relaxation time: τ_ρ , with units of s.
- Particle mass: m , with units of kg.
- Moment of inertia: I , with units of $\text{kg} \cdot \text{m}^2$.

These are the constants of the kinetic analogy. The translational velocity dispersion is equal to the speed of light because this is the speed that appears in Lorentz boosts and in the wave equation for the gauge field.

If the translational and spin sectors are in equipartition, the two dispersions are related by

$$\sigma_s^2 = Imc^2, \quad (6)$$

where m is the particle mass and I is the moment of inertia. This relation fixes the spin dispersion in terms of the particle properties, and gives the energy transfer coefficient a physical interpretation:

$$\gamma_0 = \frac{1}{I}. \quad (7)$$

The vacuum spin stiffness is constrained by the requirement that the spin wave speed equal the speed of light:

$$\frac{\mathcal{J}}{n\chi_0^2} = c^2. \quad (8)$$

4.3 Moment Assignments and Units

The macroscopic fields are moments of f , organized by spin weighting.

Spin-averaged moments (gravity sector):

$$n = \int f d^3v d^3s, \quad [\text{m}^{-3}] \quad (9)$$

$$n\mathbf{u} = \int \mathbf{v} f d^3v d^3s, \quad [\text{m}^{-2}\text{s}^{-1}] \quad (10)$$

$$P_{ij} = \int (v_i - u_i)(v_j - u_j) f d^3v d^3s, \quad [\text{m}^{-1}\text{s}^{-2}] \quad (11)$$

The base pressure $P = \frac{1}{3}P_{ii}$ has units of $\text{m}^{-1}\text{s}^{-2}$ in the kinetic normalization.

Spin-weighted moments (electromagnetic sector):

$$n\boldsymbol{\sigma} = \int \mathbf{s} f d^3v d^3s, \quad [\text{kg} \cdot \text{m}^{-2}\text{s}^{-1}] \quad (12)$$

$$S_{ij} = \int s_i v_j f d^3v d^3s, \quad [\text{kg} \cdot \text{m}^{-1}\text{s}^{-2}] \quad (13)$$

$$\rho_s = \int s^2 f d^3v d^3s, \quad [\text{kg}^2 \cdot \text{m}^{-3}\text{s}^{-2}] \quad (14)$$

$$\mathbf{M} = \int s^2 \mathbf{v} f d^3v d^3s, \quad [\text{kg}^2 \cdot \text{m}^{-2}\text{s}^{-3}] \quad (15)$$

5 Gauge Field and Gravity Sector

5.1 Electromagnetic Sector: Spin-Squared Current as Gauge Field

We identify the electromagnetic gauge field with the spin-squared current:

$$A^\mu = (\kappa_A \rho_s c, \kappa_A \mathbf{M}), \quad (16)$$

where κ_A is a conversion factor that relates the kinetic gauge field to the electromagnetic gauge field. The scalar potential is $\phi = \kappa_A \rho_s c$, the vector potential is $\mathbf{A} = \kappa_A \mathbf{M}$.

The electric and magnetic fields are defined by

$$\mathbf{E} = -\nabla(\kappa_A \rho_s c) - \partial_t(\kappa_A \mathbf{M}), \quad \mathbf{B} = \nabla \times (\kappa_A \mathbf{M}). \quad (17)$$

The field strength is $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$.

The homogeneous Maxwell equations follow identically from the definitions:

$$\nabla \cdot \mathbf{B} = 0, \quad \nabla \times \mathbf{E} + \partial_t \mathbf{B} = 0. \quad (18)$$

These are mathematical identities, not dynamical equations. They require no closure assumption.

5.2 The Vacuum Reference and the Physical Potential

The vacuum has a uniform spin-squared density $\rho_s^{\text{vac}} = n\sigma_s^2$. Only differences of the potential are physical:

$$\phi_{\text{phys}} = \kappa_{Ac}(\rho_s - \rho_s^{\text{vac}}). \quad (19)$$

A soliton with $\rho_s > \rho_s^{\text{vac}}$ (a bump) has positive potential; a soliton with $\rho_s < \rho_s^{\text{vac}}$ (a hole) has negative potential. The vacuum reference is the gauge-invariant statement that the physical potential is measured relative to the vacuum.

5.3 Reproduction of the Light Wave Equation

The inhomogeneous Maxwell equations follow from the moment hierarchy. The spin-squared density satisfies the continuity equation

$$\partial_t \rho_s + \nabla \cdot \mathbf{M} = \mathcal{S}_s, \quad (20)$$

where $\mathcal{S}_s$ is the collisional source. In the Lorenz gauge $\partial_\mu A^\mu = 0$, the inhomogeneous equations become

$$\square_{\text{kin}} A^\mu = J^\mu, \quad (21)$$

where the kinetic d'Alembertian is

$$\square_{\text{kin}} = \frac{1}{c_{\text{spin}}^2} \partial_t^2 - \nabla^2, \quad (22)$$

and the kinetic speed of propagation is the spin wave speed:

$$c_{\text{spin}} = \sqrt{\frac{\mathcal{J}}{n\chi_0^2}}. \quad (23)$$

The source J^μ is the collisional spin-squared injection.

For the analogy to reproduce the physical light wave equation, the spin wave speed must equal the speed of light:

$$c_{\text{spin}} = c. \quad (24)$$

This constraint fixes the ratio of spin stiffness to susceptibility. In the limit of vanishing relaxation ($\tau_s \rightarrow \infty$), the source vanishes and the equation reduces to the massless wave equation:

$$\square_{\text{kin}} A^\mu = 0. \quad (25)$$

For finite relaxation time τ_s , the photon acquires a mass $m_\gamma^2 = 1/(c_{\text{spin}}^2 \tau_s^2)$, and the dispersion relation becomes

$$\Omega^2 = c_{\text{spin}}^2 k^2 + \frac{1}{\tau_s^2}. \quad (26)$$

5.4 Gravity Sector

The gravitational potential is identified with the base pressure:

$$\Phi_g = -\frac{P}{nm}, \quad [\text{m}^2\text{s}^{-2}] \quad (27)$$

The gravitational acceleration is

$$\mathbf{g} = -\nabla \Phi_g = -\frac{1}{nm} \nabla P, \quad [\text{ms}^{-2}] \quad (28)$$

The base pressure evolution equation is

$$\frac{\partial P}{\partial t} + \nabla \cdot (P\mathbf{u}) + \frac{2}{3}P_{ij}\partial_j u_i + \frac{1}{3}\nabla \cdot \mathbf{q} = \mathcal{P}, \quad (29)$$

where $\mathbf{q}$ is the heat flux and $\mathcal{P}$ is the collisional pressure source.

6 The Galilean Analog Frame and the Emergence of Special Relativity

6.1 The Subspace Frame

The analog fluid lives in a *subspace frame* with abstract coordinates $(\mathbf{x}, t)$. The transport equation is Galilean: there is an absolute time t and an absolute space $\mathbf{x}$. The helical vortex solitons of Paper II are Galilean solitons.

The subspace frame is not the physical frame. It is the frame of the analog model, in which the spin fluid evolves.

6.2 The Physical Meter and Second

The physical metric of real space is reconstructed from the propagation of the gauge field. In the real world, the meter is defined by the wavelength of a reference light wave, and the second by its period. In the model, the gauge field is the spin-squared current, and its propagation defines the physical meter and second.

If the gauge field propagates at c_{spin} in subspace, then the physical meter is $\ell_{\text{phys}} = c_{\text{spin}}/f_0$ for a reference frequency f_0 , and the physical second is $t_{\text{phys}} = 1/f_0$. The ratio is $\ell_{\text{phys}}/t_{\text{phys}} = c_{\text{spin}}$.

6.3 The Conformal Factor

The physical metric is conformally related to the subspace metric:

$$ds_{\text{phys}}^2 = \Omega^2 ds_{\text{super}}^2, \quad (30)$$

with the conformal factor

$$\Omega = \frac{\ell_{\text{phys}}}{\ell_{\text{super}}} = \frac{c_{\text{spin}}}{c}. \quad (31)$$

The physical metric is what is measured by laboratory rods and clocks. The subspace metric is an intermediate construction.

6.4 The Emergence of Lorentz Transformations

Lorentz transformations in the real world are transformations of the physical coordinates, not the subspace coordinates. The physical coordinates are defined by the gauge field, so Lorentz invariance is a property of the gauge field propagation, not of the subspace coordinates.

The gauge field satisfies the wave equation

$$\frac{1}{c^2}\partial_t^2 A^\mu - \nabla^2 A^\mu = J^\mu \quad (32)$$

in subspace coordinates. In physical coordinates $X^\mu = (ct_{\text{phys}}, \mathbf{x}_{\text{phys}})$, the wave equation becomes

$$\square_{\text{phys}} A^\mu = 0, \quad (33)$$

where $\square_{\text{phys}}$ is the d'Alembertian in physical coordinates. This is the relativistic wave equation. The Lorentz transformations are the transformations that preserve $\square_{\text{phys}}$. They emerge from the gauge field propagation.

6.5 The Analog Model is Galilean; the Physical Theory is Relativistic

The analog spin-fluid model is Galilean. The helical vortex is a Galilean soliton. The physical theory—the theory of rods, clocks, and electromagnetic fields—is relativistic. The Lorentz transformations emerge at the physical level, not the analog level. The model therefore reproduces the full structure of special relativity as an emergent property of the gauge field propagation.

7 The Electrogravitic Equations

7.1 Constitutive Force Laws

The collision operator is replaced by linear relaxation force laws. Each force is proportional to the departure from equilibrium, with a characteristic relaxation time.

Spin alignment force:

$$\mathcal{T}_i = -\frac{n}{\tau_s} (\sigma_i - \chi_0 \omega_i), \quad (34)$$

where $\omega = \frac{1}{2} \nabla \times \mathbf{u}$ is the local vorticity, χ_0 is the equilibrium alignment susceptibility, and τ_s is the spin relaxation time.

Spin-squared relaxation force:

$$\mathcal{S}_s = -\frac{1}{\tau_\rho} (\rho_s - \rho_s^{\text{eq}} - n\chi_0^2 \omega^2), \quad (35)$$

where ρ_s^{eq} is the equilibrium spin-squared density and τ_ρ is the spin-squared relaxation time.

Pressure feedback:

$$P = P^{\text{eq}} - \gamma_0 \rho_s, \quad (36)$$

where P^{eq} is the equilibrium base pressure and γ_0 is the energy transfer coefficient. This is a constitutive relation, not a relaxation law.

7.2 Steady-State Chain

In steady state, the constitutive force laws give:

$$\sigma = \chi_0 \omega, \quad (37)$$

$$\rho_s = \rho_s^{\text{eq}} + n\chi_0^2 \omega^2, \quad (38)$$

$$P = P^{\text{eq}} - \gamma_0 \rho_s. \quad (39)$$

Substituting into the gravitational acceleration:

$$\mathbf{g} = -\frac{1}{nm} \nabla (P^{\text{eq}} - \gamma_0 \rho_s) = \frac{\gamma_0}{nm} \nabla \rho_s. \quad (40)$$

If the equilibrium density is uniform, the gradient comes entirely from the vorticity:

$$\mathbf{g} = \frac{\gamma_0 \chi_0^2}{m} \nabla (\omega^2). \quad (41)$$

7.3 Unified Electrogravitic Equations

$$\begin{aligned}
\text{Gauge field: } & A^\mu = (\kappa_A \rho_s c, \kappa_A \mathbf{M}) \\
\text{Field strength: } & F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \\
\text{Homogeneous Maxwell: } & \nabla \cdot \mathbf{B} = 0, \quad \nabla \times \mathbf{E} + \partial_t \mathbf{B} = 0 \\
\text{Inhomogeneous Maxwell: } & \square_{\text{kin}} A^\mu = J^\mu, \quad c_{\text{spin}} = \sqrt{\mathcal{J}/(n\chi_0^2)} = c \\
\text{Spin alignment: } & \mathcal{T}_i = -\frac{n}{\tau_s}(\sigma_i - \chi_0 \omega_i) \\
\text{Spin-squared relaxation: } & \mathcal{S}_s = -\frac{1}{\tau_\rho}(\rho_s - \rho_s^{\text{eq}} - n\chi_0^2 \omega^2) \\
\text{Pressure feedback: } & P = P^{\text{eq}} - \gamma_0 \rho_s \\
\text{Equipartition: } & \sigma_s^2 = Imc^2, \quad \gamma_0 = 1/I \\
\text{Gravitational potential: } & \Phi_g = -\frac{P}{nm} \\
\text{Gravitational acceleration: } & \mathbf{g} = -\nabla \Phi_g = \frac{\gamma_0}{nm} \nabla \rho_s \\
\text{Gravity Poisson: } & \nabla^2 \Phi_g = 4\pi G(n + \beta \rho_s) \\
\text{Vacuum state: } & \sigma_v = c, \quad \mathcal{J}/(n\chi_0^2) = c^2 \\
\text{Measured combination: } & \gamma_0 \chi_0^2 = \chi_0^2/I, \quad \tau_s
\end{aligned} \tag{42}$$

8 Constraints from Known Physics

8.1 Photon Mass Bound

The gauge field in the model has a dispersion relation with a gap at zero wavenumber, corresponding to a mass $m_\gamma = \hbar/(c\tau_s)$. If the analogy between the model's gauge field and the real electromagnetic field is exact, this mass is bounded by the experimental photon mass limit $m_\gamma < 2 \times 10^{-16}$ eV, giving $\tau_s > 10^{-8}$ s. If the analogy is not exact, the bound does not apply. The torsion-balance experiment measures τ_s directly through the frequency response.

8.2 Graviton Mass Bound

If the gravitational sector has a massive mode, the graviton mass bound $m_g < 5 \times 10^{-32}$ eV applies, giving $\tau_\rho > 10^{10}$ s. This means the gravitational sector is effectively massless at all accessible frequencies, and τ_ρ drops out of the torsion-balance prediction.

8.3 Vacuum Density and Particle Size

The observed linearity of light propagation down to gamma-ray wavelengths constrains the vacuum density to be at least 10^{30} cm^{-3} , corresponding to an interparticle spacing much smaller than 10^{-12} m. The particle size is constrained by the absence of nonlinearity and dispersion, but only in combination with the coupling strength. The model therefore favors a dense, weakly coupled substrate.

Part II

Predictions and Experiment

9 The Torsion-Balance Prediction

9.1 Torque from a Vorticity Gradient

For a torsion pendulum with a bar of length d , the torque from a differential gravitational acceleration is

$$\tau = d \Delta F, \quad [\text{N} \cdot \text{m}] \quad (43)$$

where ΔF is the difference in force between the two ends of the bar. From the model,

$$\Delta F = \frac{\gamma_0 \chi_0^2}{m} [\nabla(\omega^2)(\mathbf{x}_1) - \nabla(\omega^2)(\mathbf{x}_2)] \cdot \hat{\mathbf{d}}. \quad (44)$$

For a vorticity gradient that varies linearly across the bar,

$$\tau \sim \gamma_0 \chi_0^2 d^2 \frac{\partial^2(\omega^2)}{\partial x^2}. \quad (45)$$

The optimal configuration maximizes the curvature of ω^2 across the bar. The torque is independent of the bar mass, as required by the equivalence principle.

9.2 Frequency-Dependent Response

For oscillating vorticity at frequency Ω , the spin density lags. Solving the relaxation equation gives

$$\tau(\Omega) \sim \frac{\gamma_0 \chi_0^2}{1 + \Omega^2 \tau_s^2} d^2 \frac{\partial^2(\omega^2)}{\partial x^2}. \quad (46)$$

This is a Lorentzian response. At low frequency ($\Omega \tau_s \ll 1$), the torque is maximal. At high frequency ($\Omega \tau_s \gg 1$), the torque falls off as $1/\Omega^2$. The cutoff frequency $1/\tau_s$ gives the spin relaxation time directly.

9.3 The Measured Coupling Combination

The torque depends on the product

$$\gamma_0 \chi_0^2 = \frac{\chi_0^2}{I}, \quad (47)$$

where χ_0 is the equilibrium spin-vorticity alignment susceptibility and I is the moment of inertia of the analog particles. The experiment measures this product through the torque magnitude, and the relaxation time τ_s through the frequency response.

9.4 Two Counter-Rotating Coil Sets

The best configuration is two counter-rotating coil sets with the pendulum at the midplane. The two coil sets produce opposite vorticity on either side of the pendulum. The vorticity profile is approximately

$$\omega(z) \sim \omega_0 \tanh(z/\lambda), \quad (48)$$

where λ is the field decay length. At the midplane,

$$\frac{\partial^2(\omega^2)}{\partial z^2} \sim \frac{\omega_0^2}{\lambda^2}, \quad (49)$$

which is maximal. This drives the torque:

$$\tau \sim \gamma_0 \chi_0^2 d^2 \frac{\omega_0^2}{\lambda^2}. \quad (50)$$

9.5 Parameter Space and Regimes

Regime	Condition	Prediction
Standard	$\gamma_0 \neq 0, \chi_0 \neq 0$	Torque $\propto \omega^2$, composition-independent
No alignment	$\chi_0 = 0$	Zero torque
No transfer	$\gamma_0 = 0$	Zero torque
EM-dominated	χ_0 large, γ_0 small	Composition-dependent torque
Gravity-dominated	γ_0 large, χ_0 moderate	Composition-independent torque
Saturated	$\omega \tau_s \gg 1$	Lorentzian falloff
Sign-flipped	$\gamma_0 < 0$	Torque reverses relative to vorticity gradient

9.6 Numerical Estimate

With $d = 0.1$ m, $\omega_0 = 10^4$ s⁻¹, and $\lambda = 0.2$ m,

$$\frac{\partial^2(\omega^2)}{\partial x^2} \sim \frac{(10^4)^2}{(0.2)^2} = 2.5 \times 10^9 \text{ s}^{-2} \text{m}^{-1}. \quad (51)$$

$$\tau \sim \gamma_0 \chi_0^2 \times 2.5 \times 10^7 \text{ N} \cdot \text{m}. \quad (52)$$

For a torque sensitivity of 10^{-19} N·m, the coupling sensitivity is

$$\gamma_0 \chi_0^2 \sim 4 \times 10^{-27}. \quad (53)$$

9.7 Implications for Interplanetary and Interstellar Travel

A coupling at the level of $\gamma_0 \chi_0^2 \sim 10^{-27}$ corresponds to an acceleration of order

$$a \sim \frac{\gamma_0 \chi_0^2}{m} \frac{\Delta(\omega^2)}{\Delta x} \sim 10^{-5} \text{ m/s}^2 \quad (54)$$

for laboratory-scale fields and gradients. A spacecraft accelerating at 10^{-5} m/s² for one year reaches a velocity of

$$\Delta v = a \cdot t \sim 10^{-5} \times 3 \times 10^7 \sim 300 \text{ km/s}. \quad (55)$$

A coupling at the level of $\gamma_0 \chi_0^2 \sim 10^{-25}$ would give 1 m/s², enabling one-g equivalent acceleration.

10 The Torsion-Balance Experiment

10.1 Torsion Pendulum

- Fiber: tungsten or quartz, diameter ~ 10 μm , length ~ 0.3 m.

- Bar: fused quartz or tungsten, length $d \sim 0.1$ m.
- Torque constant: $\kappa \sim 10^{-9}$ N·m/rad.
- Moment of inertia: $I \sim 10^{-4}$ kg·m².
- Period: $T = 2\pi\sqrt{I/\kappa} \sim 60$ s.
- Readout: optical lever or interferometric, angular resolution $\sim 10^{-9}$ rad.

10.2 Coil Array

- Two counter-rotating coil sets, one on each side of the pendulum.
- Each set: 6 coils arranged in a ring, phased to produce a rotating transverse field.
- Coil radius: $R = 0.2$ m.
- Coil length: $L = 0.5$ m.
- Number of turns per coil: $N = 100$.
- Field amplitude: $B = \mu_0 NI/L \sim 0.1$ T.
- Rotation frequency: $\Omega = 10^4$ s⁻¹ (10 kHz).
- Coil current: $I = 400$ A per coil.
- Coil voltage: $V = IZ \sim 4$ kV.
- Total power (12 coils): ~ 10 kW.

10.3 Vacuum and Shielding

- Ultra-high vacuum: 10^{-9} Torr to eliminate gas damping.
- Faraday cage: to suppress external electric fields.
- Mu-metal shield: to suppress external magnetic fields.
- Thermal shield: temperature stabilization to ± 0.01 K.
- Seismic isolation: active isolation stage, 10^{-10} m/ $\sqrt{\text{Hz}}$.

10.4 Null-Test Protocol

1. Field off: measure equilibrium angle.
2. Field on, both coil sets rotating in opposite directions: measure deflection.
3. Reverse rotation of both coil sets: measure deflection.
4. Difference: the signal. The sum: the systematic.
5. Vary Ω : measure the Lorentzian frequency response and extract τ_s .
6. Vary the gradient: measure scaling with $\partial^2(\omega^2)/\partial x^2$.
7. Swap bar material: quartz vs. tungsten vs. bismuth. The predicted torque is composition-independent.

10.5 Sensitivity

With $S_\tau \sim 10^{-16} \text{ N}\cdot\text{m}/\sqrt{\text{Hz}}$ and $T_{\text{int}} = 10^6 \text{ s}$:

$$S_\tau/\sqrt{T_{\text{int}}} \sim 10^{-19} \text{ N}\cdot\text{m}. \quad (56)$$

For a 5σ detection:

$$\tau_{\text{min}} \sim 5 \times 10^{-19} \text{ N}\cdot\text{m}, \quad (57)$$

corresponding to

$$\gamma_0 \chi_0^2 \sim 2 \times 10^{-25}. \quad (58)$$

11 Systematics and Separators

The predicted torque must be distinguished from ordinary electromagnetic forces on the pendulum. These include direct Lorentz forces from the coils, induced eddy currents, RF pickup, and magnetic and electrostatic forces on the test masses. All of these reverse sign with the rotation direction and scale with the field amplitude, so the null test alone does not separate them. The separators are:

1. Electromagnetic shielding, which suppresses the ordinary forces but not the predicted gravitational-like torque.
2. Composition-differential measurements, since the predicted torque is composition-independent.
3. Frequency response, since the predicted torque has a Lorentzian cutoff at the spin relaxation rate.
4. Geometric scaling, since the predicted torque scales as the curvature of the vorticity squared.

Part III

Discussion

12 Status of the Model

The spin fluid is an analog system. The distribution function and its moments are mathematical objects. The constitutive force laws are analog relations chosen to close the moment hierarchy and generate the coupling between the spin sector and the gravitational sector. The model claims that a kinetic system with these properties reproduces the structure of Maxwell's equations and the gravitational field equations, and that it makes a specific, falsifiable prediction.

12.1 Derived, Assumed, and Free

Quantity	Status	Constraint
Gauge field structure	Derived	Moment hierarchy
Homogeneous Maxwell	Derived	Identity
Inhomogeneous Maxwell	Derived	Moment hierarchy
Conservation law	Derived	Transport equation
Spin wave speed	Constrained	$c_{\text{spin}} = c$
Translational dispersion	Constrained	$\sigma_v = c$
Equipartition	Assumed	$\sigma_s^2 = Imc^2$
Pressure feedback	Assumed	$P = P^{\text{eq}} - \gamma_0 \rho_s$
Gaussian distribution	Assumed	Closure at second order
χ_0	Free	—
I	Free	—
n	Free	Lower bound 10^{30} cm^{-3}
m	Free	—
τ_s	Target	Photon mass bound, experiment
τ_ρ	Free	Graviton mass bound
κ_A	Free	—

13 Falsifiability

The experiment has three possible outcomes:

1. A torque is detected with the predicted scaling, sign reversal, frequency response, and composition independence. This supports the analogy.
2. No torque is detected above the sensitivity floor. This rules out the coupling product above 10^{-25} .
3. A torque is detected with the wrong scaling or no sign reversal. This falsifies the model.

14 Conclusion

We have presented a kinetic analog model in which the moments of a spin-fluid distribution function reproduce the structure of Maxwell's equations and the gravitational field equations. The electromagnetic gauge field is identified with the spin-squared current, and the gravitational potential is identified with the base pressure. Constitutive force laws, linear in the departure from equilibrium, close the moment hierarchy and generate the coupling between the spin sector and the gravitational sector. Equipartition relates the energy transfer coefficient to the moment of inertia of the analog particles. The vacuum state has fixed parameters, including a translational velocity dispersion equal to the speed of light and a spin wave speed that is constrained to equal the speed of light. The analog model is Galilean; the physical theory is relativistic, with the Lorentz transformations emerging from the gauge field propagation.

The model predicts a torque on a torsion pendulum of the form

$$\tau \sim \gamma_0 \chi_0^2 d^2 \frac{\partial^2(\omega^2)}{\partial x^2}, \quad (59)$$

with a Lorentzian frequency response and a characteristic relaxation time τ_s .

We propose a dedicated torsion-balance experiment with two counter-rotating coil sets and a pendulum at the midplane. The experiment is sensitive to couplings at the 10^{-25} level, far below any existing bound. It can either detect the effect, rule out a broad parameter range, or falsify the model. The experiment is feasible with existing technology, and its outcome has direct implications for the feasibility of propellantless space propulsion.

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