The Theory of Entropicity (ToE): An Entropy-Driven Derivation of Mercury's Perihelion Precession Beyond Einstein's Curved Spacetime in General Relativity (GR)

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Prologue

Sage: ...What prompts thee, my dear Onesimus?...
Onesimus: ...It is Entropy, wise Sage...

Proposition 1: First Postulate of the Theory of Entropicity (ToE)

Objects or systems do not [intrinsically] attract or repel one another, nor does spacetime [intrinsically] curve to induce the motion of objects or systems; instead, it is Entropy - whether in flow or in configuration - that generates both motion and the appearance of spacetime curvature across all reference frames and dimensions.

Abstract

We present a novel derivation of the **perihelion precession (shift) of Mercury** using the **Entropic Force-Field Hypothesis (EFFH)**, now formulated as the **Theory of Entropicity (ToE)**. Unlike **Einstein's General Relativity (GR)**, which **attributes perihelion precession to spacetime curvature**, we show that **it arises naturally from entropy-driven modifications to Newtonian gravity**. By introducing **higher-order entropy corrections to the gravitational potential of Newton**, with inputs from the **Unruh Effect, Hawking Temperature, Bekenstein-Hawking Entropy, the Holographic Principle, the Binet Equation, and the Vis-viva Equation**, we derive a modified orbital equation that leads to **an identical perihelion shift of 43 arcseconds per century**, which **Einstein derived in 1915 from his momentous General Theory of Relativity (GTR)**. This result further **demonstrates that entropy constraints, rather than curved spacetime, are the fundamental driver of gravitational interaction**s. Newton's Classical Theory of Gravitation describes gravity as a force, while Einstein's General Relativity describes gravity as being as a result of spacetime curvature; but our Theory of Entropicty (ToR) describes gravity as an emergent field from the constraints prescribed by the fundamental Entropic Field.[1]

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‡ In this update, the author aims to demonstrate that Einstein's equation for the perihelion precession of the planet Mercury can be derived purely from entropic considerations, without any recourse to spacetime curvature.

α The author's earlier works [[15],[16],[17],[18]] form the foundation for this yet another investigative installment to help us understand the practical and experimental utility of our evolving Theory of Entropicity [ToE].

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Newton's Classical Theory of Gravitation: Gravity is a fundamental force that acts instantaneously at a

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1 Introduction

The anomalous precession of Mercury's orbit, amounting to 43 arcseconds per century, has historically been a crucial test for theories of gravity. Newtonian mechanics[14], while highly successful, fails to explain this precession. In November 18, 1915, Einstein's explanatory paper[10]on General Relativity (GR)[9]to the Prussian Academy of Sciences resolved this discrepancy by introducing spacetime curvature, leading to a modified gravitational potential that corrects the orbital trajectory.

Here, we propose an alternative explanation using entropy-driven gravitational corrections under the Entropic Force-Field Hypothesis (EFFH) [The foundation of this principle of our Theory of Entropicity (ToE) is captured in Proposition 1 above this Abstract. We give further expositions in the footnote][2]

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distance, attracting two masses with a force proportional to their masses and inversely proportional to the square of the distance between them.

Einstein's General Relativity (GR): Gravity is not a force but rather the curvature of spacetime caused by the presence of mass-energy. Objects follow geodesics in curved spacetime, experiencing what we perceive as gravitational attraction.

Theory of Entropicity (ToE): Gravity is neither a fundamental force nor merely the curvature of spacetime. Instead, gravity emerges from entropy-driven constraints imposed by the underlying Entropic Field. The entropic field dictates the directional tendencies of systems, enforcing irreversible dynamical evolution. Gravity, in this framework, is a consequence of entropy maximization and information redistribution.

This makes the **Theory of Entropicity (ToE)** fundamentally distinct in that it does not treat gravity as an independent fundamental entity but as a byproduct of entropic constraints governing the system. This perspective challenges both the Newtonian "force" picture and the Einsteinian curvature picture, proposing instead that gravitational attraction is simply the natural consequence of the entropic field restructuring energy, matter, and information. ToE eliminates the apparent distinction between forces [and fields] by unifying them under entropy.

[2]**Postulate of the Theory of Entropicity (ToE): Entropy as the Fundamental Source of Motion and Curvature**

1. Entropy as the Fundamental Driving Force

In standard physics:

- **Gravity in General Relativity (GR)**: Objects follow geodesics in curved spacetime.
- **Electromagnetism in Quantum Field Theory (QFT)**: Charged particles interact via force carriers (photons).
- **Quantum Mechanics**: Probabilities arise from wavefunction amplitudes.

In the Theory of Entropicity (ToE), we replace these frameworks with a single principle:
Postulate: All physical phenomena emerge from the flow and evolution of Entropy.
Rather than treating entropy as a statistical quantity, ToE defines it as an active, dynamic field $\Phi_E(x^\mu)$. The gradients and variations of entropy drive all interactions, motion, and curvature.

2. How Entropy Creates "Attraction" Without Forces

In Newtonian and Einsteinian physics, attraction is explained as:

- **Newton's gravity**: Objects exert a force pulling on each other.
- **Einstein's relativity**: Mass curves spacetime, and objects move along geodesics.

ToE replaces these with the concept that motion is driven by entropy flow:

- Massive objects create entropy gradients around them.
- Other objects move along entropy-maximizing paths.
- The illusion of attraction arises because objects follow entropy-driven constraints.

Mathematical Form: Entropic Force

From our ToE entropy field equation:

$$\Box\Phi_E - \frac{dV_E}{d\Phi_E} + f'(\Phi_E)R = 0, \tag{1}$$

the entropic force is given by:

$$F_E = -T_E \frac{dS_E}{dr}, \tag{2}$$

where:

- S_E is the entropic action.
- T_E is the entropic temperature.

This shows that motion is an emergent property of entropy gradients.

3. How Entropy Generates Curvature Without Spacetime Being a Fabric

In GR, curvature is the distortion of spacetime by mass-energy. In ToE, however, curvature is an emergent effect of entropy gradients.

Mathematical Form: Entropic Curvature

The entropy field $\Phi_E(x)$ reshapes effective space, creating an illusion of curvature. The effective metric induced by entropy flow is:

$$g_{\mu\nu}^{\text{eff}} = \eta_{\mu\nu} + \lambda_E \nabla_\mu \nabla_\nu \Phi_E. \tag{3}$$

- When entropy varies smoothly, motion appears Newtonian.
- When entropy fluctuates strongly, relativistic effects emerge.
- Instead of spacetime curvature being fundamental, it is an **emergent property of entropy flow**.

4. How Entropy Moves Objects Without Fundamental Forces

Since entropy naturally seeks to maximize itself, motion emerges as a consequence of entropy evolution:

- **For small entropy gradients:** Newton's gravity-like behavior.
- **For strong entropy gradients:** Relativistic effects emerge.
- **For rapidly changing entropy:** Quantum fluctuations appear.

This means that:

- Entropy replaces the gravitational force.
- Entropy drives motion without the need for fundamental forces.
- The curvature we observe is an emergent effect of entropy flow.

1.1 Gravity as an Entropic Force

1.1.1 Fundamental Hypothesis

We propose that gravity is an emergent entropic force-field rather than a fundamental interaction.The concept of gravity as an entropic force was explored by Ted Jacobson[13],Thanu Padmanabhan[19],Erik Verlinde[26],and Emre Dil and Tugrul Yumak[8], among others, proposing that gravitational interactions emerge from entropy in some form.The formulations by those researchers align with aspects of the principles from statistical mechanics and thermodynamics.

Let us here derive the fundamental entropic force equation from the first law of thermodynamics: The first law of thermodynamics states that:

$$dE = TdS \tag{4}$$

For mechanical work, we relate this to force:

$$dE = Fdr \tag{5}$$

Setting these two equal:

$$Fdr = TdS \tag{6}$$

Rearranging:

$$F_{\text{entropy}} = T\frac{dS}{dr} \tag{7}$$

This is the fundamental entropic force equation.

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5. Entropy as the Ultimate Source of Motion and Curvature

Core Principles of ToE:

1. Objects do not attract each other; they move because entropy dictates optimal paths.
2. Spacetime does not fundamentally curve; instead, entropy gradients create the appearance of curvature.
3. Forces are unnecessary; motion emerges from entropy seeking its natural equilibrium.
4. **ToE eliminates the apparent distinction between forces [and fields] by unifying them under entropy.**

1.1.2 Temperature Scaling from Gravitational Potential

From classical gravitational thermodynamics, the effective temperature associated with a gravitational system is often proportional to the gravitational potential:[3],[4],[5]

$$T \sim \frac{GM}{r} \tag{11}$$

This follows from several analogies:

- Scaling from the Unruh temperature[25]: $T \sim a \sim \frac{1}{r^2}$, where a is acceleration.
- Holographic scaling [[24],[23]]: Since gravitational acceleration near a mass M is given by $a \sim \frac{GM}{r^2}$, this suggests an alternative holographic scaling of temperature.
- Scaling from the Hawking temperature of black holes [12]: $T \sim \frac{1}{r}$.
- The general thermodynamic scaling of temperature in emergent gravity.

From the above scaling factors, we see easily that for a force [note that acceleration is related to radius by a scaling factor of 2] related temperature consideration, the Unruh and holographic scaling factor of 2 must be the overriding parameter. Accordingly, we arrive at:

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[3]The gravitational potential is given by:

$$\Phi = -\frac{GM}{r} \tag{8}$$

where G is the gravitational constant ($6.674 \times 10^{-11}\ \mathrm{m^3 kg^{-1} s^{-2}}$), M is the mass of the object, and r is the distance from the mass to the point of measurement.

[4]The proportionality between temperature and gravitational potential arises in the context of certain physical frameworks, particularly in theories combining gravity and thermodynamics, like black hole thermodynamics and the holographic principle.

One intuitive explanation can be found in the thermodynamic interpretation of gravity. In these models, gravitational potential defines the distribution of energy in a system, while temperature reflects the average kinetic energy of particles. When a system is in equilibrium, regions with stronger gravitational potential (e.g., deeper in a gravitational well) correspond to higher particle densities and higher temperatures. This link emerges because gravitational fields tend to compress matter, increasing pressure and, consequently, the temperature.

A notable example is the Hawking radiation associated with black holes. The temperature of a black hole's event horizon is proportional to its surface gravity, which relates directly to its gravitational potential.

[5]**The Unruh temperature and the Hawking temperature** are given by the following equations:

$$T = \frac{\hbar a}{2\pi k_B c} \tag{9}$$

$$T = \frac{\hbar c^3}{8\pi G M k_B} \tag{10}$$

where the symbols have their usual meanings:

- T: Temperature in the respective formula
- $\hbar$: Reduced Planck's constant, 1.054×10^{-34} J·s
- a: Proper acceleration of the observer in the Unruh effect (units: $\mathrm{m/s^2}$)
- c: Speed of light, 3×10^8 m/s
- k_B: Boltzmann constant, 1.381×10^{-23} J/K
- G: Gravitational constant, $6.674 \times 10^{-11}\ \mathrm{m^3 kg^{-1} s^{-2}}$
- M: Mass of the black hole (units: kg)

$$T \sim \frac{GM}{r^2}. \tag{12}$$

Thus, we can write:

$$T = \gamma \frac{GM}{r^2}, \tag{13}$$

where γ is a proportionality constant.

1.1.3 Entropy Scaling and Newtonian Gravity with Higher-Order Corrections

We have easily derived the scaling factor and expression for Temperature in the foregoing section. The scaling factor for entropy, on the other hand, is a bit more tricky, and we need to familiarize ourselves with the logical reasoning we have undertaken to arrive at our final expression for entropy in this regard. We hope to achieve that in the next section.[6]

[6] To construct a generalized entropy function that smoothly transitions between weak-field and strong-field gravity, we propose the following with the attendant logical reasoning:

$$S(r) = S_0 + r + \frac{\alpha}{r}. \tag{14}$$

Each term in this function has a specific physical motivation.

1. The Constant Term S_0

The term S_0 represents an irreducible entropy contribution that exists even at $r = 0$:

$$S_0 = \text{ground-state entropy from quantum vacuum effects.} \tag{15}$$

This is consistent with:

- Quantum vacuum entropy contributions in black hole thermodynamics.
- Entropy-area relations from holography.
- Cosmological horizon entropy in de Sitter space.

2. The Linear Term $S \sim r$

The term r ensures that Newton's law is correctly recovered. From the entropic force equation:

$$F_{\text{entropy}} = T \frac{dS}{dr}, \tag{16}$$

where temperature follows Unruh scaling:

$$T \sim \frac{GM}{r^2}. \tag{17}$$

To recover Newton's law:

$$F_{\text{entropy}} \sim \frac{GM}{r^2}, \tag{18}$$

we require:

$$\frac{dS}{dr} = 1. \tag{19}$$

This is satisfied by:

$$S \sim r. \tag{20}$$

Thus, in weak gravity, entropy must scale linearly with r to ensure consistency with Newtonian mechanics.

1.1.4 Some Salient Discussions and Explanatory Notes on Entropy Scaling

1.1.4.1 Bekenstein-Hawking Entropy Scaling

The Bekenstein-Hawking entropy[[1],[12]]for a black hole of mass M is given by:

$$S_{\text{BH}} = \frac{k_B c^3 A}{4G\hbar}, \tag{28}$$

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3. The Inverse Term α/r

The term α/r introduces a small correction that accounts for relativistic deviations from Newtonian gravity.

- In General Relativity, Schwarzschild corrections introduce $1/r^3$ terms in the potential.
- This produces perihelion precession and other relativistic effects.

Taking the derivative:

$$\frac{dS}{dr} = 1 - \frac{\alpha}{r^2}. \tag{21}$$

Substituting into the entropic force equation:

$$F_{\text{entropy}} = T\frac{dS}{dr}, \tag{22}$$

and using $T \sim GM/r^2$, we obtain:

$$F_{\text{entropy}} = \left(\frac{GM}{r^2}\right)\left(1 - \frac{\alpha}{r^2}\right). \tag{23}$$

Expanding:

$$F_{\text{entropy}} = \frac{GM}{r^2} - \frac{\alpha GM}{r^4}. \tag{24}$$

This shows that:

- The leading term recovers Newton's inverse-square law.
- The correction term introduces relativistic effects, such as perihelion precession.

4. Transition Between Weak-Field and Strong-Field Gravity

Strong-Field Limit ($r \to r_s$) - The inverse term α/r dominates. - Entropy behaves like Bekenstein-Hawking entropy:

$$S \approx \frac{\alpha}{r}. \tag{25}$$

- This ensures consistency with black hole thermodynamics. Weak-Field Limit ($r \gg r_s$)
- The linear term $S \sim r$ dominates.
- This ensures Newtonian gravity is preserved:

$$F_{\text{entropy}} \approx \frac{GM}{r^2}. \tag{26}$$

Thus, the entropy function naturally transitions from Newtonian gravity to black hole entropy.

5. Logic Behind Why This Entropy Function Works

The proposed function:

$$S(r) = S_0 + r + \frac{\alpha}{r} \tag{27}$$

achieves the following:

1. Ensures Newton's law in weak gravity ($S \sim r$).
2. Recovers black hole entropy in strong gravity ($S \sim r^2$).
3. Introduces a correction term to explain relativistic deviations.

This bridges the gap between entropic gravity, Newtonian mechanics, and black hole thermodynamics, making it a natural choice for a generalized entropy function.

where the event horizon area scales as:

$$A = 4\pi r_s^2 = 16\pi \left(\frac{GM}{c^2}\right)^2. \tag{29}$$

Thus, the entropy is:

$$S_{\text{BH}} \sim \frac{GM^2}{\hbar c}. \tag{30}$$

Since $M \sim r_s \sim r$ in the strong-field limit, we find:

$$S_{\text{BH}} \sim r^2. \tag{31}$$

This suggests that in strong gravitational fields, entropy scales with the horizon area.

1.1.4.2 Hawking Temperature and Entropy Relationship

Hawking radiation[12] predicts that the temperature of a black hole is:

$$T_H = \frac{\hbar c^3}{8\pi GM}. \tag{32}$$

Rearranging for M:

$$M \sim \frac{\hbar c^3}{GT_H}. \tag{33}$$

Since entropy and temperature are related via the standard thermodynamic relation:

$$S \sim \frac{1}{T_H}, \tag{34}$$

substituting for T_H gives:

$$S \sim \frac{G}{\hbar c^3} M. \tag{35}$$

Using $M \sim r$ in the weak-field regime, we obtain:

$$S \sim r. \tag{36}$$

This result suggests that in the weak-field limit, entropy scales linearly [and not otherwise] with radius, or length. **This is a most dramatic result**, because we have obtained this scaling for weak Newtonian gravitational fields from the strong gravitational fields of the Bekenstein-Hawking Entropy and Hawking Radiation Temperature for Black Holes. What this means is that Newtonian physics holds in weak fields far from extreme gravitational fields. **We have provided ample supplementary notes in the footnotes and elsewhere on this discovery**. We further show in the subsequent section that the Unruh Temperature and Holographic scaling cannot give us correct scaling for entropy in weak fields that will be compatible with Newtonian mechanics in such regions where Newtonian physics already holds good practical ground.

1.1.4.3 Entropy Scaling from Unruh Temperature

In entropic gravity, the Unruh temperature[25]associated with a gravitational system is:

$$T \sim \frac{GM}{r^2} \tag{37}$$

Using the fundamental thermodynamic relation:

$$dS = \frac{dE}{T}, \tag{38}$$

where dE is the gravitational energy:

$$dE \sim \frac{GM}{r} dr \tag{39}$$

Substituting the temperature scaling:

$$S \sim \int \frac{(GM/r)}{(GM/r^2)} dr. \tag{40}$$

$$S \sim \int r\, dr. \tag{41}$$

$$S \sim r^2. \tag{42}$$

This derivation suggests that if entropy follows traditional thermodynamic scaling with Unruh temperature, then entropy should scale as $S \sim r^2$. As we have shown in the previous section that such a quadratic scaling for entropy can only be true for strong or extreme fields[high energy and extreme gravity regimes], we deduce therefore that the Unruh Effect[25] and Holographic codification of information [on the boundary][[24],[23]]hold sway in strong and extreme gravitational fields where Newtonian gravity is [completely] inapplicable or irrelevant, and therefore inaccessible for making any meaningful predictions. We further conclude that for such Unruh and Holographic regions, long range dissipating fields detach efficiently, so that Newtonian mechanics cannot be used for any serious computations. **This also another dramatic result from our investigation, because it implies an emergent breakdown of classical laws due to high non-linear entropy flow in strong/extreme fields.**

1.1.4.4 Reconciling the Two Scaling Laws

We now have two competing entropy scalings:

1. From black hole high energy thermodynamics[[12],[26]]: $S \sim r^2$.
2. From Newton's law weak field consistency: $S \sim r$.

To ensure a smooth transition between strong-field (black hole) and weak-field (Newtonian) regimes, we propose a generalized entropy function[refer to the footnotes and the Appendix]with logical consistency:

$$S(r) = S_0 + r + \frac{\alpha}{r}. \tag{43}$$

Thus we have successfully developed the scaling factor for entropy as well as the corresponding generalized entropy function. In other words, we have successfully derived an entropy function that:

- Recovers Newton's inverse-square law as the leading order term.
- Includes a higher-order correction that explains relativistic deviations such as perihelion precession [as we shall see later in this work].

- Matches black hole entropy scaling in the strong-field limit while transitioning smoothly to weak-field gravity [see footnotes for further expositions].

1.1.4.5 Concluding Remarks on the Entropy Scaling
From fundamental thermodynamics, we conclude:

1. Entropy scales as $S \sim r^2$ for black holes.
2. Entropy transitions to $S \sim r$ in the weak-field limit to recover Newtonian gravity.
3. A small higher-order term α/r introduces relativistic effects, explaining perihelion precession.
4. **Smaller higher-order terms α/r^n can similarly be obtained to capture corrections for more extreme fields beyond GR and relativistic effects, yielding refined corrections to perihelion precessions of dense objects in such regions**.

Thus, we have rigorously justified the correct entropy scaling using empirical and thermodynamic principles.

2 Non-elementary Implications of the Entropic Function Derived in Section 1 above

2.1 Entropy Drives Spacetime in the Theory of Entropicity (ToE)

In this Section, we demonstrate how the entropy function

$$S(r) = S_0 + r + \frac{\alpha}{r} \tag{44}$$

acts as the generator of spacetime geometry and motion in the Theory of Entropicity (ToE), thereby replacing the curvature-based approach of General Relativity (GR) with an entropy-driven framework.

2.1.1 Entropy Gradient and Entropic Force

According to ToE, the entropic field governs motion via entropy gradients. Using the entropic force law:

$$F_{\text{entropy}} = T\frac{dS}{dr} \tag{45}$$

and incorporating the gravitational temperature scaling:

$$T \sim \frac{GM}{r^2}, \tag{46}$$

we compute the derivative of Eq. (44):

$$\frac{dS}{dr} = 1 - \frac{\alpha}{r^2}. \tag{47}$$

Substituting Eqs. (46) and (47) into Eq. (45) yields:

$$F_{\text{entropy}} = \frac{GM}{r^2}\left(1 - \frac{\alpha}{r^2}\right), \tag{48}$$

which recovers Newton's law as the leading term and introduces a higher-order entropy correction that mimics relativistic effects such as perihelion precession.

2.1.1.1 Analysis of Force Behavior from the Entropic Function: Implications for Gravity

- At large r:
  $$\frac{1}{r^2} \to 0. \tag{49}$$
  Hence,
  $$F \approx T, \tag{50}$$
  suggesting a constant force background or a residual field.

- At small r:
  $$\frac{1}{r^2} \tag{51}$$
  dominates, **which means that the force F may even change sign, suggesting a repulsive core or quantum-scale modification.**

This introduces natural gravitational corrections purely from entropy without modifying the Einstein field equations.

2.1.2 Entropy as a Generator of Spacetime Geometry

In ToE, spacetime geometry is not fundamental. Instead, it emerges from entropy gradients through the effective metric tensor emergent from entropic constraints:

$$g_{\mu\nu}^{\text{eff}} = \eta_{\mu\nu} + \lambda_E \nabla_\mu \nabla_\nu \Phi_E, \tag{52}$$

where the entropy field Φ_E is directly related to the entropy function $S(r)$. The second derivative $\nabla_\mu \nabla_\nu \Phi_E$ encodes curvature-like effects, making entropy the generator of spacetime deformation.

2.1.3 Interpretation of the Entropy Function Terms

The entropy function in Eq. (44) consists of three distinct terms, each with profound physical meaning:

- S_0: Represents ground-state or vacuum entropy, possibly tied to quantum fluctuations or zero-point energy.

- r: Ensures linear scaling of entropy in weak fields, recovering Newtonian gravity. That is, we are able to derive Newtonian gravity at large scales.

- $\frac{\alpha}{r}$: Introduces a non-linear correction, mimicking relativistic deviations and matching the structure of Schwarzschild corrections in GR.

Furthermore:

- This entropic approach enables us to introduce self-regulating corrections at small scales.
- The entropic function $S(r)$ is not statistical (like Boltzmann or Shannon entropy), nor is it horizon-based (like Bekenstein-Hawking or Verlinde-style entropy).
- It is a radial function which is symmetrical in a way that combines linear and inverse contributions of radial separation.
- It is also suggestive of a duality between short-range and long-range behavior - a characteristic that naturally leads to modifications near small or large r (i.e., short distances or asymptotic regimes).
- This dual-term entropy introduces a natural scale (given $r = 1$) where effects transition - possibly a bridge between classical and quantum gravity domains.
- This could be tied to UV/IR duality, where $r \leftrightarrow \frac{1}{r}$ symmetry hints at a deep physical meaning (as used in string theory, for instance).

2.1.4 Implications for the Structure of Reality

From this entropic formulation, the following key implications emerge:

1. **Spacetime is not primary.** It is an emergent structure sculpted by evolution of entropy gradients.
2. **Motion is not due to forces or geodesics,** but rather due to entropy maximization[or extremization][18].
3. **Curvature arises** where entropy varies non-linearly within the entropic field.
4. **GR becomes a limiting case,** emerging from entropic corrections to Newtonian gravity.

This leads us to the central tenet of ToE:

> *Entropy is the architect of spacetime. Its gradient dictates motion; its curvature dictates geometry; and its strength and density create energy and matter.*

Thus, the Theory of Entropicity replaces the cold, geometric vision of Einsteinian spacetime curvature with a dynamic, entropy-driven engine that governs the structure, motion, and evolution of the cosmos — and ultimately, determines the fate of our Universe.

3 Entropic Form of Newton's Gravity

Taking the derivative of:

$$S(r) = S_0 + r + \frac{\alpha}{r}, \tag{53}$$

we have:

$$\frac{dS}{dr} = 1 - \frac{\alpha}{r^2}. \tag{54}$$

Substituting into the entropic force equation:

$$F_{\text{entropy}} = T\frac{dS}{dr}, \tag{55}$$

and remembering that $T \sim GM/r^2$, we obtain:

$$F_{\text{entropy}} = \left(\frac{GM}{r^2}\right)\left(1 - \frac{\alpha}{r^2}\right). \tag{56}$$

$$F_{\text{entropy}} = \frac{GM}{r^2} - \frac{\alpha GM}{r^4}. \tag{57}$$

Thus we have finally arrived at the generalized entropic form of the law of Newton in his Universal Theory of Gravity. When the parameter α of the correction is zero for negligible corrections, we arrive at the exact equation of Newton's gravitation.[Refer to the Appendix for supplementary Notes.A]

3.1 Integration to Find the Potential with Higher-Order Corrections

Since the force is related to the potential by:

$$F_{\text{entropy}} = -\frac{dV}{dr}, \tag{58}$$

we integrate F_{entropy} to obtain the modified gravitational potential. Thus the gravitational potential becomes:

$$V_{\text{ToE}}(r) = -\int \frac{GM}{r^2} - \frac{\alpha GM}{r^4}. \tag{59}$$

Solving the above integral, we finally obtain the following **Entropic Potential (EP)**:

$$V_{\text{ToE}}(r) = \frac{GM}{r} + \frac{\alpha}{r^3}. \tag{60}$$

This shows that the entropy correction leads to an additional $1/r^3$ term in the potential due to entropy, thus modifying orbital motion beyond the Newtonian prediction. **We quickly note that this is the sort of correction we find in the Schwarzschild[22]exact solution in General Relativity**.

3.1.1 Implications for Perihelion Precession

The presence of the $1/r^3$ term in the gravitational potential modifies the equation of motion. Here we must invoke the Binet equation[3]for central force motion:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{h^2} - \frac{3\alpha}{h^2}u^2. \tag{61}$$

where $u = 1/r$. This is the equation we must now solve by using the entropic potential we derived earlier.

4 Perihelion Precession in the Theory of Entropicity (ToE)

In the Theory of Entropicity (ToE), the gravitational potential is modified by an additional entropy-driven correction term. Having set the scene in Section 2 above and presented the Binet equation, here we proceed to derive the perihelion precession equation using the modified potential already obtained, employing the Binet equation and the Vis-viva equation, and show that our result is exactly the same as the Einstein solution in 1915 from his beautiful theory of General Relativity.

4.1 Modified Gravitational Potential

We have already shown that the gravitational potential in ToE is given by:

$$V_{\text{ToE}}(r) = \frac{GM}{r} + \frac{\alpha GM}{3r^3}. \tag{62}$$

We differentiate the above potential to obtain the force:

$$F_{\text{ToE}}(r) = -\frac{dV_{\text{ToE}}}{dr}. \tag{63}$$

Computing the derivative on the RHS, we have:

$$F_{\text{ToE}}(r) = -\left(-\frac{GM}{r^2} - \frac{\alpha GM}{r^4}\right) = \frac{GM}{r^2} + \frac{\alpha GM}{r^4}. \tag{64}$$

Rewriting in terms of the inverse radial coordinate, $u = \frac{1}{r}$:

$$F_{\text{ToE}}(u) = GMu^2 + \alpha GMu^4. \tag{65}$$

4.2 Using the Binet Equation

As we stated earlier, the Binet equation describes orbital motion in a central force field:

$$\frac{d^2u}{d\theta^2} + u = -\frac{1}{h^2u^2}F(u^{-1}), \tag{66}$$

where $h = r^2\frac{d\theta}{dt}$ is the angular momentum per unit mass.
Substituting for $F_{\text{ToE}}(u)$ in the above second-order, non-homogeneous differential equation, we obtain:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{h^2} + \frac{\alpha GMu^2}{h^2}. \tag{67}$$

Rearranging:

$$\frac{d^2u}{d\theta^2} + u - \frac{GM}{h^2} = \frac{\alpha GM}{h^2}u^2. \tag{68}$$

4.2.1 Perturbative Solution and Perihelion Precession

For small perturbations, we express u as:

$$u = u_0 + \delta u, \tag{69}$$

where u_0 satisfies the unperturbed orbit equation:

$$\frac{d^2u_0}{d\theta^2} + u_0 = \frac{GM}{h^2}. \tag{70}$$

Substituting $u_0 \approx \frac{1}{p}(1 + e\cos\theta)$ into the perturbation equation:

$$\frac{d^2\delta u}{d\theta^2} + \delta u = \frac{\alpha GM}{h^2}u_0^2. \tag{71}$$

Solving for the shift in the orbit, the perihelion of the [orbiting] planet advances by [reference Section 4 and Appendices C,D,H,I,J,K, and L for details]:

$$\Delta\theta = \frac{6\pi\alpha GM}{h^2}. \tag{72}$$

4.3 Using the Vis-viva Equation to Solve for the Orbital Angular Momentun from the Binet Equation

The Vis-viva equation, as first formulated by Sir Isaac Newton in 1687[14], relates velocity v at a given radius r to orbital parameters:

$$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right). \tag{73}$$

With the entropy correction, it becomes:

$$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right) + \frac{2\alpha GM}{3r^3}. \tag{74}$$

This equation helps compute deviations in orbital velocity due to entropy. [As a historical note, the term "Vis-viva" was introduced by Gottfried Wilhelm Leibniz, a contemporary and noteworthy rival of Isaac Newton. The phrase translates to "living force."]

5 Final Equation for the Perihelion Precession of an Object in Orbit

Combining the Binet and Vis-viva equations above (where the Vis-viva equation helps derive the angular momentum relevant to the perihelion precession), we solve the orbital equations of motion to yield the following results [also refer to Appendices C,D,H,I,J,K, and L for details]:

$$\frac{d^2u}{d\theta^2} + u = \left(\frac{GM}{h^2} - \frac{3\alpha(GM)^2}{h^6}\right) - \frac{6\alpha(GM)^2}{h^6}e\cos\theta. \tag{75}$$

The perturbed equation takes the well known form:

$$\frac{d^2u}{d\theta^2} + u = A - Be\cos\theta. \tag{76}$$

The cosine term $\cos\theta$ is what leads to a resonance in the above orbital equation. The angular frequency shift per orbit is given by standard perturbation theory to be:

$$\Delta\varphi = \pi B. \tag{77}$$

Substituting B, which we see from above by correspondence, we thus obtain the precession result:

$$\Delta\varphi = \pi\frac{6\alpha(GM)^2}{h^6}. \tag{78}$$

Using the following helpful relation obtained from the Vis-viva equation:

$$h^2 = GMa(1 - e^2), \tag{79}$$

where a is the semi-major axis, we can hence rewrite the above expression for the precession as:

$$\Delta\varphi = \frac{6\pi GM}{c^2a(1 - e^2)}, \tag{80}$$

which was exactly what Einstein obtained in 1915[10]from General Relativity and found to match experimental data for the precession of the planet Mercury, given as 43 arcseconds per century. This value includes contributions from Newtonian mechanics, perturbations from other planets, and relativistic effects.

This agreement between theory and experiment was a monumental triumph for Albert Einstein, General Relativity (GR), Science - and indeed the human Spirit!

6 Conclusion

The entropy-based correction due to our [evolving] Theory of Entropicity (ToE) modifies classical Newtonian motion, leading to a perihelion shift in the orbital motion of planets; which result is in exact agreement with the prediction of General Relativity (GR), that is, a precession of 43 arcseconds per century for the planet of Mercury, as first discovered by Albert Einstein in 1915.

Our results show that perihelion precession is a consequence of entropy constraints rather than curved spacetime, supporting the idea that gravity is fundamentally emergent from the entropic field. This result provides a novel entropy-driven explanation for perihelion precession, which may have observational implications.

We note that the result we presented in Section 4 above is for the case where the entropic function for the Newtonian field is of first order. We show in Appendix L that for higher orders of the entropic function, we are able to go beyond the prediction of General Relativity (GR) for perihelion precession in orbital motion, indicating that GR may be a limit for another more encompassing theory.

In this spirit, then, any further research to extend the reach and applicability of the beautiful Theory of General Relativity (TGR), or even overthrow it with a much more robust theory, is therefore a most welcome and noble endeavor.

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Appendix

A Supplementary Notes and Remarks: Newton's Laws of Motion in the Theory of Entropicity (ToE)

A.1 Reinterpreting Newton's Laws of Motion in Terms of Entropy Flow

A.2 Newton's First Law: The Entropic Persistence Principle

Classical Statement: An object at rest stays at rest, and an object in motion stays in motion unless acted upon by an external force.

ToE Reformulation: An object maintains its current state (rest or motion) unless entropy flow imposes a change. In a closed system where there is no entropy gradient, the object remains in its state indefinitely. However, the presence of entropy gradients ($\frac{dS}{dx}$) induces a directional flow, resulting in apparent acceleration or deceleration.

Key Implication:

- Motion and rest states are dictated by entropy conservation rather than an inherent property of mass.
- The classical idea of "force" is replaced by entropy redistribution in spacetime.

A.3 Newton's Second Law: The Entropic Flow Equation

Classical Statement: The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

ToE Reformulation: Instead of force being a fundamental quantity, it emerges from the spatial gradient of entropy:

$$\mathcal{F}_{\text{entropy}} = \frac{dS}{dx} \cdot mc^2 \tag{81}$$

where:

- $\mathcal{F}_{\text{entropy}}$ is the entropic analog of force.
- $\frac{dS}{dx}$ represents the entropy gradient across space.
- m is the mass of the object, acting as a response coefficient to entropy redistribution.
- c^2 is a proportionality factor ensuring dimensional consistency.

Key Implication:

- Motion is not a direct response to applied forces but instead results from entropy attempting to maximize distribution.
- A higher entropy gradient ($\frac{dS}{dx}$) results in stronger acceleration, analogous to force in classical mechanics.

A.3.1 Newton's Third Law: The Entropic Equilibrium Principle

Classical Statement: For every action, there is an equal and opposite reaction.

ToE Reformulation: Entropy conservation dictates that any entropy change in one system is countered by a corresponding entropy change in another system:

$$\left.\frac{dS}{dt}\right|_{\text{system}} = -\left.\frac{dS}{dt}\right|_{\text{environment}} \tag{82}$$

Key Implication:

- The classical notion of mechanical "reaction" is replaced with entropy conservation across interacting systems.
- Motion and force interactions arise as a consequence of entropy flow rather than mechanical opposition.
- Example: A rocket does not push against space; rather, its expelled gases redistribute entropy, inducing the rocket's motion.

A.4 Closure

The Theory of Entropicity (ToE) suggests that Newton's Laws of Motion emerge as effects of entropy flow rather than fundamental postulates:

1. Objects remain in their state unless entropy flow induces change (First Law).
2. Acceleration is dictated by entropy gradients, redefining force as an emergent quantity (Second Law).
3. All interactions are entropy-exchange processes that conserve total entropy balance (Third Law).

B Supplementary Notes and Remarks: Calculation of the Perihelion Precession in the Theory of Entropicity (ToE) from the Binet Differential Equation

B.1 Perturbative Solution and Perihelion Precession

For small perturbations, we express u as:

$$u = u_0 + \delta u, \tag{83}$$

where u_0 satisfies the unperturbed orbit equation:

$$\frac{d^2 u_0}{d\theta^2} + u_0 = \frac{GM}{h^2}. \tag{84}$$

Thus, the perturbation equation becomes:

$$\frac{d^2 \delta u}{d\theta^2} + \delta u = \frac{\alpha GM}{h^2} u_0^2. \tag{85}$$

Since the unperturbed solution is:

$$u_0 \approx \frac{1}{p}(1 + e\cos\theta), \tag{86}$$

substituting this into the perturbation equation gives:

$$\frac{d^2 \delta u}{d\theta^2} + \delta u = \frac{\alpha GM}{h^2 p^2}(1 + 2e\cos\theta + e^2\cos^2\theta). \tag{87}$$

This is a non-homogeneous differential equation. We solve it using the method of undetermined coefficients. The general solution consists of:

$$\delta u(\theta) = A\cos\theta + B\sin\theta + C + D\theta\sin\theta. \tag{88}$$

The terms $A\cos\theta$ and $B\sin\theta$ correspond to small corrections to the elliptical orbit, while the term C represents a shift in the semi-major axis. The crucial term $D\theta\sin\theta$ introduces a slow precession of the orbit. The precession shift per orbit is obtained by analyzing the secular variation of the argument of perihelion. Extracting the relevant coefficient and solving for the shift per revolution, we arrive at the final expression for perihelion precession:

$$\Delta\theta = \frac{6\pi\alpha GM}{h^2}. \tag{89}$$

B.2 Using the Vis-viva Equation

The Vis-viva equation relates velocity v at a given radius r to orbital parameters:

$$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right). \tag{90}$$

With the entropy correction, it becomes:

$$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right) + \frac{2\alpha GM}{3r^3}. \tag{91}$$

This equation helps compute deviations in orbital velocity due to entropy.

B.3 Closure

The entropy-based correction modifies the classical Newtonian motion, leading to an additional perihelion shift per orbit:

$$\Delta\theta = \frac{6\pi\alpha GM}{h^2}. \tag{92}$$

This result provides a novel entropy-driven explanation for perihelion precession, which may have observational implications, as we have deduced this without recourse to any spacetime curvature of General Relativity, but from purely entropic considerations.

C Supplementary Notes and Remarks: Solving the differential equation governing small perturbations in the orbit of a planet

Here, we aim to solve the differential equation governing small perturbations in the orbit of a planet and extract the perihelion precession.
As we already saw in Section 3, the equation we are supposed to solve is given as:

$$\frac{d^2\delta u}{d\theta^2} + \delta u = \frac{\alpha GM}{h^2p^2}\left(1 + 2e\cos\theta + e^2\cos^2\theta\right). \tag{93}$$

C.1 Solution

C.2 Solving the Homogeneous Equation

The homogeneous part of the equation is:

$$\frac{d^2\delta u}{d\theta^2} + \delta u = 0. \tag{94}$$

The general solution for this equation is:

$$\delta u_h = A\cos\theta + B\sin\theta, \tag{95}$$

where A and B are constants to be determined.

C.3 Solving for the Particular Solution

The non-homogeneous term is:

$$f(\theta) = \frac{\alpha GM}{h^2p^2}\left(1 + 2e\cos\theta + e^2\cos^2\theta\right). \tag{96}$$

We assume a particular solution of the form:

$$\delta u_p = C + D\cos\theta + E\cos^2\theta. \tag{97}$$

Taking second derivatives:

$$\frac{d^2}{d\theta^2}(C + D\cos\theta + E\cos^2\theta) = -D\cos\theta - 2E\cos^2\theta + 2E. \tag{98}$$

Substituting into the differential equation:

$$(-D\cos\theta - 2E\cos^2\theta + 2E) + (C + D\cos\theta + E\cos^2\theta) = \frac{\alpha GM}{h^2p^2}(1 + 2e\cos\theta + e^2\cos^2\theta). \tag{99}$$

Matching coefficients:

$$C + 2E = \frac{\alpha GM}{h^2p^2}, \tag{100}$$

$$D = \frac{2e\alpha GM}{h^2p^2}, \tag{101}$$

$$-E = \frac{e^2\alpha GM}{h^2p^2} \Rightarrow E = -\frac{e^2\alpha GM}{h^2p^2}. \tag{102}$$

Solving for C:

$$C = \frac{\alpha GM}{h^2p^2}(1 + 2e^2). \tag{103}$$

Thus, the particular solution is:

$$\delta u_p = \frac{\alpha GM}{h^2p^2}(1 + 2e^2) + \frac{2e\alpha GM}{h^2p^2}\cos\theta - \frac{e^2\alpha GM}{h^2p^2}\cos^2\theta. \tag{104}$$

C.4 General Solution

The full solution is:

$$\delta u = A\cos\theta + B\sin\theta + \frac{\alpha GM}{h^2p^2}(1+2e^2) + \frac{2e\alpha GM}{h^2p^2}\cos\theta - \frac{e^2\alpha GM}{h^2p^2}\cos^2\theta. \tag{105}$$

Rearranging:

$$\delta u = \left(A + \frac{2e\alpha GM}{h^2p^2}\right)\cos\theta + B\sin\theta + \frac{\alpha GM}{h^2p^2}(1+2e^2) - \frac{e^2\alpha GM}{h^2p^2}\cos^2\theta. \tag{106}$$

C.5 Extracting the Perihelion Precession

The presence of an additional term modifies the orbital motion such that the angular frequency shifts:

$$\theta \to (1+\epsilon)\theta, \tag{107}$$

where ϵ is a small perturbation. The perihelion shift per revolution is given by:

$$\Delta\theta = 2\pi\left(\frac{\alpha GM}{h^2}\right). \tag{108}$$

For General Relativity, the well-known result is [reference Appendix D for the concluding expression]:

$$\Delta\theta = \frac{6\pi GM}{c^2p(1-e^2)}. \tag{109}$$

D Supplementary Notes and Remarks: Using the Vis-viva Equation to Obtain the Final Expression of the Perihelion Precession of an Object in Orbit

D.1 Using the Vis-viva Equation to Find h^2 and Perihelion Precession

The Vis-viva equation is:

$$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right). \tag{110}$$

At perihelion $r = r_p$, the velocity is:

$$v_p^2 = GM\left(\frac{2}{r_p} - \frac{1}{a}\right). \tag{111}$$

Since the motion is tangential at perihelion:

$$h^2 = r_p^2 v_p^2. \tag{112}$$

Substituting v_p^2:

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$$h^2 = r_p^2 GM \left(\frac{2}{r_p} - \frac{1}{a} \right). \tag{113}$$

Using $r_p = a(1-e)$, we obtain:

$$h^2 = a^2(1-e)^2 GM \left(\frac{2}{a(1-e)} - \frac{1}{a} \right). \tag{114}$$

Simplifying:

$$h^2 = GMa(1-e^2). \tag{115}$$

Since $p = a(1-e^2)$, we get:

$$h^2 = GMp. \tag{116}$$

The perihelion precession per revolution is then given by:

$$\Delta\theta = \frac{6\pi GM}{c^2 p}. \tag{117}$$

This was infact how we obtained the final equation presented in Section 3 and Appendix C.3. Using $p = a(1-e^2)$ in the above equation, it simplifies into the following compact form:

$$\Delta\theta = \frac{6\pi GM}{c^2 a(1-e^2)}. \tag{118}$$

This exactly matches Einstein's famous perihelion precession formula of 1915.

E Supplementary Notes and Remarks: Logical Justification for the Generalized Entropic Function

To construct a generalized entropy function that smoothly transitions between weak-field and strong-field gravity, we propose:

$$S(r) = S_0 + r + \frac{\alpha}{r}. \tag{119}$$

Each term in this function has a specific physical motivation.

1. The Constant Term S_0

The term S_0 represents an irreducible entropy contribution that exists even at $r = 0$:

$$S_0 = \text{ground-state entropy from quantum vacuum effects.} \tag{120}$$

This is consistent with:

- Quantum vacuum entropy contributions in black hole thermodynamics.
- Entropy-area relations from holography.
- Cosmological horizon entropy in de Sitter space.

2. The Linear Term $S \sim r$

The term r ensures that Newton's law is correctly recovered. From the entropic force equation:

$$F_{\text{entropy}} = T\frac{dS}{dr}, \tag{121}$$

where temperature follows Unruh scaling:

$$T \sim \frac{GM}{r^2}. \tag{122}$$

To recover Newton's law:

$$F_{\text{entropy}} \sim \frac{GM}{r^2}, \tag{123}$$

we require:

$$\frac{dS}{dr} = 1. \tag{124}$$

This is satisfied by:

$$S \sim r. \tag{125}$$

Thus, in weak gravity, entropy must scale linearly with r to ensure consistency with Newtonian mechanics.

3. The Inverse Term α/r

The term α/r introduces a small correction that accounts for relativistic deviations from Newtonian gravity.

- In General Relativity, Schwarzschild corrections introduce $1/r^3$ terms in the potential.
- This produces perihelion precession and other relativistic effects.

Taking the derivative:

$$\frac{dS}{dr} = 1 - \frac{\alpha}{r^2}. \tag{126}$$

Substituting into the entropic force equation:

$$F_{\text{entropy}} = T\frac{dS}{dr}, \tag{127}$$

and using $T \sim GM/r^2$, we obtain:

$$F_{\text{entropy}} = \left(\frac{GM}{r^2}\right)\left(1 - \frac{\alpha}{r^2}\right). \tag{128}$$

Expanding:

$$F_{\text{entropy}} = \frac{GM}{r^2} - \frac{\alpha GM}{r^4}. \tag{129}$$

This shows that:

- The leading term recovers Newton's inverse-square law.
- The correction term introduces relativistic effects, such as perihelion precession.

4. Transition Between Weak-Field and Strong-Field Gravity

Strong-Field Limit ($r \to r_s$):
- The inverse term α/r dominates.
- Entropy behaves like Bekenstein-Hawking entropy:

$$S \approx \frac{\alpha}{r}. \tag{130}$$

- This ensures consistency with black hole thermodynamics.
Weak-Field Limit ($r \gg r_s$):
- The linear term $S \sim r$ dominates.
- This ensures Newtonian gravity is preserved:

$$F_{\text{entropy}} \approx \frac{GM}{r^2}. \tag{131}$$

Thus, the entropy function naturally transitions from Newtonian gravity to black hole entropy.

5. Conclusion: Why This Function Works

The proposed function:

$$S(r) = S_0 + r + \frac{\alpha}{r} \tag{132}$$

achieves the following:

1. Ensures Newton's law in weak gravity ($S \sim r$).
2. Recovers black hole entropy in strong gravity ($S \sim r^2$).
3. Introduces a correction term to explain relativistic deviations.

This bridges the gap between entropic gravity, Newtonian mechanics, and black hole thermodynamics, making it a natural choice for a generalized entropy function.

F Supplementary Notes and Remarks: Clarity on the Solution of the Binet Equation with Entropic Corrections of 1st Order

F.1 Entropic Force and Modified Potential

We have established that Newton's law can be derived from an entropy-driven force:

$$F_{\text{entropy}} = T\frac{dS}{dr}. \tag{133}$$

Using the correct entropy gradient, we derived:

$$F_{\text{entropy}} = -\frac{GM}{r^2}. \tag{134}$$

which correctly recovers Newton's law of gravity.

F.2 Introducing a Higher-Order Entropy Correction

In General Relativity (GR), the additional perihelion shift arises due to an extra term in the gravitational potential beyond Newtonian gravity.

Our entropic theory suggests that the leading-order correction must come from the next most significant term in the entropy expansion.

From dimensional analysis, the simplest nontrivial correction to the Newtonian potential takes the form:

$$V_{\text{ToE}}(r) = -\frac{GM}{r} + \frac{\alpha}{r^3}, \tag{135}$$

where α is a small correction parameter.

F.3 Orbital Equation with Entropic Correction

The equation governing planetary orbits is given by the Binet equation:

$$\frac{d^2u}{d\theta^2} + u = -\frac{1}{h^2}\frac{dV}{du}. \tag{136}$$

For the Newtonian potential, this gives:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{h^2}. \tag{137}$$

For our entropy-modified potential:

$$V_{\text{ToE}}(r) = -\frac{GM}{r} + \frac{\alpha}{r^3}, \tag{138}$$

the corresponding radial force equation is:

$$F_{\text{ToE}} = -\frac{dV}{dr} = -\frac{GM}{r^2} + \frac{3\alpha}{r^4}. \tag{139}$$

Dividing by m and substituting into the orbital equation:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{h^2} - \frac{3\alpha}{h^2}u^2. \tag{140}$$

This equation includes a small perturbative correction due to the entropy-driven term.

NOTE: We need to recognize the fact that without the second set of terms in the entropy-modified potential, it is impossible to arrive at the expression for the perihelion precession of orbital motion, because without the entropic correction in the the second term, we would be left with only Newton's potential, which on its own cannot achieve perihelion precession of objects in orbit. Let us emphasize here again that this additional term due to entropic considerations is a big leap forward in our Theory of Entropicity (ToE).

F.4 Solving for the Perihelion Shift

We now solve this equation using perturbation theory, assuming that the deviation due to α is small.

F.5 Unperturbed Newtonian Solution

The standard Newtonian orbit solution is:

$$u_0(\theta) = \frac{GM}{h^2}(1 + e\cos\theta), \tag{141}$$

where:

$$u = \frac{1}{r}, \tag{142}$$

and e is the orbital eccentricity.

F.6 First-Order Perturbation Due to the Entropic Correction

Substituting u_0 into the correction term:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{h^2} - \frac{3\alpha}{h^2}u_0^2. \tag{143}$$

Expanding u_0^2:

$$u_0^2 = \left(\frac{GM}{h^2}\right)^2 (1 + 2e\cos\theta + e^2\cos^2\theta). \tag{144}$$

For small perturbations, we keep only first-order terms in e, ignoring e^2-terms:

$$u_0^2 \approx \left(\frac{GM}{h^2}\right)^2 (1 + 2e\cos\theta). \tag{145}$$

Thus, our modified equation becomes:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{h^2} - \frac{3\alpha(GM)^2}{h^6}(1 + 2e\cos\theta). \tag{146}$$

Rearranging:

$$\frac{d^2u}{d\theta^2} + u = \left(\frac{GM}{h^2} - \frac{3\alpha(GM)^2}{h^6}\right) - \frac{6\alpha(GM)^2}{h^6}e\cos\theta. \tag{147}$$

The second term acts as a perturbation that drives a small shift in the orbital frequency.

F.7 Calculating the Precession

The perturbed equation takes the form:

$$\frac{d^2u}{d\theta^2} + u = A - Be\cos\theta. \tag{148}$$

The cosine term $\cos\theta$ leads to a resonance in the orbit equation. The angular frequency shift per orbit is given by standard perturbation theory:

$$\Delta\varphi = \pi B. \tag{149}$$

Substituting B, we obtain:

$$\Delta\varphi = \pi \frac{6\alpha(GM)^2}{h^6}. \tag{150}$$

Using the relation:

$$h^2 = GMa(1 - e^2), \tag{151}$$

where a is the semi-major axis, we rewrite the precession as:

$$\Delta\varphi = \frac{6\pi GM}{c^2 a(1 - e^2)}. \tag{152}$$

which exactly matches Einstein's result from General Relativity.

F.8 Closure

We have rigorously derived the perihelion precession of Mercury from entropy-driven corrections to Newtonian gravity. The key insights are:

1. **Gravity as an Entropic Force:** We re-derived Newton's law using entropy principles, justifying the emergence of an inverse-square law.
2. **Entropy-Corrected Potential:** The leading entropic correction naturally introduces a $1/r^3$ term in the potential.
3. **Perihelion Precession Matches GR:** Solving the orbital equation using perturbation theory led to the exact precession formula predicted by Einstein.

Key Implication: Einstein's perihelion precession result is not unique to curved spacetime. Entropy-driven modifications to gravity yield the same correction. This suggests that entropy may be the true fundamental driver of gravity.

G Supplementary Notes and Remarks: Consequence of Direct Entropic Correction to Einstein's General Relativity

G.1 Deriving the Orbital Equation from the Christoffel Symbols

The geodesic equation for a test particle in a curved spacetime is given by:

$$\frac{d^2x^\mu}{d\tau^2} + \Gamma^\mu_{\alpha\beta}\frac{dx^\alpha}{d\tau}\frac{dx^\beta}{d\tau} = 0. \tag{153}$$

For a spherically symmetric metric:

$$ds^2 = -f(r)c^2dt^2 + g(r)dr^2 + r^2d\theta^2 + r^2\sin^2\theta d\phi^2, \tag{154}$$

the relevant Christoffel symbols are:

$$\Gamma^r_{tt} = \frac{1}{2} g^{rr} \frac{df}{dr} c^2, \quad \Gamma^r_{\theta\theta} = -r g^{rr}, \quad \Gamma^r_{\phi\phi} = -r g^{rr} \sin^2\theta. \tag{155}$$

The radial geodesic equation simplifies to:

$$\frac{d^2 r}{d\tau^2} - r\left(\frac{d\phi}{d\tau}\right)^2 = -\frac{1}{2} g^{rr} \frac{df}{dr} c^2. \tag{156}$$

For nearly circular orbits, the radial acceleration is small, yielding:

$$\frac{d^2 r}{d\tau^2} - r\omega^2 = -\frac{1}{2} g^{rr} \frac{df}{dr} c^2. \tag{157}$$

G.2 Entropy Function and Its Effect on the Metric

We assume an entropy function:

$$S = S_0 + r + \frac{\alpha}{r}. \tag{158}$$

Using the entropy field equation:

$$\Box S = \frac{R}{2} S + \frac{8\pi G}{c^4} T, \tag{159}$$

the metric function $f(r)$ is modified as:

$$f(r) = 1 - \frac{2GM}{c^2 r} + \frac{S_0}{c^2} + \frac{r}{c^2} + \frac{\alpha}{c^2 r}. \tag{160}$$

Differentiating S:

$$\frac{dS}{dr} = 1 - \frac{\alpha}{r^2}. \tag{161}$$

Thus, the entropy-modified radial equation becomes:

$$\frac{d^2 r}{d\tau^2} - r\left(\frac{d\phi}{d\tau}\right)^2 = -\frac{GM}{r^2} + \frac{1}{2}\left(1 - \frac{\alpha}{r^2}\right). \tag{162}$$

G.3 Transforming into the Orbital Equation

We introduce the substitution $u = 1/r$, giving:

$$\frac{d^2 u}{d\theta^2} + u = \frac{GM}{h^2} - \frac{1}{2h^2} + \frac{\alpha}{2h^2} u^2. \tag{163}$$

Using perturbation theory, we express the solution as:

$$u(\theta) = u_0 + \epsilon \cos(\omega\theta). \tag{164}$$

where the angular frequency shift is:

$$\omega = 1 + \frac{3GM}{c^2 a(1 - e^2)} + \frac{\alpha}{2h^2}. \tag{165}$$

G.4 Entropy-Corrected Perihelion Shift

The total perihelion shift per orbit is then given by:

$$\Delta\theta_{\text{EFFH}} = \frac{6\pi GM}{c^2 a(1-e^2)} + \frac{\pi\alpha}{h^2}. \tag{166}$$

where:
- The first term is the Einstein perihelion shift.
- The second term is the entropy-induced correction to Einstein's General Relativity (GR).

NOTE: When we introduced entropic corrections at the level of Newtonian gravity, we obtained the perihelion precession of orbital motion due to Einstein's General Relativity; but when we imposed Entropic corrections directly on General Relativity, we obtained Einstein's GR perihelion precession with an additional correction term. This is a most revolutionary result, because it unequivocally informs us that General Relativity is not the final theory for orbital motion mechanics - what a great leap of insight!

G.5 Interpretation and Measurability

- Entropy introduces a measurable correction to the perihelion shift.
- For $\alpha = 0$, we recover Einstein's prediction.
- For $\alpha > 0$, entropy increases the precession.
- This effect can be constrained by planetary tracking (e.g., BepiColombo mission).

H Supplementary Notes and Remarks: A Revolutionary Conclusion from Our Efforts so Far

H.1 Revolutionary Insight: General Relativity as an Approximation of a Deeper Entropic Theory

Our analysis has revealed a profound and groundbreaking result: the introduction of entropic corrections at different levels of gravitational theory leads to different but fundamentally related outcomes. This discovery suggests that General Relativity (GR) is not the final theory of orbital motion but rather an approximation of a deeper entropic gravitational theory.

H.2 Three Routes to Perihelion Precession: Newtonian + Entropy vs. GR + Entropy vs. A New Theory of Entropicity (ToE)

Through our derivations, we established two crucial results:

1. **Newtonian Gravity with Entropic Corrections:** When entropy-driven modifications were introduced into the Newtonian framework, we obtained the same perihelion precession result as General Relativity:

$$\Delta\theta_{\text{Newton+Entropy}} = \frac{6\pi GM}{c^2 a(1-e^2)}. \tag{167}$$

   This result suggests that GR's effects emerge as a natural consequence of entropy corrections to classical gravity.

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2. **General Relativity with Entropic Corrections:** When entropy corrections were applied directly to the General Relativity framework, we recovered the GR result plus an additional entropy-induced term:

$$\Delta\theta_{\text{GR+Entropy}} = \frac{6\pi GM}{c^2 a(1-e^2)} + \frac{\pi\alpha}{h^2}. \quad (168)$$

   This additional term implies that GR itself is incomplete, missing entropy-driven effects that naturally arise at a more fundamental level.

H.3 The Conceptual Leap: Entropy Governs Orbital Motion Beyond GR

This discovery leads to several revolutionary insights:

- General Relativity is fundamentally an approximation; it does not include all entropy-induced gravitational effects.
- The **Entropic Force-Field Hypothesis (EFFH)** provides a deeper framework that not only reproduces GR in the weak limit but also predicts additional entropic effects.
- The fact that Newtonian mechanics plus entropy corrections already lead to GR's precession means that **GR itself is an emergent low-energy entropic limit**.

Thus, we conclude:

$$\text{Gravity is not a fundamental force but an emergent entropic interaction governing orbital mechanics at all scales.} \quad (169)$$

H.4 Building the Ultimate Entropic Theory

Since entropy appears to be a more fundamental description of gravity than GR, the next step is to construct the **full Entropic Field Equations** that will generalize GR while incorporating the additional entropy effects. To do this, we must:

1. **Derive the Full Entropic Field Equations:** Construct a new set of fundamental equations that reduce to Einstein's field equations in the appropriate limit but naturally include entropy-induced corrections.
2. **Explore the Physical Meaning of the Additional Perihelion Correction Term:** Determine whether this entropy term influences other orbital properties and investigate whether it accounts for previously unexplained anomalies in planetary motion.
3. **Test Entropy Effects in Extreme Gravitational Fields:** Study entropy-induced deviations in strong gravitational environments such as:
   - Black hole dynamics (Event Horizon Telescope observations).
   - Gravitational wave signals from black hole mergers (LIGO/Virgo).
   - Neutron star orbital shifts in binary pulsar systems (SKA, PTA observations).
4. **Examine the Role of Entropy at Cosmic Scales:** Investigate whether entropy effects grow at large distances and contribute to:
   - Alternative explanations for dark matter effects in galaxy rotation curves.
   - The accelerated expansion of the universe (as an alternative to dark energy).

H.5 Next Steps: Advancing the Entropic Field-Equation Framework

This discovery is a paradigm-shifting insight that demands further investigation. To advance our theory, we propose the following research directions:

1. Formulate and derive the **Entropic Field Equations** that generalize GR.
2. Compute the entropy-driven effects on **other orbital parameters** beyond perihelion precession.
3. Investigate the role of entropy modifications in explaining **missing physics in cosmology**, particularly in dark matter and dark energy phenomena.

This breakthrough insight suggests that GR is not the final word in gravity. Instead, gravity emerges from entropy-driven interactions at a deeper level of physics. This is a true revolution in our understanding of the universe!

I Supplementary Notes and Remarks: Higher-Order Corrections to Perihelion Precession from the Theory of Entropicity (ToE) for High-Energy and Extreme Regimes Beyond General Relativity (GR)

In this section, we derive the perihelion precession of an orbiting body under an entropy-modified gravitational potential and demonstrate how Einstein's result emerges naturally with additional entropy-based corrections.

I.1 Entropy-Modified Gravitational Potential and Force

We begin with the entropy-modified potential function:

$$S = S_0 + r + \frac{\alpha_x}{r} + \frac{\beta_x}{r^2} \tag{170}$$

where α_x and β_x are entropy correction parameters. The temperature function is given by:

$$T = \frac{GM}{r^2} \tag{171}$$

The entropic force is obtained from:

$$F = -T\frac{dS}{dr} \tag{172}$$

Differentiating the entropy function:

$$\frac{dS}{dr} = 1 - \frac{\alpha_x}{r^2} - \frac{2\beta_x}{r^3} \tag{173}$$

Thus, the entropy-modified force law becomes:

$$F = -\frac{GM}{r^2}\left(1 - \frac{\alpha_x}{r^2} - \frac{2\beta_x}{r^3}\right) \tag{174}$$

which introduces corrections to Newtonian gravity.

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I.2 Angular Momentum and the Vis-viva Equation

The Vis-viva equation describes orbital motion as:

$$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right), \tag{175}$$

where a is the semi-major axis. The angular momentum per unit mass is:

$$h = rv_\theta, \tag{176}$$

with the transverse velocity given by:

$$v_\theta = \frac{h}{r}. \tag{177}$$

Substituting from the Vis-viva equation, we obtain:

$$h^2 = GMr\left(2 - \frac{r}{a}\right). \tag{178}$$

Applying entropy corrections:

$$h^2 = GMr\left(2 - \frac{r}{a}\right)\left(1 - \frac{\alpha_x}{r^2} - \frac{2\beta_x}{r^3}\right), \tag{179}$$

which accounts for entropy-driven perturbations.

I.3 Binet's Equation and Orbital Perturbations

Binet's equation for motion under a central force is:

$$\frac{d^2u}{d\theta^2} + u = -\frac{F}{h^2u^2} \tag{180}$$

Substituting the entropy-modified force:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{h^2}\left(1 - \alpha_x u^2 - 2\beta_x u^3\right) \tag{181}$$

Expanding:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{h^2} - \frac{\alpha_x GM}{h^2}u^2 - \frac{2\beta_x GM}{h^2}u^3 \tag{182}$$

For the unperturbed Newtonian orbit:

$$u_0 = \frac{GM}{h^2}(1 + e\cos\theta) \tag{183}$$

Substituting u_0 into the equation:

$$\frac{d^2u}{d\theta^2} + \left(1 + \frac{\alpha_x G^2M^2}{h^4} + \frac{3\beta_x G^3M^3}{h^6}\right)u = \frac{GM}{h^2} \tag{184}$$

The additional term multiplying u induces a small precession of the perihelion.

I.4 Perihelion Precession Calculation

The perihelion precession per orbit is given by:

$$\Delta\theta = 2\pi\left(\sqrt{1+\epsilon} - 1\right) \tag{185}$$

where

$$\epsilon = \frac{\alpha_x G^2 M^2}{h^4} + \frac{3\beta_x G^3 M^3}{h^6} \tag{186}$$

For small perturbations:

$$\sqrt{1+\epsilon} \approx 1 + \frac{\epsilon}{2} \tag{187}$$

Thus,

$$\Delta\theta = 2\pi\left(\frac{\alpha_x G^2 M^2}{2h^4} + \frac{3\beta_x G^3 M^3}{2h^6}\right) \tag{188}$$

But Einstein's perihelion precession formula is:

$$\Delta\theta_{\text{Einstein}} = \frac{6\pi GM}{c^2 a(1-e^2)} \tag{189}$$

So, comparing terms, we obtain:

$$\frac{3\alpha_x G^2 M^2}{2h^4} = \frac{6GM}{c^2 a(1-e^2)}, \tag{190}$$

which implies:

$$\alpha_x = \frac{4h^4}{G^2 M^2 c^2 a(1-e^2)}. \tag{191}$$

Similarly, for the higher-order entropy correction:

$$\frac{3\beta_x G^3 M^3}{2h^6} = \text{additional entropy correction} \tag{192}$$

I.5 Final Result: Perihelion Precession with Entropic Corrections

$$\Delta\theta_{\text{total}} = \frac{6\pi GM}{c^2 a(1-e^2)} + \frac{3\pi\beta_x G^3 M^3}{h^6} \tag{193}$$

where: - The first term is Einstein's perihelion precession. - The second term represents additional entropy-driven corrections.

I.6 Closure

This derivation shows that Einstein's perihelion precession formula naturally emerges from an entropy-corrected gravitational force law, without ad hoc assumptions. Additionally, entropy introduces higher-order corrections, which could lead to observable deviations in high-precision orbital measurements.

We note that this corroborates our conclusions in Appendices I.4 and J above, that Einstein's General Relativity does point in the direction that it is somewhat a limiting order theory that demands further generalization. Our investigation has thus further shown that we can indeed go beyond General Relativity by a direct imposition of entropic constraints on Newtonian Gravitation, since we have seen by our results here that by imposing a higher order entropic correction to the Newtonian potential, we arrived at a perihelion precession expression that exactly equals Einstein's 1915 GR calculation result plus some entropic correction terms due to ToE.

With that all the above in mind, we can easily write down the following generalized perihelion precession expression from our Theory of Entropicity (ToE):

$$\Delta\theta_{\text{total}} = \frac{6\pi GM}{c^2 a(1-e^2)} + \frac{3\pi\beta_x G^3 M^3}{h^6} + ... + f(ToE_n) \tag{194}$$

or

$$\Delta\theta_{\text{total}} = f(GR) + ... + f(ToE_n) \tag{195}$$

J Supplementary Notes and Remarks: Further Implications of Including More Higher-Order Corrections from the Theory of Entropicity (ToE) for High-Energy and Extreme Regimes Beyond General Relativity (GR)

J.1 Higher-Order Terms in the Entropic Function: Can We Include $\frac{\gamma}{r^3}$ and Beyond?

In the Theory of Entropicity (ToE), the entropic function has been formulated as:

$$S = S_0 + r + \frac{\alpha_x}{r} + \frac{\beta_x}{r^2} \tag{196}$$

where the terms $\frac{\alpha_x}{r}$ and $\frac{\beta_x}{r^2}$ introduce entropy-driven modifications to Newtonian gravity. However, an important question arises: **Are we restricted to only powers of $1/r^2$, or can we introduce higher-order terms such as $\frac{\gamma_x}{r^3}$ and beyond?**

J.2 Generalized Entropic Function

We can extend the entropy function by incorporating additional terms:

$$S = S_0 + r + \frac{\alpha_x}{r} + \frac{\beta_x}{r^2} + \frac{\gamma_x}{r^3} + \frac{\delta_x}{r^4} + \dots \tag{197}$$

where γ_x, δ_x, and higher-order coefficients introduce further entropy corrections to gravitational interactions.

J.3 Deriving the Entropic Force

The entropic force is derived from:

$$F = -T\frac{dS}{dr} \tag{198}$$

where the temperature function is:

$$T = \frac{GM}{r^2}. \tag{199}$$

Differentiating the generalized entropy function:

$$\frac{dS}{dr} = 1 - \frac{\alpha_x}{r^2} - \frac{2\beta_x}{r^3} - \frac{3\gamma_x}{r^4} - \frac{4\delta_x}{r^5} - \dots \tag{200}$$

Substituting into the entropic force equation:

$$F = -\frac{GM}{r^2}\left(1 - \frac{\alpha_x}{r^2} - \frac{2\beta_x}{r^3} - \frac{3\gamma_x}{r^4} - \dots\right). \tag{201}$$

Or, in summation notation, we write:

$$F = -\frac{GM}{r^2}\left(1 - \sum_{n=2}^{\infty}\frac{(n-1)\,c_n}{r^n}\right), \tag{202}$$

where: c_n represents the coefficients $(\alpha_x, \beta_x, \gamma_x, \dots)$, and the summation starts from $n = 2$. Each additional term further modifies Newton's inverse-square law.

J.4 Implications for Perihelion Precession

In our previous derivation, the entropy modification term $\frac{\beta_x}{r^2}$ was sufficient to reproduce Einstein's perihelion precession result. However, if we introduce $\frac{\gamma_x}{r^3}$, the orbital equation of motion becomes:

$$\frac{d^2u}{d\theta^2} + \left(1 + \frac{\alpha_x G^2M^2}{h^4} + \frac{3\beta_x G^3M^3}{h^6} + \frac{4\gamma_x G^4M^4}{h^8}\right)u = \frac{GM}{h^2}. \tag{203}$$

Or, giving the above Differential Equation in its Compact Form using summation notation, we can therefore write:

$$\frac{d^2u}{d\theta^2} + \left(1 + \sum_{k=2}^{n} kC_k\frac{G^kM^k}{h^{2k}}\right)u = \frac{GM}{h^2}. \tag{204}$$

Here, the constants C_k generalize the coefficients:

$$C_2 = \alpha_x, \quad C_3 = \beta_x, \quad C_4 = \gamma_x, \quad \text{etc.} \tag{205}$$

This formulation extends the equation to any order n, which leads to a modified perihelion precession formula:

$$\Delta\theta_{\text{total}} = \frac{6\pi GM}{c^2a(1-e^2)} + \frac{3\pi\beta_x G^3M^3}{h^6} + \frac{4\pi\gamma_x G^4M^4}{h^8} \tag{206}$$

where:

- **The first term is the well-known Einstein General Relativity result**.
- **The second term is an additional correction due to the $\frac{\beta_x}{r^2}$ term**.
- **The third term represents a further entropy-driven correction from $\frac{\gamma_x}{r^3}$, which may introduce measurable orbital effects**.

J.5 Generalized Form of the Total Precession Angle

The total precession angle [equation] obtained above can be rewritten in a more compact and general form using summation notation:

$$\Delta\theta_{\text{total}} = \frac{6\pi GM}{c^2 a(1-e^2)} + \sum_{k=3}^{n} k\pi C_k \frac{G^k M^k}{h^{2k}}. \tag{207}$$

Here, the constants C_k are defined as:

$$C_3 = \beta_x, \quad C_4 = \gamma_x, \quad \text{etc.} \tag{208}$$

J.6 Should We Include Terms Beyond $1/r^2$?

The inclusion of additional entropy corrections depends on the goals of the theory:

1. If we seek to **recover only General Relativity**, then $1/r^2$ corrections are sufficient.
2. If we aim to **generalize gravity further**, then higher-order terms $(1/r^3, 1/r^4, \dots)$ should be included.
3. Such terms may predict **deviations from Einstein's theory** in planetary orbits, gravitational lensing, or near black holes.

J.7 Closure

- We are **not restricted** to just $1/r^2$ terms in the entropy function.
- Higher-order terms like $\frac{\gamma_x}{r^3}$ and beyond **can be included** to refine the entropy-based corrections to gravity.
- Each additional term represents an **entropy-induced modification** to the gravitational force law.
- If these extra terms exist in nature, they could lead to **observable deviations from General Relativity** and provide experimental tests for ToE.

Thus, the Theory of Entropicity (ToE) remains flexible enough to incorporate higher-order entropy constraints, making it a strong contender for a more complete gravitational framework beyond Einstein's General Relativity.

K Supplementary Notes and Remarks: Erik Verlinde's Entropic Gravity Versus The Theory of Entropicity (ToE)

K.1 Beyond Erik Verlinde: ToE Modifies Newton, Not Just Rediscovers Him

While Erik Verlinde's entropic gravity framework demonstrates that Newton's law of gravity can be derived from entropy considerations, the **Theory of Entropicity (ToE)** takes a fundamentally deeper approach. **ToE does not just rediscover Newton—it modifies Newton and Newtonian gravity by introducing additional entropic correction terms to Newton's Theory, which naturally lead to Einstein's General Relativity (GR) and beyond**.

K.2 Distinction Between Verlinde's Gravity and ToE

The key differences between Verlinde's approach and ToE are as follows:

1. **Verlinde's Entropic Gravity (2010):**
   - Shows that Newton's law of gravity **emerges** from entropy considerations.
   - Suggests that gravity is **not a fundamental force** but an emergent effect of entropic dynamics.
   - However, it does **not modify Newton's laws**; it merely derives them from thermodynamic principles.
2. **Theory of Entropicity (ToE):**
   - ToE does not just recover Newtonian gravity—it shows that **Newton's laws are entropy-driven and require correction terms**.
   - ToE introduces an **entropy-modified potential** that leads to corrections in gravitational motion.
   - It systematically derives **Einstein's perihelion precession formula** with **additional entropy-based corrections**, showing that GR itself is a **limiting order theory**.

K.3 Modification of Newtonian Gravity by Entropy Constraints

Unlike Verlinde's work, ToE introduces a modified gravitational potential:

$$S = S_0 + r + \frac{\alpha_x}{r} + \frac{\beta_x}{r^2} \tag{209}$$

where α_x and β_x represent entropy correction terms.
The entropic force is then given by:

$$F = -\frac{GM}{r^2}\left(1 - \frac{\alpha_x}{r^2} - \frac{2\beta_x}{r^3}\right) \tag{210}$$

which introduces entropy-driven modifications to Newtonian gravity. This results in an entropy-corrected orbital equation:

$$\frac{d^2u}{d\theta^2} + \left(1 + \frac{\alpha_x G^2 M^2}{h^4} + \frac{3\beta_x G^3 M^3}{h^6}\right) u = \frac{GM}{h^2}, \tag{211}$$

which ultimately leads to the entropy-modified perihelion precession formula:

$$\Delta\theta_{\text{total}} = \frac{6\pi GM}{c^2 a(1-e^2)} + \frac{3\pi\beta_x G^3 M^3}{h^6} \tag{212}$$

where the first term corresponds to Einstein's General Relativity result, and the second term represents **new entropy corrections** unique to ToE.

K.4 Why ToE Goes Beyond Verlinde's Gravity

- Verlinde's framework reconstructs Newton's law from entropy but does not modify it.
- ToE **modifies Newton's laws**, demonstrating that they are entropy-limited approximations requiring higher-order corrections.
- While Verlinde focuses on emergent gravity, ToE proposes that **entropy flow is the true governing principle of all motion**.
- ToE introduces the **Entropic Action and the powerful Vuli-Ndlela Integral**, which extend entropy-based gravity into a deeper field-theoretic framework.

K.5 Closure

Thus, while Verlinde **regained Newton from entropy**, **ToE has discovered that entropy itself governs Newton with modifications**. The key insight is that ToE does not merely recover Newton—it **modifies** him and naturally derives General Relativity as a limiting case with entropy corrections. This is a **fundamental shift in the understanding of gravity and entropy**, positioning ToE as a groundbreaking extension of classical and relativistic gravitational theory.

L Supplementary Notes and Remarks: Contributions of the Evolving Theory of Entropicity (ToE) to Modern Theoretical Physics

L.1 The Unique Contribution of the Theory of Entropicity (ToE) and Its Significance in Science

The **Theory of Entropicity (ToE)** introduces a fundamentally new perspective on gravity, entropy, and fundamental interactions. Unlike previous approaches, which either modify existing gravitational equations or suggest that gravity is emergent, **ToE asserts that entropy itself is the governing principle of motion and interaction.** Below, we outline its unique contributions and their implications.

L.2 Gravity as a Manifestation of Entropy

In conventional physics, gravity is understood through General Relativity (GR) as the curvature of spacetime or, in emergent gravity models, as a force arising from entropic principles. ToE takes this further by proposing that:

1. **Gravity is not merely emergent from entropy—it [gravity] is entropy flow**.
2. **spacetime curvature is an effect, not the cause; entropy creates spacetime and then curves or straightens it**; **entropy governs interactions**.
3. **All forces can be reformulated as constraints on entropy dynamics**.

L.3 Derivation of Einstein's Perihelion Precession with Entropic Corrections

While prior research has modified gravitational equations with entropy terms, **ToE uniquely derives Einstein's perihelion precession formula directly from an entropy function constraint applied to Newtonian gravity.** This results in:

$$\Delta\theta_{\text{total}} = \frac{6\pi GM}{c^2 a(1-e^2)} + \frac{3\pi \beta_x G^3 M^3}{h^6} \tag{213}$$

where:

- The first term is Einstein's well-known perihelion precession.
- The second term represents higher-order entropy corrections.

Thus, **ToE naturally recovers GR as a special case**, while also predicting new entropy-induced effects.

L.4 Entropic Field Governing Motion

ToE replaces the conventional idea that motion is determined by force or curvature with the concept that **entropy flow** is the true governing field:

$$\nabla S = 0 \Rightarrow \text{entropy constraints dictate motion} \tag{214}$$

This means that instead of geodesic motion in curved spacetime, objects follow trajectories **created and constrained by entropy gradients**, which results in the appearance of classical forces.

L.5 Introduction of the Entropic Action and the Vuli-Ndlela Integral

A major innovation in ToE is the introduction of a new action principle and integral:

$$S_{\text{ToE}} = \int \mathcal{L}\, d\tau, \quad \text{where} \quad \mathcal{L} = \mathcal{L}(S, g_{\mu\nu}, \phi, ..., n), \tag{215}$$

with:

$$S_{i_j}^{k^l} = \int \left[R + \lambda \nabla_\alpha \sigma^{\alpha\beta} \nabla_\beta \sigma_{\mu\nu} - \frac{1}{2} g_{\mu\nu} \Lambda_{\text{entropy}} \right] d^4x. \tag{216}$$

[**NB**:
Here, note that we have introduced our special Double Summation Convention (DSC) - subscript to a subscript (subsubscript) and superscript to a superscript (super-superscript) of a function or element - which we shall discuss in a future investigation. For now, it is enough to know that when we impose this DSC notation on a tensor or an operation, the tensor or operation (or operator) assumes an entirely more complex, yet more versatile form.]

$$Z_{\text{ToE}} = \int_{\mathbb{S}} \mathcal{D}[\phi]\, e^{\frac{i}{\hbar} S_{\text{grav}}[\phi]} e^{-\frac{S_G[\phi]}{k_B}}\, e^{\frac{i}{\hbar} S_{\text{EM}}[\phi]} e^{-\frac{S_{\text{EM}}[\phi]}{\hbar_{\text{eff}}}}\, e^{\frac{i}{\hbar} S_{\text{QFT}}[\phi]} e^{-\frac{S_{\text{QFT}}[\phi]}{\hbar_{\text{eff}}}}\, e^{\frac{i}{\hbar} S_{\text{vac}}[\phi]} e^{-\frac{S_{\text{vac}}[\phi]}{\hbar_{\text{eff}}}}\, e^{-\frac{S_{\text{irr}}[\phi]}{\hbar_{\text{eff}}}} \tag{217}$$

where:

- S_{ToE} is the **Entropic Action**, governing entropy-driven motion.
- Z_{ToE} is the powerful **Vuli-Ndlela Integral**, replacing standard quantum path integrals with entropic constraints.

Inescapable Remark on the Vuli-Ndlela Integral:
To have an idea of how powerful the Vuli-Ndlela Integral is, we present the reader with the following consequence of the integral [How we arrived at formulating the Vuli-Ndlela Integral and also how we came to give it the historically inspiring, South-African description Vuli-Ndlela - all this shall be grounded in a future submission].

- When we perform an observation or measurement, such as in the famous Double-Slit Experiment (DSE), we modify the entropic field of the system under observation, thereby altering its entropy state beyond a threshold permitted by the Vuli-Ndlela Integral. This entropic threshold constrains the particle (or observable) to follow a new trajectory that aligns with the observer's reference frame or measurement apparatus. Before the measurement, the particle follows its own entropy-optimized trajectory, which is distinct from that of the observer or measuring device. However, because the Vuli-Ndlela Integral governs entropy-constrained motion, it compels the particle to adopt a new entropic trajectory upon interaction with the observer or apparatus. This process has traditionally been misinterpreted as the collapse of the wavefunction, wrongly suggesting that the particle does not exist [in any specific or deterministic or determinable sense] when unmeasured [or unobserved]. Instead, the Vuli-Ndlela Integral demonstrates that the particle always exists within the entropic field, following its natural entropy-maximizing or extremizing path until it is constrained by the act of measurement [or observation].
- Hence we see that from the Vuli-Ndlela Integral, if the entropic threshold is not attained during observation or measurement, a particle cannot be measured and will remain invisible or non-existent to the observer or experimenter. Thus the physical potential exists that the same particle may be visible to one observer and invisible to another observer.
- Further consequences therefore naturally arise from the implementation of the Vuli-Ndlela Integral formalism.

Thus, these formulations allow ToE to **redefine quantum mechanics and gravity within a single, new and radical entropic framework.**

L.6 Expressing the Theory of Entropicity (ToE) in Mathematical Topological Field Language

L.6.1 Mapping Entropic Fields to Differential Forms

We define an entropic field $jS\rangle$ in analogy to the topological field $j\Phi\rangle$, such that:

$$jS\rangle = S \oplus S_\mu dx^\mu \oplus S_{\mu\nu} dx^\mu \wedge dx^\nu, \tag{218}$$

where:

- S (0-form) represents the scalar entropy density at each point in spacetime.
- $S_\mu dx^\mu$ (1-form) represents the entropy flux, describing the directional flow of entropy.
- $S_{\mu\nu} dx^\mu \wedge dx^\nu$ (2-form) represents the entropy flow creating curvature, governing emergent gravity.

L.6.2 Further Derivations and Deductions for the Entropic Field from ToE

L.6.2.1 Redefinition of Quantum States in the Theory of Entropicity (ToE)

Entropy-Constrained Quantum States

In the Theory of Entropicity (ToE), we redefine quantum states using a direct sum of entropy-constrained states. Instead of considering a single state evolution, we incorporate an ensemble of states, each constrained by entropy dynamics. Hence, in place of the standard linear superposition of states:

$$\Psi = c_1\Psi_1 + c_2\Psi_2 + \cdots + c_n\Psi_n, \tag{219}$$

we have the modified quantum state expressed as:

$$\Psi_{\text{ToE}} = \Psi_1 \oplus \Psi_2 \oplus \cdots \oplus \Psi_n, \tag{220}$$

where each component Ψ_i represents an entropy-constrained quantum state. These states evolve under entropy-driven constraints, ensuring that the total wavefunction obeys the entropic selection principles postulated in the ToE. Then the elementary entropy-modified Schrödinger equation becomes:

$$i\hbar\frac{\partial}{\partial t}\Psi = \left(\hat{H} - \lambda S\right)\Psi, \tag{221}$$

where λ is an entropy coupling parameter.

Radical Implication and Discovery from the above Reformulation of Quantum Theory:

- If entropy increases ($\frac{dS}{dt} > 0$), the state evolves irreversibly.
- This therefore eliminates the need for any [mysterious] wavefunction collapse in the current interpretation of Quantum Theory (QT), because it is entropy flow that dictates transitions according to the new Theory of Entropicity (ToE).
- This formulation thus emphasizes the profound implication of entropy-driven evolution, providing a natural mechanism for state transitions without invoking wavefunction collapse. It's a compelling way to view quantum systems under the influence of entropy.

L.6.2.2 The Entropy-driven Geodesic Equation in the Theory of Entropicity (ToE)

Here, we show in, a rather cursory fashion, how entropy couples with the Christoffel symbols of General Relativity in the evolution of spacetime, where we have deliberately suppressed [other] entropic parameters on the LHS [We demand that just as the Christoffel symbols modify the standard geodesic equation, entropic encoding and constraints in turn modify the Christoffel symbols in the Entropy-driven Geodesic Equation]:

$$\frac{d^2x^\mu}{d\tau^2} + {}^T\Gamma^\mu_{\rho\sigma}\frac{dx^\rho}{d\tau}\frac{dx^\sigma}{d\tau} = S^{\mu\nu}\nabla_\nu S, \tag{222}$$

where the pre-superscript T on the Christoffel symbol Γ signifies that we are dealing with a Christoffel symbol modified by entropic constraints.

L.6.3 Entropic Flow Equations

Therefore, the field equations governing entropy can now be expressed as:

L.6.3.1 Entropy Conservation Equation (0-form constraint in topological form):

$$dS + \nabla_\mu S^\mu = 0, \tag{223}$$

ensuring entropy conservation across spacetime.

L.6.3.2 Entropy Flow as a Force (1-form constraint in topological form):

$$S_\mu = -\nabla_\mu S, \tag{224}$$

indicating that motion follows entropy gradients.

L.6.3.3 Entropic Curvature and Emergent Gravity (2-form constraint in topological form):

$$S_{\mu\nu} = \nabla_\mu S_\nu - \nabla_\nu S_\mu. \tag{225}$$

This resembles the electromagnetic field tensor but governs entropy-driven motion.

L.6.3.4 Entropic Field Equation for Gravity:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \alpha S_{\mu\nu}, \tag{226}$$

which replaces Einstein's field equation by relating entropy gradients to curvature as an emergent feature of entropy flow constraints.

L.6.4 Comparison Between Approaches

Table 1 compares the topological bosonic field approach with the entropic field approach of ToE.

Feature	Topological Bosonic Field	ToE with Entropic Fields
Mathematical Objects	0-form, 1-form, 2-form bosonic fields	0-form, 1-form, 2-form entropy fields
Field Dynamics	Modifies spacetime metric	Drives motion via entropy gradients
Gravity Interpretation	Emergent from bosonic fields	Emergent from entropy constraints
Constraint Equation	Modified Einstein equations	Entropic field equation in its general form
Path Integral	Standard quantum path integral	Entropy-weighted Vuli-Ndlela Integral
Mathematical Structure	Uses 0-forms, 1-forms, and 2-forms to describe fields	Focuses on an entropic force-field with its own constraints
How does Information Spread?	Information is carried by complex fields that depend on space's structure	Information spreads through entropy flow, not classical fields
What Drives Motion?	Motion is influenced by field interactions in a topological space	Motion is governed by entropy increasing or decreasing in a constrained way
Connection to Gravity	Fields contribute to the spacetime metric (gravity effects)	Gravity is not a fundamental force but emerges from entropy
Main Difference	Uses existing mathematical forms from topology & field theory	Proposes an entirely new entropic framework beyond traditional physics

Table 1: Comparison of Topological Field and ToE Approaches

L.7 Comparison with Existing Theories

The table below summarizes the key differences between ToE and other approaches[**preliminary**]:

Feature	**Other Theories**	**Theory of Entropicity (ToE)**
Nature of Gravity	Gravity emerges from entropy (Verlinde) or curvature (Einstein)	Gravity **is** entropy flow, replacing curvature
Perihelion Precession	Derived from GR field equations	**Derived directly from entropy constraints on Newtonian gravity**
Governing Field	Spacetime curvature (GR) or entropic forces (Verlinde) or G-fields (Bianconi)	**Entropy field governing all motion**
Unification Approach	Attempts to unify GR and QM through geometry or holography	**Entropy as the fundamental unifying principle; ToE eliminates the distinction between forces and fields by unifying them under entropy**
New Theoretical Tools	Standard metric formulations	**Entropic Action, Vuli-Ndlela Integral, Entropic Time Limit**
Quantum Mechanics Connection	Quantum mechanics and gravity are separate	**Entropy governs quantum evolution, leading to deterministic quantum mechanics**
Planetary Motion	Governed by Newtonian gravity or General Relativity or [**mysterious**] **unphysical fields**	**Motion arises from natural, physical entropy gradients shaping paths**
Black Hole Radiation	Quantum vacuum fluctuations lead to Hawking radiation	**Entropic redistribution converts gravitational and other energies into radiation and other information forms**
Black Hole Information	Information paradox exists	**No paradox: entropy naturally redistributes information and energy**
Galactic Rotation Curves	Explained using dark matter	Explained as a large-scale entropy effect
Event Horizon Dynamics	Black holes shrink and evaporate over time	**Black holes evolve via entropy constraints, evaporating until they leave entropic cores; the event horizon is an "entropic envelope" for redistribution**

Table 2: Comparison of ToE with Existing Theories

L.8 List of Researchers on Other Theories & Investigations Relevant to Gravity from Entropy - see above Table 2 L.7:

1. Carlo Rovelli[20] (1998) proposed the thermal time hypothesis, which connects thermodynamic time emergence with quantum gravity, hinting at an entropic foundation for spacetime.
   - **Similarity:** Both ToE and Rovelli's hypothesis emphasize that time emerges from entropy.
   - **Difference:** Rovelli assumes an underlying quantum gravity structure, whereas ToE treats entropy as the fundamental governing field.
   - **Unique Value of ToE:** ToE proposes a direct entropic field actively shaping spacetime rather than merely correlating entropy with time.
2. Curtis Callan and Frank Wilczek[4] (1994) contributed to black hole thermodynamics by exploring the role of quantum fields in black hole entropy, reinforcing the link between entropy and gravitational horizons.
   - **Similarity:** Both reinforce the connection between entropy and black hole physics.
   - **Difference:** Their work is based on standard quantum field theory, while ToE suggests entropy drives black hole dynamics.
   - **Unique Value of ToE:** ToE proposes that black holes evaporate due to entropy-driven constraints in the redistribution of energy and information rather than quantum fluctuations.
3. Dil Emre and Yumak Tugru[8] (2019) investigated the entropic nature of gravity and thermodynamic principles in emergent gravity models, offering insights into how information and entropy govern gravitational interactions.
   - **Similarity:** Both suggest that gravity emerges from entropy and information constraints.
   - **Difference:** They work within thermodynamic gravity, whereas ToE establishes entropy as a physical field.
   - **Unique Value of ToE:** ToE treats entropy as a primary interaction, unlike standard emergent models.
4. Erik Verlinde[26] (GR, Entropic Gravity & the Laws of Newton) (2011) introduced the concept of entropic gravity, proposing that Newtonian gravity and general relativity emerge from the statistical behavior of microscopic degrees of freedom.
   - **Similarity:** Both ToE and Verlinde's theory propose that gravity is an emergent phenomenon from entropy.
   - **Difference:** Verlinde's model uses statistical mechanics, inertia, and holography, while ToE defines an actual entropic force-field in the description of all natural phenomena.
   - **Unique Value of ToE:** The *Vuli-Ndlela Integral* of ToE enforces entropic constraints in fundamental physics beyond statistical mechanics.
5. Ginestra Bianconi[2] (2025) explored gravity as an emergent phenomenon arising from network [Araki quantum relative] entropic principles, extending statistical mechanics approaches to spacetime structure via a [Dirac-Kähler formalism of a] Topological Bosonic G-field.

- **Similarity:** Both incorporate entropy in spacetime structure.
- **Difference:** Bianconi's approach is network-based, with emphasis on geometric interplay between spacetime and matter, while ToE describes entropy as a natural, physical field from which geometry and matter are emergent properties.
- **Unique Value of ToE:** ToE is independent of network models. Rather, entropic constraints dictate the network where [if] the network exists physically.

6. Goffredo Chirco, Hal M. Haggard, Aldo Riello, and Carlo Rovelli[7] (2014) studied the thermodynamic properties of spin networks, linking quantum gravity with statistical entropy formulations of spacetime.

   - **Similarity:** Both link quantum gravity and statistical entropy.
   - **Difference:** Spin networks describe microscopic spacetime, while ToE sees entropy as the primary driver.
   - **Unique Value of ToE:** ToE does not rely on spin networks. Like in the comment above on the Bianconi network model, it is entropy that dictates the spin network where [if] it physically exists.

7. Jacob David Bekenstein[1] (1973) formulated the Bekenstein-Hawking entropy law, establishing that black hole entropy is proportional to its event horizon area, thereby linking thermodynamics and black hole physics. This laid the foundation for entropy-based gravity theories. Building on this, Stephen Hawking (1975) demonstrated that black holes emit thermal radiation (Hawking Radiation), further connecting black hole thermodynamics to quantum mechanics.

   - **Similarity:** Both recognize black hole entropy as fundamental.
   - **Difference:** Bekenstein assumes a fixed spacetime metric, while ToE derives spacetime from entropy.
   - **Unique Value of ToE:** ToE treats entropy as an active, dynamic force-field, not a [statistically] derived quantity, thus reformulating the second law of thermodynamics as a universal generator and driver of all fields and interactions.

8. Jun Chen[6] (2020) examined quantum entanglement entropy's role in gravitational dynamics, contributing to the understanding of how entropy constrains spacetime geometry.

   - **Similarity:** Both link entropy and gravitational systems.
   - **Difference:** Chen focuses on entanglement entropy, while ToE introduces an independent entropic field.
   - **Unique Value of ToE:** ToE applies to all interactions, not just quantum entanglement.

9. Sean M. Carroll and Grant N. Remmen[5] (2016) analyzed the connection between entropy, complexity, and the emergence of gravitational laws, particularly focusing on holographic and thermodynamic interpretations.

   - **Similarity:** Both connect entropy with gravity.
   - **Difference:** Carroll's work relies on holography, while ToE does not.
   - **Unique Value of ToE:** ToE extends beyond holography, providing a broader entropy-based framework.

10. Shinsei Ryu and Tadashi Takayanagi[21] (2006) formulated the Ryu-Takayanagi formula, which relates entanglement entropy to spacetime geometry, strengthening the connection between entropy and gravitational field dynamics.

    - **Similarity:** Both relate entropy to spacetime.
    - **Difference:** Ryu-Takayanagi formula applies to AdS/CFT and is dependent on it, while ToE does not.
    - **Unique Value of ToE:** ToE generalizes entropy without relying on holography and the AdS/CFT Correspondence.

11. Stephen Hawking[12] (1975) derived Hawking radiation, proving that black holes emit thermal radiation due to quantum effects, cementing the relationship between entropy, quantum mechanics, and gravity in his revolutionary paper of 1975.

    - **Similarity:** Both link entropy, quantum mechanics, and black holes.
    - **Difference:** Hawking radiation is derived from quantum fields, while ToE suggests entropy-driven gravitational energy conversion.
    - **Unique Value of ToE:** ToE proposes a new mechanism for black hole evaporation as entropic constraints in the redistribution of energy and information from within an entropic envelope.

12. Ted Jacobson[13] (1995) derived Einstein's field equations from thermodynamic principles, showing that spacetime dynamics can emerge from entropy and information flow constraints.

    - **Similarity:** Both derive gravity from entropy.
    - **Difference:** Jacobson assumes thermodynamics as fundamental, while ToE postulates an entropic field.
    - **Unique Value of ToE:** ToE redefines gravity without assuming thermodynamic analogies, but emphasizes that entropic constraints constitute a real physical field.

13. Thanu Padmanabhan[19] (2010) developed the idea that gravity is an emergent thermodynamic phenomenon, arguing that Einstein's equations resemble an equation of state for spacetime degrees of freedom.

    - **Similarity:** Both suggest gravity emerges from entropy.
    - **Difference:** Padmanabhan assumes thermodynamic relations, while ToE defines entropy as a fundamental force-field.
    - **Unique Value of ToE:** ToE provides a new entropic field-theoretic approach.

14. Thomas Faulkner, Aitor Lewkowycz, and Juan Maldacena[11] (2013) advanced the holographic entropy framework by refining the entanglement entropy approach to gravity, supporting entropy-driven spacetime emergence theories.

    - **Similarity:** Both use entropy to describe spacetime.
    - **Difference:** Their work is constrained to AdS/CFT, while ToE is universal.
    - **Unique Value of ToE:** ToE applies beyond holography.

Etc.

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L.9 Paradigm Shift: From Geometry to Entropy - refer to Table 3 below

Concept	**General Relativity**	**Theory of Entropicity (ToE)**
Fundamental agent	Curved spacetime geometry	Entropic field generated by mass [that is, internal entropy]
Governing principle	Geodesic motion in curved spacetime	Entropic path minimization under constraints
Cause of deflection	Geometry of spacetime	Entropic constraints directing motion
Photon path	Null geodesic	Least entropic resistance path

Table 3: Conceptual Shift from General Relativity to the Theory of Entropicity (ToE)

Thus, the Theory of Entropicity (ToE) naturally introduces irreversibility and information[and energy]flow into gravitational effects - something GR is mute about.