Verlinde in the Elevator: A Thermodynamic Review

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1 Introduction

Einstein's elevator remains one of the most iconic thought experiments in physics, illustrating the equivalence principle: an observer inside a sealed elevator cannot distinguish whether the force they experience stems from gravitational attraction or uniform acceleration. This implies a profound connection between inertia and gravitation, traditionally interpreted through the geometry of spacetime in general relativity. However, inspired by Verlinde's entropic gravity proposal [1], we revisit this connection from a purely classical thermodynamic perspective, reimagining the elevator not just as a geometric construct but as a thermodynamic laboratory.

Verlinde suggested that gravity emerges as an entropic force, driven by the statistical tendency of microscopic degrees of freedom to maximize entropy in the presence of mass [1]. While his framework relies on holographic principles and information theory, we propose a simpler, classical alternative: gravity as a thermodynamic response of a system in free fall, modeled as a compact thermometer within the elevator. By focusing on the interplay of energy conservation, dissipative effects, and entropy gradients, we aim to reproduce Newtonian gravity without invoking quantum mechanics or speculative microphysics.

Our approach begins with the elevator's equivalence principle as a thermodynamic equivalence. We explore how a classical system, subjected to gravitational acceleration or its inertial counterpart, exhibits internal heating—interpreted as a consequence of energy redistribution akin to the gravitational blueshift of classical waves. This heating drives an entropy gradient, yielding an effective force consistent with Newton's inverse-square law. Unlike previous critiques of entropic gravity [2, 3], which highlight quantum inconsistencies or energy conservation issues, our model remains firmly rooted in macroscopic thermodynamics, offering an intuitive and pedagogically valuable reinterpretation of gravitational attraction as a classical emergent phenomenon.

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2 Introduction

3 Heat Capacity and Self-Heating in Free Fall

We consider a compact thermodynamic system—modeled as a thermometer—freely falling in a gravitational field, or equivalently, residing within Einstein's accelerating elevator. Classically, free fall is an inertial motion, implying no local work is done on the system. However, from a global perspective, the gravitational potential energy decreases as the system approaches the central mass. We investigate whether this energy shift can manifest as internal heating, driven by classical thermodynamic processes rather than quantum effects.

A key feature of our model is the system's response to acceleration, which we propose mimics the behavior of gravitationally bound systems with negative heat capacity [4]. Unlike macroscopic stellar clusters, a compact thermometer lacks significant self-gravitation. Instead, we suggest that tidal forces or dynamic compression, induced by the gravitational gradient, could effectively endow the system with a negative heat capacity-like response. As the thermometer falls, these forces subtly alter its internal energy distribution, leading to a temperature increase.

Using the Newtonian potential $\Phi(r) = -\frac{GMm}{r}$, the change in potential energy from r_0 to r is:

$$\Delta\Phi = -\frac{GMm}{r} + \frac{GMm}{r_0}.$$

Assuming total energy conservation, this loss corresponds to an increase in internal energy:

$$\Delta U = -\Delta\Phi = \frac{GMm}{r} - \frac{GMm}{r_0}.$$

If the system exhibits an effective negative heat capacity $C < 0$, the temperature change becomes:

$$\Delta T = \frac{\Delta U}{C} = -\frac{1}{|C|}\left(\frac{GMm}{r} - \frac{GMm}{r_0}\right),$$

indicating a temperature rise as r decreases. This self-heating, akin to the blueshift of classical waves in a gravitational field, arises without external work, purely as a dissipative response to the field's gradient.

In the elevator, an observer under uniform acceleration $a = g$ perceives an equivalent force. Dissipative processes—such as internal friction or compression—could similarly convert this perceived energy shift into heat, reinforcing the thermodynamic equivalence of gravitation and acceleration.

4 Deriving Gravity from Entropic Arguments

Building on the self-heating observed in a freely falling thermometer, we now derive an effective gravitational force using classical thermodynamics within the elevator framework. We propose that the temperature increase, driven by dissipative processes, generates an entropy gradient that manifests as an attractive force. This approach aligns with Verlinde's entropic concept [1] but avoids holographic assumptions, grounding itself in macroscopic energy redistribution.

The thermodynamic force arises from the relation:

$$F = T\frac{dS}{dR},$$

where T is the system's temperature and $\frac{dS}{dR}$ the entropy gradient with respect to radial position R. As the thermometer falls, its internal energy increases due to the gravitational blueshift-like effect, interpreted classically as energy dissipation from the potential gradient. We define the heat absorbed as:

$$\Delta Q = -\Delta U = \frac{GMm}{R},$$

reflecting the conversion of potential energy into thermal energy. The entropy change follows:

$$\Delta S = \frac{\Delta Q}{T(R)}.$$

Assuming a temperature scaling inspired by classical dynamics in a gravitational field, such as $T(R) \propto \frac{1}{R}$—motivated by the increasing energy density as R decreases—we obtain:

$$\Delta S \propto GMm.$$

This suggests a constant entropy gain per radial step, leading to:

$$\frac{dS}{dR} \propto -\frac{GMm}{R^2},$$

since entropy increases as R decreases. Combining with $T \propto \frac{1}{R}$, the force becomes:

$$F = T\frac{dS}{dR} \propto \frac{1}{R} \cdot \frac{GMm}{R^2} \propto \frac{GMm}{R^2},$$

reproducing Newton's inverse-square law.

In the elevator, an observer under acceleration $a = g$ experiences a similar entropy production due to dissipative heating, yielding an equivalent force. This classical derivation hinges on energy conservation and dissipation, offering a thermodynamic reinterpretation of the equivalence principle without requiring quantum or informational constructs.

5 Comparison with Standard Models

In classical physics, gravity is a fundamental force described by Newton's law:

$$F = \frac{GMm}{r^2}.$$

In general relativity, it emerges from spacetime curvature, with freely falling bodies following geodesics and no inherent thermodynamic change in the absence of external work. Our model, however, posits gravity as an emergent thermodynamic effect tied to entropy gradients in systems undergoing gravitational or inertial acceleration.

Unlike geometric models, our approach links the force $F = T\frac{dS}{dR}$ to internal heating from dissipative processes, such as those induced by tidal gradients or acceleration-induced compression. With $T \propto 1/R$ and an entropy gradient driven by energy redistribution, we recover Newton's law in the weak-field limit. This aligns conceptually with Verlinde's framework [1] but relies solely on classical mechanics and thermodynamics.

In the elevator, the equivalence principle manifests as a thermodynamic symmetry: whether falling in a gravitational field or accelerating at $a = g$, the system's heating and entropy production yield an identical force. This contrasts with standard models, where thermodynamic properties are incidental, not causative. Our classical perspective thus reframes gravity as a macroscopic response to acceleration, bridging the elevator's inertial and gravitational interpretations through energy dissipation.

6 Discussion

We have outlined a classical thermodynamic framework where gravity emerges from entropy gradients in a freely falling system, reimagining Einstein's elevator as a setting for thermodynamic equivalence. By leveraging energy conservation and dissipative heating—interpreted as a classical analog to gravitational blueshift—we derive a force mimicking Newtonian gravity. This approach retains the simplicity of classical physics while offering an intuitive explanation for the universality of gravitational acceleration: all systems responding dissipatively to a potential gradient exhibit a consistent force.

The model's reliance on effective negative heat capacity, induced by tidal forces or compression, remains a key assumption. While plausible for compact systems under dynamic conditions, it requires further exploration to confirm its applicability beyond self-gravitating scales. The transition from potential energy to internal heat, though consistent with global conservation, hinges on dissipative mechanisms that warrant detailed study.

Nonetheless, this framework reframes the equivalence principle as a statement about thermodynamic response, not just inertial symmetry. It provides a classical lens for phenomena like acceleration-induced heating, offering a pedagogical bridge between traditional mechanics and emergent gravity concepts without speculative microphysics.

7 Outlook

Future work could refine this classical thermodynamic model by:

- **Experimental Tests:** Measuring dissipative heating in freely falling or accelerated systems with tunable properties, such as viscous materials, to validate internal temperature changes.
- **Detailed Mechanisms:** Investigating how tidal forces or compression induce effective negative heat capacity in compact systems, using classical simulations.
- **Pedagogical Value:** Developing this framework as a teaching tool to connect classical thermodynamics with gravitational concepts.

In this view, Einstein's elevator becomes a classical laboratory for exploring gravity's thermodynamic roots, grounded in the first law and the equivalence principle.

Classical Consistency and Future Integration

The results presented in this paper build on classical thermodynamic reasoning and are consistent with the broader attempt to reformulate gravity as an emergent, entropy-driven phenomenon. Unlike speculative modifications of general relativity or quantum gravity, the approach here stays within the well-tested regime of thermodynamic laws, negative heat capacities, and energy conservation in gravitational systems.

This thermodynamic perspective is complementary to and consistent with more advanced dual-holographic models proposed by the author [5, 6], which explore the emergence of space, time, and cosmological expansion from a thermodynamic domain wall between AdS-like and dS-like regions. There, gravitational attraction and repulsion emerge from entropy gradients across a scalar kink field Φ, while the present analysis provides a simplified classical foundation from which such effects become plausible.

In parallel, the entropic quantum gravity (EQG) framework developed by Ginestra Bianconi and collaborators [7, 8, 9] provides a network-theoretic approach to quantum gravity, in which space and time emerge from entropic optimization principles. While EQG emphasizes the statistical structure of quantum spacetime, both approaches share the underlying assumption that gravity arises from the thermodynamic behavior of microstates.

The classical derivation presented here supports this broader direction of research. It shows that even within a fully classical and non-quantized setting, the assumption of negative heat capacity and thermodynamic self-heating suffices to generate an effective gravitational force. This strengthens the case for entropic gravity as a viable alternative framework, consistent with existing observations and open to further refinement at both classical and quantum levels.

References

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