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Contradictory Paradigms – Thermal Equilibrium vs Conservation of Mechanical Energy

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ABSTRACT

This study explores the impact of the gravitational field on the distribution of kinetic and potential energies in gaseous systems. It is proposed that in an isolated system under gravitational influence, the initial thermal equilibrium evolves into a state where the deeper regions of the system exhibit higher temperatures than its periphery, challenging classical thermodynamic principles. This phenomenon is analyzed in the context of stellar formation and an idealized gas cloud, concluding with the necessity to reconsider traditional thermodynamic postulates or deepen our understanding of gravity.

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Foundations

There are two fundamental principles routinely applied to describe the macroscopic behavior of the physical universe:

1. Under the action of conservative forces, the mechanical energy (i.e., the sum of the kinetic and potential energy of a system of bodies) remains constant.
2. When two or more objects with different temperatures come into contact, they exchange heat until thermal equilibrium is reached.

If we take these two principles as premises of a syllogism and analyze the behavior of a column of gas at constant temperature—where molecules are constantly rising and falling due to intermolecular collisions—we must conclude that the molecules descending toward the base of the column have only two options:

- Either they preserve their mechanical energy by converting potential energy into kinetic energy (which implies an increase in temperature), or
- They maintain their temperature (i.e., kinetic energy) while losing mechanical energy due to a reduction in potential energy.

An equivalent situation applies to molecules ascending the column: they either gain mechanical energy or lose kinetic energy (i.e., cool down).

Thus, the situation leads us to one of two possible scenarios:

1. Gravity has no effect on the vertical components of molecular velocity during collisions. This would imply that what holds true for macroscopic particle collisions does not apply at the molecular scale.
2. Gravity does influence the vertical components of velocity in every molecular collision. In this scenario, a gas column initially at uniform temperature would spontaneously evolve into one with a warmer base and a cooler top.

Since gravity is a classic example of a conservative force—because the work it does to move a body from one point to another is independent of the path taken—we are forced to conclude that one of the two initial premises requires deeper examination.

Introduction

Thermodynamics, one of the foundational branches of physics, emerged in the 19th century [1,2] in response to the need to understand and optimize heat engines that converted thermal energy into work. Its basic principles, developed through empirical observations, provide a solid framework for describing energy exchange in physical systems. Along the way, the kinetic theory of gases was developed, linking temperature to the average kinetic energy of molecules [3].

Simply put, the first law of thermodynamics states that energy can neither be created nor destroyed—only transformed. Heat and work are two manifestations of this energy transfer. The second law asserts that it is impossible to extract heat from a source at a given temperature and convert it entirely into work without producing other changes in the system or its surroundings. This introduces the concept of entropy: in any thermodynamic process, the entropy of an isolated system tends to increase, thereby limiting energy conversion efficiency. The third law states that it is impossible to reach absolute zero temperature, where the entropy of a perfect crystal would be zero.

Within this context, thermal equilibrium in an isolated system implies the absence of temperature differences among its parts. However, this concept deserves reconsideration in the presence of gravitational fields, where variations in potential energy may lead to kinetic energy shifts, resulting in non-uniform temperature distributions—even in isolated systems.

Although this issue was discussed by J. Loschmidt, who had a historical debate with Maxwell on thermal equilibrium in gas columns, this work introduces new elements to deepen the discussion with elements that were not previously addressed, largely because the systems originally studied (like most that shaped thermodynamics) were bound to Earth's surface and its immediate surroundings [4].

Subsequent studies have revisited this topic, and today it remains the subject of ongoing debate in various online forums [5]. Indeed, many scientists believe the original controversy remains unresolved.

To further develop Loschmidt's analysis—originally applied to systems where the gravitational field was external to the gas column—this paper examines an isolated system in which a gas cloud generates its own gravitational field, as proposed in cosmological models of stellar formation.

The objective is to examine the impact of gravity on what we currently define as classical thermodynamic theory.

The Impact of Gravity on Thermodynamics

As noted earlier, gas temperature is directly linked to the average molecular speed but, in a gravitational field, the mechanical energy of each molecule combines kinetic and potential components. Analogous to a vertical projectile, ascending molecules lose kinetic energy as they gain potential energy.

Therefore, since potential energy does not appear in the Boltzmann equation [3], a significant number of gas molecules gaining altitude should exhibit a temperature drop.
In Earth's atmosphere, this effect is evident, but such a system cannot be considered isolated due to the influence of Earth's external gravitational field and internal/external energy sources.

Accordingly, we now analyze a gas cloud isolated from both thermal and gravitational influences of other systems.

Conceptual Analysis: An Isolated Gas Cloud

For an initial qualitative analysis, we can imagine an ideal gas cloud (whether helium or molecular hydrogen are conceptually equivalent) at low pressure and far from any material sources that could affect it via gravity or significant electromagnetic radiation.

To simplify further, let us assume the gas cloud is enclosed within a large spherical shell that acts as both a thermal and physical insulator.

The shell's size and the gas mass can be arbitrary. In this scenario, if the gas is at the lowest possible temperature (very close to absolute zero), then—according to thermodynamic principles—it should be impossible to extract any useful work from such a system. It represents an extremely low-pressure, low-temperature source, devoid of thermal gradients.

However, this idealized configuration conceptually resembles the interstellar gas clouds that give rise to star formation. Since the pioneering work of James Hopwood Jeans [6]—whose analysis of dynamic stability and gas cloud fragmentation led to the concept of the "Jeans length"—it has been accepted that an interstellar cloud may spontaneously collapse under gravity when its size exceeds a critical threshold.

This collapse results in astonishing amounts of mechanical energy and local temperature increases. This fact alone challenges the compatibility between gravity and classical thermodynamic principles—but we can push the analysis further by considering that some fragments from the original cloud may not reach the temperatures required to initiate nuclear fusion.

By isolating one of these fragments and analyzing its behavior, we can expand on Loschmidt's original inquiry.

This planetary-mass fragment can also be studied within a similar insulating spherical shell.

At the end of the gravitational collapse, we would observe a hot core (ranging from thousands to hundreds of thousands of degrees Kelvin, depending on the fragment's mass) surrounded by a cooler region (possibly near the original gas cloud's temperature), where molecular mechanical energy remains as potential energy, without conversion into kinetic energy as occurred for molecules "absorbed" by the core.

Assuming perfect isolation, the key question is whether the system will preserve the resulting thermal gradient or, in line with thermodynamic paradigms, evolve toward uniform temperature. In a sense, this question restates Loschmidt's original dilemma, but now in a system where the gravitational field is generated by the gas cloud itself—free of external interactions.

First Scenario – Thermal Equilibrium

In this case, the system is assumed to evolve toward uniform temperature. This implies that molecules escaping the gravitational core would gain potential energy without losing kinetic energy. Similarly, molecules falling toward the core would lose potential energy without gaining kinetic energy.

Such a scenario would violate the principle of conservation of energy and contradict the very mechanism responsible for generating the hot core in the gravitational collapse. The contradiction is clear.

Second Scenario – Thermo-Gravitational Equilibrium

Here, the system's final state preserves the thermal gradient generated by the collapse. Since the system is isolated, there is no energy loss via external radiation; any emitted radiation would be reflected back by the spherical shell.

In this case, the persistence of the thermal gradient would allow continuous work extraction mechanisms, thereby contradicting the second law of thermodynamics. If the system restored the temperature gradient through the same mechanisms that created it (without external inputs), it would become either an inexhaustible energy source—or, if it depleted its own internal energy, an example of a self-cooling isolated system.

Discussion

The first described scenario is untenable because it contradicts the well-established gravitational collapse mechanism used to explain stellar formation, which relies on the conversion of potential to kinetic energy to reach high temperatures.

The second scenario leads to three possible outcomes for systems extracting work from the gravitationally-induced thermal gradient:

1. The system's average temperature remains constant.

2. The average temperature increases.
3. The average temperature decreases.

In none of these cases would the system reach classical thermal equilibrium—since, once work extraction ceases, the system would reestablish the original temperature gradient. Therefore, none of these possibilities are compatible with traditional thermodynamics.

This analysis therefore suggests the need to:

- Reconsider thermodynamic principles to accommodate possible exceptions involving gravitational potential energy.
- Explore a deeper theory of gravity that could explain the apparent ability to extract indefinite energy from a thermodynamic equilibrium.

This second point may require a complete reformulation of thermodynamic laws—or may imply that gravity itself undergoes some form of degradation in scenarios such as those examined in this brief article.

Conclusions

The phenomenon of thermo-gravitational equilibrium challenges classical thermodynamic paradigms.

The analysis of idealized systems, such as an isolated gas cloud, shows that when only conservative forces are at play, it may become impossible to simultaneously satisfy the principles of mechanical energy conservation and thermal equilibrium.
Given that thermodynamic laws were originally developed in contexts where no gravitational fields were created during the process (but rather relied on pre-existing fields), these analyses open the door to new research on the interaction between gravity and thermodynamics.

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