The Restoration Principle

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Abstract

The second law of thermodynamics is widely regarded as a universal principle, yet its scope is limited. Entropy increases as components disperse in systems dominated by repulsive forces; but, in domains governed by attractive forces, such as gravity, entropy can instead decrease—a phenomenon evident in the condensation of stars and galaxies from diffuse matter. This explains why the universe has avoided "heat death", instead developing increasingly organized structures. Moreover, the second law addresses only directional progression, whereas many natural processes exhibit periodic oscillations, suggesting it captures only part of nature's dynamics. To address these limitations, we propose the **Restoration Principle**, which unifies entropy-increasing, entropy-decreasing, and oscillatory processes. Owing to mass–energy equivalence, all entities exist as forms of energy, with matter as a concentrated manifestation. Every process involves the transformations and redistributions of energy. Each system evolves toward a characteristic balance at a given energy level, its *balanced energy distribution*. The total energy determines the forms and distributions of energy, which in turn dictate the dominant forces that maintain or restore this balance. Disturbances trigger spontaneous restorative dynamics, often expressed as oscillations, while external energy inputs can shift the balance and drive progressive development toward a new equilibrium. The Restoration Principle thus provides a unifying framework for diverse systemic behaviors, offering a more fundamental perspective on universal evolution than the second law of thermodynamics.

Introduction

What governs the operation of the universe? A principle often applied to address this question is the second law of thermodynamics, which claims that the entropy of an isolated system never decreases. However, there are challenges to treating it as a truly universal law. First, the second law characterizes the directional, irreversible evolution of systems, whereas many natural systems exhibit reversible dynamics in the form of oscillatory or periodic processes. Second, while entropy often increases under the influence of repulsive forces,[1-8] it can in fact decrease in processes dominated by attractive forces.[9]

To evaluate the claim that entropy can decrease, it is useful to revisit the definition of entropy. In classical thermodynamics, the change in a system's entropy is defined as the infinitesimal amount of heat transferred from the surroundings to the system during a reversible process, divided by the system's instantaneous temperature at the time of transfer:

$$(1) \qquad dS = \frac{dQ}{T}$$

In this definition, T is the absolute temperature of the system, S denotes the entropy, dQ represents the heat transferred, and dS is the resulting change in entropy due to that heat transfer. Later, Ludwig Boltzmann formulated a statistical definition of entropy by examining the microscopic behavior of a system's components. This definition can be expressed in several equivalent forms; one of them is:

$$(2) \qquad S = k_B ln(N)$$

Here, k_B denotes the Boltzmann constant, and N represents the number of all possible microstates of the system. Although Boltzmann is often credited with establishing an equivalence between the thermodynamic and statistical definitions, the two are fundamentally distinct. This difference becomes especially evident near absolute zero. At absolute zero, a system occupies only a single microstate ($N = 1$), the ground state, resulting in zero entropy according to Definition 2.

In contrast, the thermodynamic definition predicts a different outcome: as temperature approaches zero, its reciprocal diverges to infinity, causing the entropy in Definition 1 to also diverge toward infinity. This discrepancy underscores a fundamental mismatch between the statistical and thermodynamic formulations of entropy.

To demonstrate that entropy often increases under the influence of repulsive forces, consider two systems with temperatures T_1 and T_2, where $T_1 > T_2$. When these systems interact, a dQ of heat flows from the higher-temperature system to the lower-temperature one. According to the thermodynamic definition (1), the total entropy change of the two systems is:

$$(3) \qquad dS = \frac{dQ}{T_2} - \frac{dQ}{T_1} = \frac{dQ}{T_1 T_2}\left(T_1 - T_2\right) > 0$$

This demonstrates that the total entropy of the combined system increases through such interactions. A simple example is the melting of ice in a cup of water at room temperature. If we consider the water as system T_1 and the ice as system T_2, the ice will melt, and the entropy of the combined system rises, as described by Expression 3. In this scenario, the reverse process, where water spontaneously assembles into ice, cannot occur.

The increase in entropy in this proof relies on the intuitive assumption that heat always flows down a temperature gradient. This assumption generally holds in systems dominated by repulsive interactions—for example, gases where electrostatic repulsion between valence electrons governs molecular behavior. In such cases, particles tend to disperse, promoting mixing and spontaneous heat transfer along the gradient. The idea that heat naturally follows the temperature gradient has long been treated as an intrinsic property of nature and is implicitly built into models of interacting systems. Under this premise, Expression 3 follows directly, and it is often taken for granted that entropy cannot decrease. However, the assumption breaks down in systems governed primarily by attractive forces.

To demonstrate that the claim that entropy never decreases is not universally valid, it suffices to identify a single case in which heat flows from a lower-temperature system to a higher-temperature one, making the right-hand side of Expression 3 negative. One such example is supercooled water. Supercooled water is liquid water below its freezing point that has not solidified yet. When disturbed, the water begins to freeze. This can occur even in an isolated environment. As it freezes into ice, it releases heat—the potential energy associated with the formation of intermolecular bonds. This released heat is absorbed by the container, warming it. In this case, heat flows from the colder water to the warmer container, rendering the right-hand side of Expression 3 negative, so the entropy of the combined system decreases.

Moreover, because the freedom of molecular motion is constrained by bond formation, reducing the number of accessible microstates, the system's entropy also decreases according to the statistical definition (2). The formation of bonds indicates that attractive electrostatic forces between molecules dominate the process. Compared with the melting ice example, the key difference is that in this low-energy environment, attractive forces dominate the process, causing heat to flow against the temperature gradient.

This type of anti-gradient heat flow is exploited in a commercial product known as a heating pad. The pad contains a supersaturated solution of sodium acetate in water sealed within a plastic bag, along with a stainless steel disc. Flexing the disc, analogous to disturbing supercooled water, initiates the crystallization of sodium acetate. The rapid release of bond energy warms the pad. Sodium acetate (CH_3COONa), the sodium salt of acetic acid, forms trihydrate crystals that melt at approximately 58–58.4 °C. When the pad is placed in hot water, these crystals melt normally. Upon slow cooling, the solution becomes supersaturated at room temperature without crystallizing. Similar to the supercooled water scenario, the resulting entropy decrease and anti-gradient heat flow are governed by attractive intermolecular forces.

Similar decreases in entropy and anti-gradient energy flows are also common in the evolution of celestial bodies under the influence of gravity. Take Earth as an example: if we consider Earth as system T_1 and the rest of the universe as system T_2, then tracing backward in time reveals a warmer Earth dispersing into a cold cosmic cloud. This entropy increase resembles the case of ice melting in water. However, when viewed as a combined system moving forward in time, Earth and the universe evolve toward a net decrease in total entropy. This demonstrates that energy flow does not always follow a decreasing temperature gradient; it can instead proceed in the opposite direction. On cosmic scales, according to both statistical and thermodynamic definitions of entropy, the evolution of the universe, from the formation of stars to the clustering of galaxies, appears to favor lower-entropy states, rather than the uniform particle and energy distribution predicted by the "heat death" scenario.

Thus, entropy may increase or decrease depending on the dominant forces within a system. Furthermore, the evolution of systems in the universe does not invariably follow the single, unidirectional trajectory implied by the second law of thermodynamics; it can also exhibit periodic oscillations. More critically, the second law fails to capture the fundamental nature of universal dynamics—the continuous transformation and redistribution of energy—a principle more accurately embodied by the Restoration Principle.

The Restoration Principle

According to Einstein's principle of mass–energy equivalence, everything in the universe exists in some form of energy, with matter itself being a concentrated manifestation. The evolution of any system is driven fundamentally by the transformation of its energy. Such transformations tend either to restore or to oscillate around a balanced distribution of energy. The **Restoration Principle** posits that nature exhibits an inherent tendency for systems to evolve toward such balance, defined by a characteristic ratio among different forms of energy at a given total energy level. This balance emerges through continuous energy transformations as the system seeks greater dynamic stability. It reflects the interplay of competing internal drives, with the dominant force directing redistribution to minimize potential energy while conserving total energy. The core concepts are summarized in the following equations and expressions:

(4) $E = M + D$

(5) $D = U + K + R$

(6) $U{:}K{:}R \succ u{:}k{:}r$

These relations define a system's state of balanced energy distribution at a given total energy. According to Einstein's mass–energy equivalence principle, the total energy (*E*) of a system equals its effective mass (*m*) multiplied by the square of the speed of light (c^2). The effective mass includes not only the system's rest mass but also contributions from all other forms of energy. In Equation 4, this total energy is more informatively expressed as the sum of two components: dynamic energy (*D*) and matter energy (*M*). Here, *M* denotes the energy associated with the system's rest mass at absolute zero, while (*D*) represents the dynamic portion of the system's energy. Temperature typically represents the measurement of radiation level, which is determined by the total dynamic energy of a system, rather than merely the kinetic energy (*K*) of particle motion, as many textbooks mistakenly suggest.[10] Absolute zero corresponds to a state in which dynamic energy (D) disappears. Because potential, kinetic, and radiative energies continuously transform into one another, reaching absolute zero requires all three forms of energy to simultaneously attain their minimum values.[11]

Although the energy bound in matter is not usually reflected in temperature measurements, it can manifest as heat once released. For instance, the potential energy between nucleons is normally confined within matter and treated as part of its mass. During nuclear fusion, this energy is liberated along with a corresponding loss of mass, emitting radiation and giving rise to the extreme temperatures of stars such as the Sun. In positron–electron annihilation, the entire mass of both particles is transformed into radiation. Likewise, any fundamental particle can annihilate with its antiparticle, releasing the full energy of their combined mass. Conversely, in pair production, a high-energy photon interacting near a nucleus can generate an electron–positron pair, illustrating the creation of matter directly from radiant energy.

Although matter energy (*M*) and dynamic energy (*D*) can transform into one another, their forms and distributions within a system are primarily governed by the system's total energy. Just as water can exist as a solid, liquid, or gas, depending on its dynamic energy, typically represented by temperature, matter in celestial systems evolves into distinct states determined by total energy. When a celestial body exceeds roughly 0.08 solar masses, gravitational collapse becomes strong enough to overcome Coulomb repulsion, bringing nucleons from different atoms sufficiently close for the short-range nuclear force to act. This initiates the process of hydrogen fusion and the birth of a star. Through nuclear fusion, lighter elements combine into heavier ones, progressing up to the formation of iron. Beyond iron, however, nuclei become unstable: Coulomb repulsion among protons outweighs the short-range nuclear attraction, leading heavy elements to undergo fission or radioactive decay into smaller nuclei. Iron thus represents the most stable nucleus and accumulates within stars across successive stellar cycles.

When a star with an initial mass of 8–25 solar masses develops an iron core exceeding the Chandrasekhar limit (~1.4 solar masses),[12-13] electron degeneracy pressure can no longer counteract gravity, and the core collapses. In this process, electrons combine with protons to form neutrons, giving rise to a neutron star in which matter exists predominantly as neutrons. For stars with initial masses above 25 solar masses, the iron core may exceed the Tolman–Oppenheimer–Volkoff (TOV) limit (~2.2 solar masses).[14-16] In such cases, neutron degeneracy pressure, the strong nuclear repulsion force at short distances, is insufficient to resist further collapse, leading to the formation of a black hole. Within a black hole, matter is thought to be compressed to a singularity of effectively infinite density. Its gravitational field is so strong that not even light can escape, rendering direct observation impossible. Instead, black holes are inferred indirectly from the motion of nearby stars and from radiation emitted by accreting matter. These transformations illustrate the universe's tendency to evolve toward characteristic forms of matter and energy distributions under given energy conditions.

Stars with masses insufficient to exceed the Chandrasekhar limit eventually evolve into white or red dwarfs. Objects with masses below about 0.08 solar masses cannot initiate nuclear fusion at all and thus remain as planetary bodies, such as Earth. In such systems, gravitational forces are no longer the dominant factor determining the form of matter. Instead, Coulomb interactions, dominant at microscopic scales, govern the structure and behavior of matter. Because electrostatic forces can be both attractive and repulsive, and because elements can combine in countless ways, an immense diversity of materials arises. Depending on their dynamic energy levels, matter may exist in solid, liquid, or gaseous states, and myriad chemical reactions occur among different compounds. Within this spectrum of energy states, especially under Earth's unique conditions, life can emerge from material complexity, and intelligence can evolve from living systems.

Unlike large-scale systems dominated by gravity, where transformations from matter energy (M) to dynamic energy (D) are common, systems governed by Coulomb forces evolve primarily through transformations and exchanges among potential energy (U), kinetic energy (K), and radiative energy (R) within the broader dynamic energy (D), as described in Equation 5. These exchanges continually adjust the relative proportions of the three forms of energy, tending toward a stable configuration characterized by the balance ratio (u:k:r), as expressed in Equation 6. For an isolated system at a given dynamic energy level, this ratio remains effectively constant. Within a particular phase (solid, liquid, or gas), the ratio typically falls within a narrow range. Any deviation from this balance initiates internal exchanges among the three energy forms to restore equilibrium, a process often manifesting as periodic oscillations around the balance point. By contrast, long-term progressive developments usually reflect transitions from one equilibrium state to another, typically triggered by shifts in the system's overall dynamic energy. In all cases, the system evolves toward a balanced distribution among its energy forms.

It is important to emphasize that temperature reflects a system's radiative energy, not its kinetic energy. The level and relative proportion of radiative energy are determined by the system's total dynamic energy, which in turn dictates the dominant forces controlling the state of matter—solid, liquid, or gas. At low dynamic energy levels, Coulomb attraction between molecules dominates, forming bonds and increasing the system's potential energy. To sustain high potential energy under low temperatures, water crystallizes into the solid state. Similarly, the direction of a chemical reaction is governed by the system's dynamic energy: the input of radiative energy to a heat-sensitive reaction can shift its course by altering the balance among energy components. Likewise, changing the quantities of reactants or products modifies the potential energy contributions and, thereby, the overall energy balance. In short, a system's total dynamic energy determines both the balance ratio of its energy components and its state of matter.

Changes in entropy—whether increase or decrease—reflect a system's tendency to restore a balanced energy distribution at different energy levels. At low energy levels, attractive forces dominate, promoting the formation of additional bonds between particles and the storage of greater potential energy. In such conditions, balanced distributions are typically characterized by a high proportion of potential energy. Under these forces, particles tend to aggregate, reducing the number of accessible microstates and thus lowering entropy. This behavior explains the spontaneous formation of crystals and solid matter at low temperatures, as well as why celestial systems evolve from diffuse cosmic clouds into stars and galaxies under gravity, resulting in a decrease in entropy rather than a progression toward “heat death”.

At high dynamic energy levels, repulsive interactions between particles, primarily arising from Coulomb repulsion, become dominant, breaking bonds and dispersing the system. This accounts for why substances melt or vaporize at high temperatures, processes that are accompanied by an increase in entropy. As bonds are broken, potential energy contributions diminish, lowering the potential share within the dynamic energy while relatively increasing other energy forms. From the perspective of the Restoration Principle, such entropy increases represent the system’s response to reestablish a balanced energy distribution under high energy conditions.

This principle likewise helps explain why many objects degrade over time—a process often described as an increase in entropy. Such materials are typically formed under conditions of different energy, and their eventual breakdown reflects the system’s natural tendency to reestablish a balanced energy configuration at a new energy level. For instance, polylactic acid (PLA), a bioplastic derived from cornstarch, is synthesized at high temperatures of approximately 170–200 °C. Once at room temperature, the energy level shifts; to restore balance at this lower level, PLA undergoes hydrolysis of its ester bonds, resulting in rapid degradation. Yet not all natural processes follow the path of breakdown. Crystallization, for example, reflects the opposite trend: the system becomes more ordered and stable, representing another manifestation of the Restoration Principle.

Introduction to Balanced Energy Distribution

A central idea of the Restoration Principle is **balanced energy distribution**—a stable ratio among the different forms of energy in a system at a given total energy. Within any system, energy continually transforms from one form to another, including energy in the form of matter, and the share of each form typically fluctuates around a characteristic balance point. At this point, the ratio among these proportions remains constant for the system. When the distribution deviates from this balance ratio, the system tends to restore it—the greater the departure, the stronger the restoring drive. Thus, a system’s evolution either converges toward this balance or oscillates around it, but its overall trajectory is always directed toward restoring its balance.

Potential energy, inherently tied to forces, naturally tends to minimize under their influence. Because a system’s total energy is conserved, any reduction in one form of energy must be compensated by an increase in another, shifting the system away from its balanced distribution. When a particular energy form deviates from its equilibrium share, the system restores balance through transformations and compensations among the other forms. Consequently, each form of energy typically oscillates around its characteristic proportion of the total. This balanced distribution acts like a gravitational pull, continually drawing every form of energy back toward its equilibrium level.

To illustrate this concept, consider a pendulum, a simple system governed by gravity. As the pendulum’s potential energy increases, its kinetic energy decreases, keeping the total energy constant. Each form of energy oscillates around a characteristic balance value—a fixed proportion of the system’s total energy. The ratio of these balance values remains unchanged.

For a more advanced example, consider a planet in a circular orbit, where both potential and kinetic energy remain constant. Their ratio is therefore fixed, representing the stable state of orbital motion. However, this balance ratio is not universal—it varies across planetary systems. When potential energy is measured relative to the orbital center, the ratio increases with orbital radius. Moreover, while in this simplified model each form of energy appears constant, in reality, they are never perfectly so, because most planetary orbits are not perfectly circular, and both energies typically fluctuate around their balance values.

Imagine a planet struck from behind by a smaller body, gaining additional energy. This disturbance can cause the planet to oscillate around its mean orbit—a behavior known as epicyclic motion. In this state, both potential and kinetic energies fluctuate about their average values. If the impact is sufficiently strong, the orbit may become elliptical; indeed, most planetary orbits are naturally elliptical rather than perfectly circular. In such cases, a planet's potential and kinetic energies vary periodically around their respective means. As kinetic energy increases, potential energy decreases proportionally, preserving the constancy of total mechanical energy. Focusing on a single component, such as potential energy, one can see it oscillate over time around its balance value. This example also illustrates how an external input of energy shifts the system's **energy balance ratio**.

These are only a few examples of mechanical systems that preserve a balanced energy distribution in stable states governed by gravity. Comparable forms of balance also appear in chemical reactions. Chemical equilibrium is the state of a reversible reaction in which the forward and reverse reaction rates are equal, keeping the concentrations of reactants and products constant over time. At first glance, oscillatory behavior in chemical reactions may seem fundamentally different from that of mechanical systems. In reality, the transformation of matter between reactants and products also entails the redistribution of energy, particularly potential energy stored in different chemical bonds—and, ultimately, matter itself is a form of energy. The energy transformations in chemical reactions are governed primarily by Coulomb forces, which will be the focus of the following sections.

Dynamics of Radiative Energy

As a component of dynamic energy, radiative energy due to gravity was previously neglected because its effect is minimal. However, in the domain of Coulomb forces, its role becomes significant and cannot be ignored. Indeed, it is essential for the transformation and redistribution of dynamic energy among its various forms—processes that lie at the heart of the Restoration Principle.

When a body accelerates, changes in its associated force field can lead to the emission of energy in the form of waves.[17] Each of the fundamental forces gives rise to a distinct type of radiation, with the energy of the emitted radiation reflecting the strength of the force: stronger forces produce higher-energy radiation, whereas weaker forces result in lower-energy emissions. For example, when a charged particle accelerates, such as an electron undergoing an orbital transition, it emits energy as electromagnetic radiation, including visible light.

It is important to note that a purely magnetic wave does not exist. The magnetic field is fundamentally a mathematical construct that arises from the behavior of a changing electric field. The smallest quantum of the magnetic field is associated with the intrinsic spin of the electron, which inherently possesses both north and south magnetic poles. This duality is why isolated magnetic monopoles, magnetic fields with only one pole, have never been observed, indicating that magnetic fields are not physical existences. Nonetheless, the concept of a magnetic field remains a powerful and indispensable part of the mathematical framework for describing electromagnetic phenomena, as formalized in Maxwell's equations.[18] In reality, what propagates through space is only the waves or the changes in electric fields.

Any charged particle in an electric field experiences a force and absorbs the energy carried by the waves of the electric field. Upon absorbing this energy, electrons can be excited to higher orbitals, thereby storing energy. Potential energy is also stored in the bonds between charged particles; as these bonds stretch, they accumulate additional energy.[10] This mechanism explains why materials tend to expand at higher temperatures: bonds stretch to store extra energy between particles.[19] The ability of a spring to store potential energy when stretched is a macroscopic manifestation of this principle. In fact, chemical bonds serve as a more substantial energy reservoir than orbital electrons. Conversely, when a bond contracts, the stored potential energy is released as radiation, analogous to the emission that occurs when an electron transitions to a lower orbital.

The intensity of a system's radiative energy is positively correlated with its potential energy components, which in turn are determined by the strength of the underlying forces. Among the three fundamental forces, gravity is the weakest, which is why gravitational waves carry the least energy; this energy is extremely difficult to detect and has been considered negligible in previous discussions. In contrast, gamma rays—emitted in processes primarily governed by the strong nuclear force—possess the highest energies. Electric waves, generated by interactions between charged particles under Coulomb forces, fall between these extremes. However, because the strength of electric bonds varies widely across different bonds, the energy of electric waves spans an enormous spectrum, from a few kilohertz to over 10^{23} hertz.

Since a charged particle also possesses mass, its acceleration gives rise to waves in both electrical and gravitational fields, each occurring at the same frequency. As a result, every wave of the electrical field is accompanied by a corresponding gravitational wave of identical frequency. In addition to neutrally charged masses distributed throughout the universe, gravitational waves are likely far more prevalent than waves in electrical fields. However, because they carry extremely low energy, these gravitational waves often go undetected, making their presence largely imperceptible.

The first indirect evidence of gravitational waves came in 1974 with the discovery of the Hulse–Taylor binary pulsar. The observed orbital decay of this system matched the predictions of general relativity, which attributed the decay to energy lost through gravitational radiation. The first direct detection of gravitational waves occurred in September 2015, when the LIGO detectors recorded a signal produced by the merger of two black holes.[20] The rotation of the Moon–Earth system around their common center of mass also emits gravitational radiation; however, the energy released is so minuscule that it remains undetectable with current technology.

Through these transitions, energy is continuously transformed and exchanged between potential and radiative forms—one of the fundamental processes governing the dynamics of a system's energy. In the next section, we will examine the mechanisms that facilitate energy exchange between kinetic energy and other forms; together, these mechanisms enable the full transformation of energy among all three forms of dynamic energy. Such processes are especially significant at the microscopic scale, where particle interactions are common and play a critical role.

The Origin and Transformation of Kinetic Energy

The development and evolution of a system are driven by the transformation of its energy, particularly among the three dynamic energies defined in Equation 5. In the previous section, we examined the mechanism of energy exchange between radiative and potential energy. In this section, we focus on other key mechanisms—those that govern the transformation of energy to and from kinetic energy.

At the macroscale, when an object moves from a high-potential position to a lower one, the resulting loss in potential energy is typically converted into kinetic energy, and vice versa. However, the origin of kinetic energy at the microscopic level, such as in particle vibrations, raises a deeper question. This form of kinetic energy arises from a process known as **transimpact**, a side-effect resulting from an atomic electron transition.[21]

Coulomb attraction typically occurs between atoms or molecules nearby. However, when the distance between them becomes too close, electron-electron repulsion increases rapidly. A balance between this repulsion and attraction is reached at a characteristic spacing known as the van der Waals distance. This equilibrium is often disrupted during atomic electron transitions. When an electron absorbs energy, it becomes excited and jumps to higher orbitals, usually within a few nanoseconds or less.[22-23] As the electron cloud expands, the volume of the host atom increases, reducing the distance to adjacent atoms. This sudden decrease in spacing disrupts the established balance and usually leads to an increase in repulsive force, pushing the atoms apart. This effect, illustrated in Figure 1, is known as transimpact.

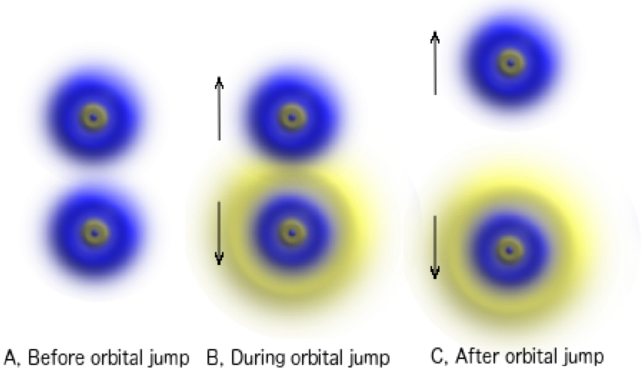

Figure 1: Transimpact due to an atomic electron transition.

Transimpacts are explosive, similar to the sudden burst of popcorn. The resulting momentum delivers significant kinetic energy to adjacent particles, driving them apart and triggering or amplifying their motion. Atomic electron transitions are routine processes at the microscopic scale, continuously occurring in all matter. Consequently, transimpacts are common interactions that influence many aspects of physics, particularly in thermodynamics. They also serve as the underlying mechanism behind phenomena such as Brownian motion,[24-26] phase transitions,[27] and the operation of the Crookes radiometer.[28-32] Therefore, the kinetic energy of microscopic particles originates ultimately from radiative energy and reflects changes in both radiative and potential energy.

Through transimpacts, kinetic energy accumulates within a system, but not indefinitely. There must be a mechanism by which kinetic energy is transformed into other forms of energy, a process referred to as **impactrans**.[21] During this process, the motion or vibration of particles, such as molecules, atoms, or subatomic particles, can cause collisions with adjacent particles through electric interactions, effectively “knocking” their electrons into different, even off, orbitals, thereby changing their potential energy. These impacts also accelerate electrons, leading them to emit radiation. In this way, the kinetic energy of particle motion is transformed into potential and radiative energy.

The conversion of kinetic energy into radiative energy can be observed in many everyday phenomena. For instance, frictional heat results from impactrans: when you rub your palms together, the warmth you feel arises from kinetic energy being transformed into radiation through electrostatic interaction of surface molecules between hands. Similarly, the heating observed at the bottom of a pump tube is also due to the effect of impactrans. Static electricity is generated when electrons are dislodged from atoms, such as when a plastic rod is rubbed against fur.

We have now explored the mechanisms of energy transformation among the various forms of dynamic energy. Under the influence of fundamental forces, potential energy tends to minimize, and the released energy is emitted as radiative energy. High levels of radiative energy increase the likelihood of absorption by potential components, such as orbital electrons and chemical bonds, converting it back into potential energy. This process also enhances the kinetic energy of particle motion through transimpacts. When a system’s kinetic energy is high, the probability of impactrans rises, transforming kinetic energy into other forms. Through these interactions, a system eventually establishes a balanced distribution among its different forms of energy. Whenever the system deviates from this balance, these processes act to restore it.

The Balance Ratio of Dynamic Energy

Dynamic energy continuously transforms and exchanges among its three forms within a system through the mechanisms discussed above. Each type of potential energy is associated with a force that drives the system to minimize that energy, guiding its evolution over time. Although potential energy tends toward a minimum—ideally at absolute zero—the conservation of energy requires that any decrease in one form be compensated by an increase in another, most notably radiative energy. When radiative energy is high, atomic electron transitions and transimpacts intensify, which in turn raise both potential and kinetic energy. Elevated kinetic energy enhances impactranses, further reinforcing potential and radiative contributions. Thus, as long as the system remains above absolute zero, these ongoing exchanges prevent potential energy from reaching its absolute minimum. Instead, the system converges toward a balanced distribution at a stable ratio among the three energy forms. Accordingly, Equation 5 can be expressed by the following set of equations:

(7) $U = uD$
(8) $K = kD$
(9) $R = rD$
(10) $u + k + r = 1$

The ratios among the dynamic energy components, potential (*u*), kinetic (*k*), and radiative (*r*), converge to constant values at the stable state, as described by Expression 6. Within a given phase of matter, these ratios typically show little variation, but they can vary substantially across different phases, as illustrated in Figure 2. Temperature represents a measurement of the radiative energy level, reflecting the overall dynamic energy level of the system. When the distribution among these energy forms deviates from the balance ratio at a specific level of dynamic energy, the system undergoes a spontaneous rebalancing process to restore a steady-state configuration. This rebalancing underlies many of the directional progressions observed in physical systems. Moreover, each energy component may oscillate around its balance value, giving rise to periodic or quasi-periodic fluctuations.

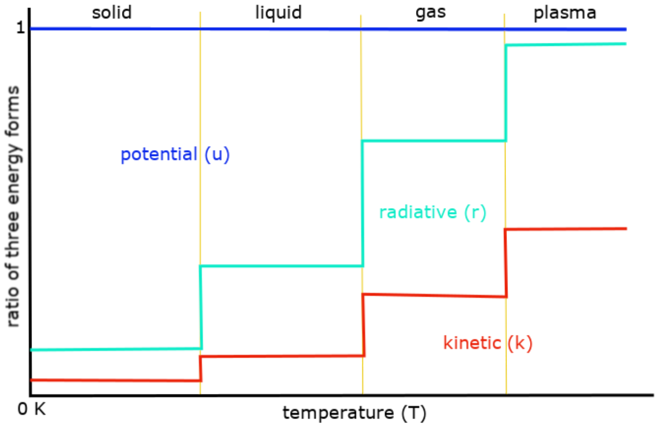

Figure 2: The balance ratio of three forms of dynamic energy at different states

Starting from the left of the figure, absolute zero represents a state in which total dynamic energy is zero.[11] Because dynamic energy continuously transforms among its three forms, this condition requires that *U*, *K*, and *R* are all minimized to zero. For example, even if the kinetic and radiative components are minimized, an electron in an excited orbital can still transition to a lower energy level, releasing potential energy as radiation. This radiation may then be absorbed by another electron, exciting it to a higher orbital. As long as such energy exchanges remain possible, the system has not truly reached absolute zero.

In the solid state, kinetic energy primarily arises from the vibrations of particles, which remain relatively low due to the constraints of molecular bonds. Most dynamic energy is stored as potential. Potential energy is stored in orbital electrons, molecular bonds, and intermolecular bonds. Radiative energy spans a broad spectrum, reflecting the diversity of bonding types. As energy is added to a system, its balance ratio may be temporarily disturbed. A transformation process then redistributes the energy to restore the balance ratio at a higher energy level. A portion of the added energy increases the kinetic motion of particles; some is stored as potential energy in stretched bonds, while the rest contributes to the increase in radiative energy. Although the system's energy shifts to a higher level, the ratio among the three energy forms remains largely stable until the phase transition from solid to liquid begins, typically at a constant temperature.

Phase transitions involve the breaking of intermolecular bonds. When these bonds are stretched to their maximum limit, beyond which further extension leads to rupture, the system undergoes a phase transition. At this point, potential and radiative energy levels plateau, as the bonds can no longer accommodate additional energy. Any further energy input is instead redirected toward breaking the bonds and increasing the kinetic energy associated with molecular motion. Since temperature is primarily determined by a system's potential and radiative energy, it remains unchanged during the transition, even as kinetic energy rises. In this way, temperature is fixed and becomes effectively decoupled from changes in kinetic energy throughout the phase transition.

In the liquid state, the partial breaking of intermolecular bonds reduces the system's capacity to store potential energy, lowering the proportions of both potential energy and radiative energy in the balance ratio. Liberated from the rigid structure of the solid state, molecules are no longer confined to fixed positions and gain increased freedom to move and vibrate. This enhanced mobility results in a substantial rise in kinetic energy. Together, these changes significantly increase the kinetic energy fraction relative to the other energy forms, shifting the system's balanced energy distribution, as shown in Figure 2.

It is important to note that although intermolecular bonds are disrupted in the liquid state, attractive forces between molecules remain influential. These residual interactions cause molecules to stick together to some extent, resulting in viscosity between molecules and limiting the freedom of their motion. After vaporization, all intermolecular bonds are fully broken, further reducing the system's capacity to store potential energy. At the same time, the now free-moving molecules can accommodate additional translational kinetic energy, resulting in a greater proportion of kinetic energy in the balance ratio in the gas phase. In this state, potential energy is primarily stored in orbital electrons, and in the case of polyatomic molecules, substantial potential energy resides in intramolecular bonds.

In the plasma state, all chemical bonds are broken, and some electrons are stripped from atoms, effectively eliminating nearly all components capable of storing potential energy associated with Coulomb forces. As a result, the majority of dynamic energy is manifested as radiative energy and the kinetic energy of free particles. High-frequency radiation can interact directly with particles, facilitating energy exchange between radiative and kinetic forms. Potential energy associated with the strong nuclear force between nucleons is typically inaccessible and does not contribute to thermodynamic interactions, unless a nuclear reaction is involved.

As the total dynamic energy of a system increases from the cool solid state to the hot plasma state, several general trends become apparent. During the solid-to-liquid transition, weaker intermolecular bonds are disrupted; these bonds are fully broken in the liquid-to-gas transition. In the subsequent transition from gas to plasma, stronger molecular bonds are destroyed, and some electrons are stripped from atoms. With each phase change, the system's capacity to store potential energy declines due to the loss of bonded structures; meanwhile, the increasing freedom of individual particles enhances their ability to carry kinetic energy. Consequently, the proportion of dynamic energy stored as potential energy decreases, while the fraction attributed to kinetic energy rises. Radiative energy also increases, especially as high-frequency radiation begins to interact more directly with free particles, enabling efficient energy exchange. As matter density typically decreases across these transitions, the time required for the system to restore the balance generally shortens, reflecting the enhanced mobility and interaction rates of liberated particles.

So far, we have introduced the foundational concepts that define the Restoration Principle, including the classification of dynamic energy into potential, kinetic, and radiative forms; the mechanisms of transformation among these forms; and the role of balance ratios in governing the behavior of system evolution. Together, these concepts provide a cohesive framework for understanding how systems respond to energy input and internal redistribution. In the following sections, we will apply the Restoration Principle, along with its mathematical formulations, to various scenarios, illustrating how it explains phenomena such as directional evolution and periodic oscillations. Through these applications, the practical relevance and predictive power of the Restoration Principle will become increasingly evident.

System Behavior Governed by Coulomb Forces

As discussed earlier, the behavior and forms of matter in large celestial systems are governed primarily by gravity. In contrast, within smaller systems such as Earth, transformations between matter energy (*M*) and dynamic energy (*D*) are relatively uncommon. Instead, the states and behavior of matter are typically determined by transformations among the different forms of dynamic energy under the influence of electrostatic forces. Although gravity is still present in small systems, it is far weaker than the Coulomb force and can thus be neglected at microscopic scales, where electrostatic interactions dominate the behavior of charged particles. Consequently, while gravity governs macroscopic processes, phenomena such as phase transitions and chemical reactions are driven mainly by Coulomb forces. Within this framework, it becomes clear that most processes on Earth serve to restore a balanced distribution among the three forms of dynamic energy—potential (*U*), kinetic (*K*), and radiative (*R*)—at the system's specific total dynamic energy level, in accordance with the Restoration Principle.

For example, why does water solidify below its freezing point? At low dynamic energy levels, hydrogen bonds—Coulomb attractions between water molecules—become dominant, while other interactions play only a minor role. A significant proportion of the system's dynamic energy is stored in these bonds as potential energy. This reflects the system's tendency to shift matter into a state that can accommodate a larger share of potential energy, thereby maintaining the high potential-to-total energy ratio characteristic of low dynamic energy conditions.

As the energy level rises, all three forms of dynamic energy increase: the increase in potential energy stretches molecular bonds, weakening them, while the rise in radiative energy elevates the frequency and intensity of transimpacts, which can ultimately break these weakened bonds. This leads to a phase transition. As a result, the system settles into a new balance ratio of dynamic energies in the liquid or gaseous state, corresponding to the higher dynamic energy levels.

This example illustrates how the state of matter adjusts in response to different dynamic energy levels to maintain a balanced energy distribution appropriate for each level. Consequently, matter aggregates or disperses—manifesting as entropy decrease or increase—reflecting the system's behavior at different energy levels according to the underlying Restoration Principle. In other words, the balance ratio among the forms of dynamic energy determines the state of matter.

The Restoration Principle likewise governs physical, chemical, and biochemical reactions. In a reversible reaction, for instance, adding reactants drives the reaction forward, while removing them shifts it backward. Each chemical species possesses a characteristic balance ratio of dynamic energy at a given energy level. Reaction equilibrium reflects a stable ratio of reactants to products, determining the overall energy distribution. When this balance is disturbed—by adding or removing reactants or products—the system restores equilibrium by generating more products or reactants accordingly. By the principle of mass–energy equivalence, energy itself can act as a reactant or product in reactions that absorb or release it, so adding energy to a system produces effects analogous to adding chemical species.

For instance, the charging and discharging cycles of a Li-ion battery are also governed by the Restoration Principle, which seeks to reestablish the balance ratio among various forms of dynamic energy at different energy levels. During charging, the applied voltage between the cathode and anode raises the system's energy level by increasing potential energy. This external input disturbs the existing balance. To restore equilibrium, lithium ions (Li^+) migrate from the cathode lattice through the electrolyte to the anode, where they intercalate between graphite layers, storing the added potential energy:

(11) $Energy + C_6 + Li^+ + e^- \Leftrightarrow LiC_6$

In effect, the battery stores energy as the chemical potential of bonds within the anode. When the battery powers a device, this process reverses. The battery now holds a higher potential energy than the device. To reestablish balance in this case, lithium ions (Li^+) de-intercalate from the anode and migrate through the electrolyte back to the cathode. There, they recombine with incoming electrons and reinsert into the crystal lattice. The stored chemical energy is thus converted back into electrical energy, lowering the battery's potential energy.

Similar to electrical batteries, living systems evolved their own forms of biological energy storage through evolution. A classic example is photosynthesis, expressed by the following chemical equation:

(12) $Energy + 6CO_2 + 6H_2O \Leftrightarrow C_6H_{12}O_6 + 6O_2$

With the input of light energy, carbon dioxide and water react to form glucose, releasing oxygen as byproducts. From the perspective of the Restoration Principle, the influx of radiative energy disrupts the system's original balance ratio of dynamic energies. To restore equilibrium, the system redistributes this excess radiative energy into other forms, including potential energy, which is stored in the chemical bonds of glucose. In other words, when external energy perturbs a system's balance, the system responds through spontaneous transformations of matter, generating new molecular structures that can accommodate the additional energy and thereby establish a new equilibrium.

This process is reversible. At night, when light energy is no longer available, the system's radiative energy level declines. This shifts the energy level and distribution. To reestablish the balance ratio, plants metabolize stored glucose, lowering the potential energy contained in chemical bonds and releasing heat, along with water and carbon dioxide as byproducts.

Essentially, by adjusting the relative amounts of components at each end of the reaction, the system can maintain a balance ratio of dynamic energies in accordance with the dynamic energy level, manifesting the reaction to shift direction in response to changes in energy supply. This process illustrates how the **Restoration Principle** regulates the behavior of a chemical reaction and, by extension, the functioning of a living system.

Shaping the Form and Evolution of Life

An electrical battery performs best within its designed charging and discharging voltage. Likewise, the biological battery represented by reaction (12) operates most efficiently only under specific conditions, such as the ranges of temperature and sunlight on Earth. Beyond these ranges, its efficiency decreases, reducing the effectiveness of life processes. To optimize energy use, living systems have evolved a variety of adaptations suited to their environments, gaining selective advantages and securing evolutionary success. In this sense, the evolution of life itself is governed by the Restoration Principle.

For example, plants in tropical regions often develop large evergreen leaves to maximize sunlight absorption in environments abundant in solar energy. In contrast, many temperate plants shed their leaves to cope with seasonal decreases in energy availability. In cooler or mountainous areas, needle-shaped leaves help reduce energy loss and conserve water. Similarly, in response to seasonal fluctuations in energy, some animals migrate to track more favorable conditions, while others hibernate during winter because maintaining body temperature in cold environments requires substantial energy. By entering a dormant state, these organisms lower their metabolic rate and minimize energy consumption. These adaptive strategies illustrate the various ways in which the Restoration Principle manifests in living systems.

The examples above illustrate life forms optimized for the normal conditions of Earth. However, if these organisms were relocated to a drastically different environment—such as a hot spring—they would generally be unable to survive, since the balance ratio of dynamic energies there differs, and their “batteries” could not function. Yet certain bacteria thrive in hot springs with temperatures as high as 60–80 °C. Rather than relying on photosynthesis, many of these microbes use chemosynthesis, oxidizing sulfur, iron, or hydrogen to obtain energy. In the cooler margins of hot springs, cyanobacteria carry out photosynthesis, forming strikingly colorful microbial mats.

As AI technologies advance rapidly, a provocative question emerges: could silicon-based life, or intelligence, eventually replace carbon-based humans? This question can be examined through the lens of the Restoration Principle. The Earth’s energy level defines the optimal balance ratio of energy distribution, and over billions of years of evolution, carbon-based life has proven most adaptable, naturally aligning with Earth’s energetic conditions. Unless the planet’s energy landscape undergoes a dramatic shift, silicon-based life is unlikely to gain either a natural or competitive advantage over its carbon-based counterpart in terms of energy optimization. Put differently, if silicon-based life were to exist, it would have to arise at an energy level different from that of Earth’s present environment with an entirely different ecosystem. Furthermore, the immense energy demands of current AI technologies highlight their lack of sustainability under Earth’s energetic constraints.

The Invisible Hand of Economics

The fundamental principle of economics is making rational choices to maximize benefit under limited resources. When considered alongside the evolution of life, it becomes clear that this principle is rooted in the Restoration Principle. The behavior of economic systems is ultimately driven by human needs and desires, which, like those of all living organisms, are shaped by the same principle. As one species within Earth’s broader ecosystem, humans—like all others—depend on food and other goods to survive. Producing these necessities requires energy, and both human survival and human industry rely on using that energy efficiently. At its core, this reflects the biological imperative to sustain life with minimal energy expenditure, keeping processes near equilibrium where energy use is optimized.

Life forms are passively shaped by the Restoration Principle under Earth’s energetic conditions, whereas economic activities are consciously guided by humanity’s application of the same principle. For example, consider two companies, A and B, both producing milk of identical quality and initially selling it at the same price. Company A refines its production process, reducing energy use and lowering costs. This efficiency enables it to cut prices while remaining profitable. Customers naturally choose the cheaper option, giving Company A a competitive advantage. Company B, unable to match the lower price, loses market share and may eventually fail. This example shows how optimizing energy efficiency can determine long-term success in a competitive environment, underscoring the fundamental role of the Restoration Principle in shaping economic systems.

This principle is also reflected in financial markets. While bond and stock prices may fluctuate in the short term, their long-term values remain anchored to intrinsic worth. Investment decisions are typically guided by the pursuit of maximizing returns while minimizing costs. Attractive high-yield opportunities rapidly draw in capital; however, excessive investment can drive prices above intrinsic value, eroding returns. As competition rises and profits fall, capital drifts toward newer and more promising opportunities, sometimes pushing prices below intrinsic value. These cycles of overvaluation and undervaluation generate ongoing fluctuations. Through such dynamic reallocations of resources, industries are directed to operate effectively in accordance with the Restoration Principle, ultimately shaping financial markets around the same goal of energy optimization.

At the most fundamental level, all resources—whether financial, material, or otherwise—can be understood as forms of energy or as proxies for the energy required to obtain them. Viewed this way, every aspect of economic activity centers on the transformation, storage, exchange, and consumption of energy. Human decision-making may seem complex, but the underlying imperative remains unchanged: minimize energy expenditure while maximizing energy return. Energy efficiency thus anchors both the survival of living systems and the sustainability of economies, embodying the Restoration Principle in practice.

Equilibrium vs. Balanced Energy Distribution

Equilibrium generally refers to a state of balance in which opposing forces or influences are equal, so no change occurs unless the system is disturbed. The concept takes different forms across disciplines. In thermodynamics, when two systems at different temperatures interact, energy flows between them until their temperatures equalize; at this point, the net flow of energy is equal in both directions, representing thermal equilibrium. In chemistry, equilibrium is reached when the forward and reverse reactions occur at the same rate, keeping concentrations of reactants and products constant. In ecology, equilibrium occurs when species populations and resources remain in balance. In economics, a market is in equilibrium when supply matches demand, stabilizing prices. In mechanics, a body is in equilibrium when all forces and torques cancel out, so it does not accelerate and remains either at rest or in uniform motion.

All these equilibria are manifestations of a **balanced energy distribution** governed by the **Restoration Principle**. Since everything exists as energy in one form or another, all phenomena and behaviors can be understood as processes of energy transformation. The charging and discharging of electrical or biological batteries, for example, demonstrate how systems establish new equilibria as their environments change. A fully charged battery represents such an equilibrium under a high energy level. Because energy takes many forms—including matter itself—these transformations may involve conversions between different types of energy or forms of matter. Yet despite their diversity, they all share a common tendency: the drive toward a balanced distribution of energy, which gives rise to different forms of equilibrium. Thus, the Restoration Principle serves as the foundational mechanism underlying all equilibria.

Conclusions

All matter and processes in the universe are manifestations of energy and its continual transformations. The dominant forces within any system are determined by its total energy, which shapes both the structure and dynamics of matter. In large-scale celestial systems, gravity prevails, giving rise to structures such as black holes and neutron stars. In smaller-scale systems, such as Earth, Coulomb forces dominate. Here, the governing interaction depends on the level of dynamic energy: at low levels, attractive electrostatic forces predominate, while at higher levels, repulsive interactions take precedence. Within such systems, matter evolves through transformations among three dynamic forms of energy—potential, kinetic, and radiative. These transformations drive systems toward a stable distribution, described as the balance ratio of dynamic energies. When this balance is disrupted, systems respond spontaneously, either through periodic oscillations or progressive developments, to restore equilibrium. This universal tendency, articulated in the **Restoration Principle**, provides a unifying framework for understanding systemic behavior across physical, biological, and even social domains. By contrast, the classical concept of entropy emphasizes the dispersal of energy. While this holds in systems dominated by repulsive interactions, the trend can reverse in those where attractive interactions prevail. The second law of thermodynamics, therefore, captures only a subset of natural processes, rather than the full spectrum of the universe's dynamic behavior.

Revision History

- 05/23/2025: Initial Post on Stanford Site
- 11/01/2025: Published on Zenodo
- 12/17/2025: Adding Links to Summaries of Related Articles

Links to Summaries of Related Articles

- https://cs.stanford.edu/people/zjl/abstract.html, PDF
- https://sites.google.com/view/zjl/abstracts, PDF
- https://xenon.stanford.edu/~zjl/abstract.html, PDF
- https://doi.org/10.5281/zenodo.17967154, PDF

Further Literature

- Misconceptions in Thermodynamics (PDF: DOI) (中文: DOI)
- The Mechanism Driving Crookes Radiometers (PDF: DOI) (中文: DOI)
- The Cause of Brownian Motion (PDF: DOI) (中文: DOI)
- Can Temperature Represent Average Kinetic Energy? (PDF: DOI) (中文: DOI)
- The Nature of Absolute Zero Temperature (PDF: DOI) (中文: DOI)
- The Triangle of Energy Transformation (PDF: DOI) (中文: DOI)
- Is Thermal Expansion Due to Particle Vibration? (PDF: DOI) (中文: DOI)
- Superfluids Are Not Fluids (PDF: DOI) (中文: DOI)
- Why a Phase Transition Temperature Remains Constant (PDF: DOI) (中文: DOI)
- What Causes Friction to Produce Heat? (PDF: DOI) (中文: DOI)
- The Easiest Way to Grasp Entropy (PDF: DOI) (中文: DOI)
- Entropy Can Decrease (PDF: DOI) (中文: DOI)
- The Restoration Principle (PDF: DOI) (中文: DOI)

- Is There a Sea of Free Electrons in Metals? (PDF: DOI) (中文: DOI)
- Electron Tunnel (PDF: DOI) (中文: DOI)
- Unified Theory of Low and High-Temperature Superconductivity (PDF: DOI) (中文: DOI)
- LK-99 Limitations and Significances (PDF: DOI) (中文: DOI)
- Superconductor Origin of Earth's Magnetic Field (PDF: DOI) (中文: DOI)
- Fundamental Problems about Mass (PDF: DOI) (中文: DOI)
- The Evolution from the Law of Gravitation to General Relativity (PDF: DOI) (中文: DOI)
- The Simplest Derivation of $E = mc^2$ (PDF: DOI) (中文: DOI)
- How to Understand Relativity (PDF: DOI) (中文: DOI)
- Mathematics Is Not Science (PDF: DOI) (中文: DOI)
- Tidal Energy Is Not Renewable (PDF: DOI) (中文: DOI)
- AI Contamination (PDF) (中文)
- DeepSeek pk ChatGPT (PDF) (中文)

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