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Why We Should Make Our Bed in the Morning: Life as Localized Order in the Flow of Entropy

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Abstract

Life depends on acquiring and using energy. Organisms survive by extracting energy from their surroundings through metabolism, which converts the chemical potential of food and oxygen into electrochemical gradients that power cellular processes. These gradients allow living systems to maintain an organized structure while actively interacting with their environment.

In thermodynamics, energy gradients tend to naturally dissipate as systems move toward equilibrium. Biological systems are constantly balancing the need to maintain local order with the universal drive toward entropy. From this perspective, life can be understood as a series of organized processes that capture, regulate, and dissipate environmental energy gradients.

Seen this way, the evolution of biological complexity reflects the gradual improvement of systems that efficiently control energy flow. Living organisms temporarily maintain organized structures—forming localized zones of order—while participating in larger thermodynamic processes that influence the universe. Recognizing this connection highlights the importance of protecting environmental systems that support these energy flows and the life that depends on them.

Keywords: Energy gradients; Thermodynamics of life; Dissipative systems; Bioenergetics; Evolutionary biology; Entropy

Introduction

The world around us

A classic philosophical question asks: if a tree falls in a forest and no one is there to hear it, does it make a sound? Although often framed as a puzzle about perception, the question points to a deeper reality: the physical world contains signals that exist independently of whether any organism is present to detect them. A falling tree produces pressure waves in the air and vibrations in the ground that travel regardless of whether an ear is there to 'hear' them or a foot standing to feel their tremor. The ear and the rest of the body are therefore not the cause of these sensations; they are biological systems evolved to perceive them.

The same principle applies to vision. We have eyes because light exists. Photons propagate as radiating energy, and organisms capable of detecting and using those signals gain a selective advantage [1]. Vision, therefore, is not the cause of light; it is a response to it and the information it encodes about events in the surrounding world. When environments change, sensory systems change with them. Species that live in dark caves may lose functional eyes, while deep-sea organisms may develop alternative sensory adaptations suited to their surroundings. The form and function of biological structures, therefore, reflect the physical characteristics of the environments where organisms evolve [2].

These observations reveal a significant reversal in our typical understanding of life. We often assume that we see because we have eyes or hear because we have ears on either side of our heads. The truth is the opposite. Biology did not create the environment; it was shaped by it. The same logic applies to the body's structure itself. Survival depends not only on sensing signals but also on acting within the physical world that produces them. Sensory systems identify opportunities and threats, while the body provides the means to respond to that information. Throughout the diversity of life, bodies have evolved structures that enable organisms to interact with their surroundings. Limbs, fins, muscles, wings, and specialized body forms allow organisms to move through space, gather food, escape predators, catch prey, navigate complex environments, and find mates—all essential for survival and reproduction. Therefore, sensory organs and bodily structures are not arbitrary inventions; they are adaptive responses to the physical signals and energy flows in the environment, which evolution has gradually refined [2].

We often define life by its visible behaviours—movement, communication, thought, and interaction with the environment. These activities seem to represent the purpose of living systems. However, from a thermodynamic perspective, they can be understood differently. Similar to breathing, where inhalation and exhalation appear mainly related to ventilation or speech, the real function is deeper. Oxygen is not necessary for the mechanics of breathing itself but serves as a terminal electron acceptor in cellular metabolism, enabling the controlled flow of electrons through biochemical pathways that maintain electrochemical gradients. The visible act is thus only a surface expression of a more fundamental process. Likewise, many behaviours that define life are better understood not as end goals but as evolved mechanisms that capture, maintain, and dissipate energy gradients. What seems like purpose at the organism level actually reflects a deeper thermodynamic necessity operating at the molecular level and in the flow of energy.

This article explores the implications of this understanding, revealing a much deeper and more intrinsic connection between life and the world it inhabits. It suggests that while shape and form are shaped by natural selection, the core purpose of life is to engage in the thermodynamic processes that govern the universe and the flow of matter and energy.

Energy gradients

We might think that life is about the comfort of love and safety or the pleasures of indulgence and stimulation, but these are luxuries added to a more basic necessity. Essentially, life centers on the constant gathering of energy to sustain physical existence, with many outward behaviours serving as surface expressions of this deeper need.

At a fundamental level, organisms must continuously produce energy to survive. Sensing and responding to the environment require effort, and this work needs energy. Muscle's contract, cells maintain ionic gradients across membranes, damaged tissues heal, and organisms move through the physical world to find resources. Each of these processes depends on the ongoing conversion of chemical energy within cells [3].

The energy that sustains these processes comes from the chemical bonds of metabolic substrates such as glucose, fatty acids, and amino acids. Food provides substrates that fuel cellular metabolism and ATP production, which is the molecular currency of biological energy [3]. Metabolic pathways, including glycolysis, β-oxidation, and the citric acid cycle, remove electrons from these molecules and transfer them to reduced coenzymes such as NADH and $FADH_2$. These carriers deliver high-energy electrons to the mitochondrial electron transport chain, where their step-by-step transfer to oxygen—the terminal electron acceptor—releases energy that powers proton pumping across the inner mitochondrial membrane and creates the proton motive force [4]. As protons flow back through ATP synthase, this gradient drives ATP production [4].

Within individual cells, the energy of metabolism powers processes such as contraction, replication, and biosynthesis. At the organism level, these cellular activities work together to enable movement, hunting or foraging, tissue growth and repair, homeostasis, and consciousness. To keep the fires burning, organisms must continually absorb new resources for a demand that is as voracious as it is perennial.

Yet, this tells only part of the story. The energy produced by metabolism does more than just move air with breathing, or lift legs over thickets, and wings through the sky; it supports the vital electrochemical gradients that enable the cell to function [5]. The proton gradient mentioned earlier, for instance, creates the potential energy needed to generate ATP. ATP then serves as a universal messenger that helps maintain many other electrochemical gradients across the cell. ATP-dependent pumps maintain sodium–potassium gradients across the plasma membrane, calcium gradients within intracellular compartments, and proton gradients within organelles such as lysosomes and endosomes [5].

These gradients enable processes such as nutrient transport, cellular signalling, muscle contraction, and neuronal activity. In this way, the energy from food ultimately sustains a hierarchy of interconnected gradients that regulate the organization and function of living systems. Without a continuous energy supply, these gradients would dissipate through diffusion, leading the system toward equilibrium—a state in which differences in concentration, charge, and energy are evenly distributed. Reaching equilibrium results in a disorganized state where living cells cease to function.

From this perspective, the fundamental role of metabolism is to constantly rebuild and maintain the electrochemical gradients that prevent living systems from reaching thermodynamic equilibrium. The biology of life—the development of eyes, ears, limbs, lungs, and digestive systems—can thus be viewed as an architecture designed to enable an organism to interact effectively with its environment so it can satisfy the gradients through which energy and function are generated.

Entropy and the Second Law of Thermodynamics

The universe is not just a blank canvas where biology somehow eventually forms. Instead, it is a landscape shaped by differences in energy density. These differences can take many forms: gradients between hot and cold, variations in chemical potential, electrical charge imbalances, pressure gradients, or disparities in gravitational pull. Energy naturally moves along these gradients,

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dissipating as it flows from regions of higher to lower potential. As this process unfolds, the energy released can be harnessed by physical and chemical systems to perform work [6].

The second law of thermodynamics describes how energy and matter tend to disperse through systems over time. As gradients diminish, systems move toward equilibrium, a state in which differences in temperature, charge, concentration, and potential are evenly distributed. Consequently, entropy increases as energy becomes more dispersed [6]. This behaviour can be seen in many common physical processes. Heat flows from hot objects to cold ones. Gas spreads throughout a room until it is evenly mixed. Electrical potentials equalize as charges flow through conductive pathways. Chemical concentrations diffuse until gradients disappear.

In this way, the movement of energy can create organized structures. Examples are seen across many scales of nature. On cosmic scales, these processes have shaped the structure of the universe itself. Gravitational forces in the early universe led to the formation of stars, where nuclear fusion converts hydrogen into heavier elements while releasing vast amounts of energy as electromagnetic radiation [7]. Stellar evolution and explosive events later dispersed these elements through space, enabling planetary systems to form.

Despite the appearance of structures that show localized order and complexity within a broader trend toward disorder and entropy, they do not violate the second law of thermodynamics. Instead, they form because they help energy gradients dissipate more effectively. In such systems, order is not opposite to entropy but a temporary state that allows for its dissipation on a larger scale. These systems are known as dissipative structures [8].

A helpful way to picture this is by thinking of eddies forming in a flowing stream. As water moves downhill, driven by gravity, swirling patterns appear where the flow interacts with obstacles or changes in the riverbed. These eddies look like stable, organized structures, but they do not exist independently of the flow itself. They are sustained by it. Water constantly enters and leaves the eddy, and its form persists only because energy continues to move through the system. When the flow slows down, the eddy disappears. In this way, the structure isn't separate from the process—it is the process. Living cells and ecosystems are especially complex examples of this principle and can be understood as localized, dynamic patterns that develop within the flow of energy and persist only as long as that flow continues.

The emergence of life

On Earth, solar radiation provides a steady energy source that sustains chemical and thermal imbalances across the planet, fuelling atmospheric, geological, and chemical processes. Early life developed in environments with existing energy gradients, where flows of energy could be harnessed, transferred, and eventually released as heat. It started as metabolic systems around naturally occurring deep-ocean hydrothermal vents, where geochemical differences in pH and ionic potential across semipermeable mineral barriers created natural proton flows sufficient to generate usable chemical energy. These systems laid the foundation for membrane-based energy conversion systems that later became central to biological metabolism [9-11].

Containment proved to be transformative in this process. By enclosing reaction networks within bounded spaces, the extraction of energy from environmental differences became more efficient. Intermediates could be stabilized, and chemical gradients, rather than dissipating randomly, could be coupled to generate usable energy for constructing macromolecules, maintaining structure, and driving movement [10].

Adenosine triphosphate (ATP) is a crucial mediator linking energy-releasing reactions to energy-demanding processes in living organisms. The phosphate bonds in ATP store transferable chemical energy, allowing cells to link energy-releasing reactions with energy-consuming processes [3]. Food molecules provide high-energy electrons, while oxygen functions as the final electron acceptor in the electron transport chain. As electrons move through this chain, energy is released and used to pump protons across the cell membrane, creating an electrochemical gradient [4]. The controlled return of these protons through ATP synthase captures this gradient to produce ATP. In this process, chemical energy is transformed into mechanical force, biosynthesis, ion transport, and cellular signalling, supporting organized activity within the cell.

Oxidative phosphorylation is one of the most efficient biological strategies for producing ATP. It occurs across biological membranes. In bacteria and other prokaryotes, it takes place across the cell wall. Endosymbiosis, the evolutionary milestone where a bacterium was engulfed by an ancestral archaeal host, led to the internalization of oxidative phosphorylation and a dramatic increase in energy production. The bacterium evolved into the mitochondrion, and the newly empowered host became the eukaryotic cell, which went on to seed the emergence of biological complexity that characterizes life as we know it today [9,12].

With increased energetic capacity, multicellularity emerged, allowing the division of labour as biological structures became progressively specialised and task-specific. This transition enabled the differentiation of tissues and organs, giving rise to complex systems such as the nervous, respiratory, and circulatory systems, each optimised to sense, distribute, and utilise energy more efficiently. The advent of sexual reproduction further enhanced this framework, introducing genetic recombination and thereby increasing organisms' capacity to adapt to dynamic energetic environments [13].

Photosynthesis extended this energetic process to a planetary scale. By capturing solar photons and transforming electromagnetic radiation into chemical energy, photosynthetic organisms created a continuous global energy source for the

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biosphere. Oxygen accumulated in the atmosphere as a by-product of this process, enabling the widespread evolution of aerobic metabolism and further expanding the energy options available to life [14].

Energy gradients drive change. Organized structures develop spontaneously to redistribute energy within a system, allowing it to flow more efficiently. Evolutionary innovations transformed how energy moved through biological systems. Over time, living organisms became increasingly sophisticated at capturing environmental energy, internalizing it into electrochemical gradients, and using those potentials to maintain structure and perform work. In this way, evolution can be viewed as the gradual improvement of systems in managing energy flow more effectively. Simultaneously, this developing architecture creates an even greater dependence on environmental energy for support. Biology and life are therefore not inventions but resonant adaptations that optimize the capture, transformation, and controlled dissipation of environmental energy in ways that more effectively lead to universal entropy.

Aging

Entropy not only explains how energy moves within systems; it also influences how systems evolve over time. Entropy introduces a preferred direction in physical processes, often called the arrow of time**.** Processes happen irreversibly: eggs break but don't reassemble spontaneously, cream mixes into coffee but doesn't separate again, and stars burn nuclear fuel without reforming hydrogen. The direction in which entropy increases is the same direction we perceive as time moving forward.

Biological life exists within this temporal framework. In physical systems, gradients naturally dissipate as energy spreads more evenly through matter. Maintaining order, therefore, requires a continuous input of energy. Living systems do not avoid this principle. Cells and organisms sustain local organization by continually capturing and regulating energy flows that support electrochemical and chemical gradients, and they persist only as long as these gradients are actively maintained.

One of the most significant innovations in the history of life was the integration of mitochondria through endosymbiosis. By internalizing oxidative phosphorylation, eukaryotic cells greatly enhanced their ability to extract energy from metabolic substrates. This allowed for the evolution of larger cells, more complex genomes, and increasingly sophisticated biological organization. However, this energetic benefit came with a cost**.** Oxidative phosphorylation depends on oxygen as a terminal electron acceptor, and oxygen's high electronegativity produces reactive oxygen species that can damage proteins, lipids, and DNA [15]. The same metabolic processes that support complex life also introduce mechanisms of molecular deterioration.

Biological evolution has developed many strategies to mitigate these vulnerabilities. Cellular repair systems, antioxidant defences, multicellularity, tissue specialization, and reproductive strategies all help maintain functional metabolism despite ongoing molecular damage. These mechanisms slow deterioration but cannot prevent it entirely. Over time, molecular injury accumulates, contributing to cellular dysfunction. When energy input stops, gradients dissipate, and biological structures gradually revert to more dispersed configurations. Tissues and organs degenerate and atrophy, disease occurs, aging advances, and ultimately death follows. Living systems, therefore, follow trajectories through time that reflect the irreversible nature of thermodynamic processes.

Conclusion

We began with a common assumption: that we hear the world because we have ears. However, the deeper truth is the opposite. Pressure waves move through the air whether or not an ear is there to listen. Ears developed because such waves exist. At every level of biological organization, the same idea holds true. Life did not create the physical conditions of the universe; it formed within them and was influenced by them.

Looking more closely, we see that the pleasures of the senses are not simply the luxuries of living but the means by which organisms sustain the deeper energetic processes that allow them to persist. The Second Law of Thermodynamics states that entropy tends to increase, gradients dissipate, and equilibrium becomes more likely. In this process, localized structures can form, helping redistribute energy more effectively than would otherwise occur. At their core, organisms do this by using substrates with high-energy electrons to maintain electrochemical gradients that can do work. Biological complexity can be viewed as the gradual improvement and sophistication of systems to manage these energy flows more efficiently.

Living systems can therefore be seen as the resonance of biological structures aligned with the broader flow of thermodynamics, much like the contours of a river valley, the winds of a storm, and the orbits of planetary systems. Aging is one expression of the limits of this strategy, in which the cumulative costs of maintaining order eventually outweigh the ability to sustain it. From this perspective, our existence is inseparable from the physical systems that sustain life on Earth. Our future depends not on trying to escape the laws of nature but on recognizing that we must live and resonate within them, alongside the environment and ecological systems that support us.

This brings us back to a simple question: why should we make our bed in the morning? Maintaining order requires energy. If left unchecked, any system naturally tends toward disorder as energy disperses and gradients diminish. To keep structure—even in small ways—takes effort. Making the bed doesn't change the Second Law of Thermodynamics, but this small act of restoring order mirrors the same principle that keeps living systems alive: the constant need to maintain structure in a universe - and a bedroom - which, if left unkept, might otherwise descend into chaos.

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