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Systematically Challenging Three Prevailing Notions About Entropy and Life

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This article reveals the original, fundamental, and uncontroversial nature of entropy and systematically challenges three notions prevailing in diverse disciplines: (1) entropy is a measure of disorder; (2) life relies on negative entropy; (3) many systems tend to become increasingly disordered due to the second law of thermodynamics. The challenge is supported by numerous compelling facts and the modern explanation of the second law of thermodynamics. The challenge, if widely accepted, could facilitate the eradication of the entrenched misleading effects of the three misconceptions in diverse disciplines and facilitate relevant research and education on complexity, entropy, disorder, order, evolution, life, and thermodynamics.

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1. Introduction

Multiple notions associated with entropy, such as the idea of animals struggling for entropy proposed by Ludwig Boltzmann in the 1880s[1], the concept of animals relying on negative entropy proposed by Erwin Schrödinger in the 1940s[2], the maximum entropy production hypothesis[3], and minimum energy dissipation principle[4], have been frequently applied to interpret complexity, disorder, and order in life sciences and other disciplines[4][5][6][7][8][9][10][11][12][13][14][15][16]. It is desirable to investigate whether these notions are correct to ensure the validity of their applications.

2. Methods

The original, fundamental, and uncontroversial (OFU) nature of entropy is clarified and employed below as the criterion to judge whether an entropy-associated notion is correct, according to the basic logic in science: any notions derived from a valid concept (e.g., entropy) should not contradict the OFU nature of the concept. In turn, due to this basic logic in science, the conclusions of this article should not be debunked with any notions that contradict the OFU nature of entropy, no matter whether the notions have been prevailing, self-consistent using sophisticated mathematical calculation, or supported by famous scientists.

As explained in the following sections, the notions challenged in this article are dubious because of their flawed reasoning (for instance, they confuse certain concepts), not because of incorrect mathematical computations or the omission of pertinent factors such as free energy. Consequently, this article focuses on revealing the flawed reasoning behind these notions using the OFU nature of entropy and compelling examples.

If not specified, entropy in this article represents the entropy of a system, which can be an isolated, closed, or open thermodynamic system. For example, a man's entropy should include the entropy of the water he has drunk and exclude the entropy of the urine he has discharged.

3. Results

3.1. The OFU nature and features of entropy

In 1854, Rudolf Clausius created the concept of entropy (S) and the Clausius equation of entropy,

$$\Delta S = \Delta Q/T \qquad (1)$$

This equation involves heat energy (Q), which is the kinetic energy of vibrating and colliding atoms in a substance[17][18][19][20], and thermodynamic temperature (T). T is higher than zero for all objects worldwide, according to the third law of thermodynamics[17][18][19][20][21][22]. The Clausius equation denotes that, at a time instant, the entropy variation of an object (ΔS) is equal to the heat absorbed or released by the object (ΔQ) divided by its thermodynamic temperature (T)[17][18][19][20][21]

[22]. The entropy of an object increases when it absorbs heat from its surroundings ($\Delta Q > 0$ and $\Delta S > 0$) and decreases when it dissipates heat into its surroundings ($\Delta Q < 0$ and $\Delta S < 0$). From Eq.(1), it can be deduced that the entropy of an isolated system always increases until its components reach the same temperature, which accurately describes in mathematical language the second law of thermodynamics (Box 1)[17]. The law states that heat can spontaneously flow from a hot object to a cold object and cannot spontaneously flow reversely.

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In an isolated system containing only hot A and cold B, heat spontaneously flows from A to B, and, for any time point before A and B reach the same temperature, A is hotter than B ($T_A > T_B > 0$), the heat released by A is equal to the heat absorbed by B ($Q_B = -Q_A > 0$).

The change of entropy ($\Delta S = \Delta Q/T$) of B, A, and the isolated system (i-system) are:

$\Delta S_B = \Delta Q_B/T_B > 0$ because B absorbs heat ($\Delta Q_B > 0$) and $T_B > 0$

$\Delta S_A = \Delta Q_A/T_A < 0$ because A dissipates heat ($Q_A = -Q_B < 0$) and $T_A > 0$

$\Delta S_{i\text{-system}} > 0$ because $\Delta S_{i\text{-system}} = \Delta S_A + \Delta S_B = \Delta Q_A/T_A + \Delta Q_B/T_B = -\Delta Q_B/T_A + \Delta Q_B/T_B = \Delta Q_B (1/T_B - 1/T_A)$, $\Delta Q_B > 0$, and $T_A > T_B$.

The above inequality $\Delta S_{i\text{-system}} > 0$ accurately describes in mathematical language the second law of thermodynamics in finite terms[17][18][21].

Box 1. **Changes of the entropy of an isolated system**

The Clausius equation defines the OFU nature of entropy: entropy is analogous to energy and the quotient of heat energy and the corresponding thermodynamic temperature. This OFU nature of entropy is widely applied in current thermodynamics[18][19][20][21][22][23] and aligns with Clausius' statement: "I have designedly coined the word 'entropy' to be similar to 'energy', for these two quantities are so analogous in their physical significance"[22].

Entropy has the following two features.

1. Entropy is a derived quantity with the unit Joule/Kelvin (J/K)[18][19][20], where "Kelvin" is the unit of thermodynamic temperature and "Joule" is the unit of energy. As 1 Joule = 1 Kg × 1 (m/s^2), entropy can be considered a quantity derived from four basic quantities in physics: mass, length, time, and thermodynamic temperature.
2. Entropy is an additive quantity in physics[18][19][20]. The entropy of the isolated system composed of objects A and B is equal to the entropy of object A plus the entropy of object B.

Approximately in 1900, Max Planck suggested another equation for entropy:

$$S = k \ln W \qquad (2)$$

Planck termed this equation the Boltzmann equation because it originated from Boltzmann's view that the second law of thermodynamics can be explained by means of statistical probability[1][24]. In this equation, ln represents the natural logarithm, k denotes the Boltzmann constant (1.38065×10^{-23} J/K), and W represents a quantity associated with heat transfer having a probabilistic meaning[24][25][26][27].

3.2. Five types of changes caused by entropy increases

Entropy increases due to heat absorption or heat transfer are prevalent and can lead to various types of changes. Here we list five examples below.

1. A stone, metal, or ideal gas becomes hotter.
2. Ice melts into water.
3. The energy in an isolated system is distributed more evenly, as shown in Box 1, where no chemical reactions occur.
4. A solar battery gains electrical energy.
5. Carbon dioxide, along with water, forms glucose through heat-absorbing organic synthesis (photosynthesis) in plant leaves[28][29].

In the first two types of changes, the increased heat or entropy of the objects remains as heat energy, which can be dissipated if the surroundings become colder. In contrast, some of the increased heat or entropy of the objects in the last two types of changes is stored as electrical energy or chemical energy, which can be stored in the objects even if the surroundings become colder[28]. The last two types of changes, which involve electric or chemical changes, demonstrate that energy can be more unevenly distributed in a system due to an increase in its entropy, which contradicts the tendency shown by the third type of change (the energy of a system distributes more evenly due to an increase in its entropy).

3.3. Animals struggle for entropy

Ludwig Boltzmann stated in 1886 that animals struggle for entropy that is transformed in plants from solar energy[1] (Box 2).

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... The general struggle for existence of animate beings is therefore not a struggle for raw materials—these, for organisms, are air, water and soil, all abundantly available—nor for energy, which exists in plenty in anybody in the form of heat (albeit unfortunately not transformable), but a struggle for entropy, which becomes available through the transition of energy from the hot sun to the cold earth. In order to exploit this transition as much as possible, plants spread their immense surface of leaves and force the sun's energy, before it falls to the earth's temperature, to perform in ways yet unexplored certain chemical syntheses of which no one in our laboratories has so far the least idea. The products of this chemical kitchen constitute the object of struggle of the animal world...

Box 2. A part of the lecture of Boltzmann on entropy and life[1]

This notion is correct according to the OFU nature of entropy. When plants absorb heat from sunlight, their entropy increases, and the increased entropy, or the absorbed energy, is stored as chemical energy in carbohydrate molecules through photosynthesis (see Section 3.2)[28][29]. Animals can utilize the entropy or energy stored in the carbohydrate molecules in plants (plants serve as animals' food) and released through the metabolic degradation of animals' food, for movement, maintaining body temperatures, and other purposes. Animals do not struggle for the heat energy abundant on Earth that they cannot directly utilize.

3.4. Can entropy be a measure of disorder?

The notion that entropy is a measure of disorder (higher entropy means greater disorder) has been widely stated in numerous dictionaries[30], encyclopedias[21][22][31][32], textbooks[18][20], and research articles[4][5][33][34][35][36][37][38], and has been applied frequently to explore the changes of disorder or order in the biomedical and social sciences[13][14][15][16][17][18][19][20].

The notion that entropy is a measure of disorder has faced challenges for decades[6][7][19][39][40][41], usually from a single respect or discipline of physics. The challenges could start as early as in 1934 by an Indian scientist[41]. Here we systematically challenge this notion from diverse respects or disciplines, including history, physics, chemistry, and biology.

First, entropy and disorder are two distinct concepts. Entropy, in its OFU nature, is an additive quality analogous to energy with the unit of J/K, being the quotient of heat energy and the corresponding thermodynamic temperature[18][19][20]. In contrast, disorder is neither additive nor analogous to energy, and its unit is not J/K. According to various Oxford dictionaries[42], the Collins Dictionary[43], and entropy-associated research articles[4][32][33][34][35], disorder refers to chaos, untidiness, or abnormalities, and typically arises from a decline in a system's order.

Second, entropy is a precise and measurable quantity and holds a single, clear meaning. Entropy can be expressed using a single equation (the Clausius equation or the Boltzmann equation), while order or disorder has distinct meanings in physics and other disciplines under different contexts, and order or disorder cannot be expressed using a single equation. Consequently, entropy cannot be a measure of disorder and the relationship between these two concepts is not so straightforward. In effect, order can be categorized into at least three distinct types: (1) structural regularity, which, for example, is embodied in crystals; (2) temporal regularity, which, for example, is embodied in mechanic clocks, the Belousov-Zhabotinsky reaction (a chemical reaction that exhibit periodic color changes)[44], and many other systems; (3) internal cooperation, which, for example, is embodied in living organisms and important for the health of organisms. These three types of order correspond to three types of disorder, namely destroying of structural regularity, destroying of temporal regularity, and destroying of internal cooperation. Accordingly, disorder in biomedical sciences usually refers to diseases[2][42][43]. As elucidated in Box 3, none of these three types of order or disorder change consistently with entropy. For example, when messily placed books are placed orderly, their order increases, but their entropy remains unchanged because they have not absorbed heat from the surroundings or dissipated heat into the surroundings. An electronic clock cannot run regularly without the support of electricity no matter how much the entropy of the clock reduces through releasing heat to its surroundings. Heat absorption by plants from warm sunlight, which increases plants' entropy, usually does not reduce the order of internal cooperation of plants. Meanwhile, the order of organisms largely accumulates through natural selection, the order of computers results from precise design and production, and the order of the rotation of Earth and Moon results from gravitational force. None of these types of order results from the decline in the entropy of the relevant systems. These facts demonstrate that entropy is distinct from disorder.

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(1) Usually, entropy decline cannot lead to the order of structural regularity. For example, according to the OFU nature of entropy, when an ideal gas dissipates heat into its surroundings, it becomes colder, its entropy declines, and the velocity of its unordered molecular vibration and collision declines. However, its molecular vibration and collision remain fully unordered without an increase in the structural regularity at the macroscopic or microscopic level. For another example, when messily placed books are placed orderly, their order increases, but their entropy remains unchanged because they have not absorbed heat from the surroundings or dissipated heat into the surroundings. Occasionally, entropy decline can lead to the order of structural regularity, as seen in the formation of snowflakes.

(2) Usually, entropy decline cannot lead to the order of temporal regularity[45]. For example, the regular cycling of an electronic clock does not result from the decline of the entropy of the clock but from electricity and the specific structure of the clock.

(3) Usually, entropy decline cannot lead to the order of internal cooperation of organisms. For example, heat absorption by plants from warm sunlight, which increases plants' entropy, usually does not reduce the order of internal cooperation of plants. Humans who die acutely due to myocardial infarction dissipate heat into their surroundings, and their body temperatures decrease during the process of death, resulting in a decline in their entropy, which does not lead to an increase in the order of internal cooperation of their bodies, so entropy cannot represent disorder in humans. Drinking water can restore the order of internal cooperation in a highly thirsty man, which simultaneously increases the man's entropy because entropy is an additive quantity[18][19][20].

Box 3. Relationships between entropy decline and three types of order

Third, entropy is an objective concept, whereas perceptions of order and disorder can sometimes be subjective. For instance, a complex film might be seen as orderly from an adult's viewpoint and as disordered from a child's. Thus, entropy is not a proxy for disorder in this context.

Fourth, in history, the three founders of the concept of entropy, Clausius, Boltzmann, and Planck, did not claim that entropy is a measure of disorder[1][17][24]. Boltzmann even stated in 1886 that animals struggle for entropy, which becomes available through the transition of energy from the hot sun to the cold earth (Box 2). This statement demonstrates that Boltzmann believed that entropy is essential for animal lives.

Fifth, the first scientist who stated that entropy is a measure of disorder could be Hermann von Helmholtz, who stated: "... Unordered motion, in contrast, would be such that the motion of each individual particle need have no similarity to that of its neighbors. We have ample ground to believe that heat-motion is of the latter kind, and one may in this sense characterize the magnitude of the entropy as the measure of the disorder...[25]" This statement suggested that the misconception that entropy is a measure of disorder could arise from two confusions: the confusion of unordered statuses (which are prone to normal) with disorder (which is prone to be abnormal) and the confusion of the velocity of fully unordered molecular motion with the extent of the disorder of the molecular motion or even the disorder of the relevant system.

Sixth, the misconception that entropy is a measure of disorder could arise from the confusion of the two concepts: disorder and the *W* quantity in the Boltzmann equation, as exemplified below in Section 3.5. Initially, the *W* quantity was termed thermodynamic probability[26], because it is from the German "Wahrscheinlichkeit," which means probability. However, probability should be located between 0 and 1, while *W* is usually a very large value. Later, *W* was termed complexions and permutations[26]. In 1999, *W* was termed multiplicity, which refers to the count of possible microstates, and this term has been widely accepted[18][19][20]. Because heat is usually associated with the locations and movements of electrons and photons, if *W* really means the count of possible microstates, microstates should be associated with sub-atomic particles of electrons and photons. However, we have not seen any one has given some exact examples for the microstate of an atom, electron, or photon. Rather, microstates have been explained only with analogy[18][19][20][21][22], which is not a scientific method. Consequently, microstates or multiplicity is not a proper term for the *W* quantity. It is abnormal in science that a famous equation of a concept has been applied for more than one century, but the concept itself has not been termed properly. Nevertheless, strictly speaking, none of the above terms of *W* support that *W* is a measure of disorder, which mostly refers to chaos, untidiness, or abnormalities. By combining Eq. (1) and Eq. (2), it can be deduced that, at a time point:

$$\Delta S = \Delta Q/T = S_2 - S_1 = k\ln W_2 - k\ln W_1 = k(\ln W_2 - \ln W_1) = k(\Delta \ln W) \qquad (3)$$

$$\Delta \ln W = \Delta Q/(kT) \qquad (4)$$

□

Eq. (4), which is consistent with a recent publication[27], shows that *W*, like *S*, is also a quantity associated with heat energy (*Q*) and thermodynamic temperature (*T*). This relationship further supports that *W* does not directly correlate with disorder because disorder does not consistently change with heat energy and thermodynamic temperature.

Some argue that "disorder" in thermodynamics means how close a system is to thermodynamic equilibrium or a measure of energy's diffusion or dispersal[31]. This argument contradicts the

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general meaning of disorder (chaos, untidiness, or abnormalities) and the OFU nature of entropy (entropy is analogous to energy and the quotient of heat energy and the corresponding thermodynamic temperature, rather than the extent of thermodynamic equilibrium). The argument also contradicts the last two types of changes listed in Section 3.2.

3.5. Is Schrödinger's negative entropy notion correct?

Nobel laureate Erwin Schrödinger stated in 1944 that life relies on negative entropy in his famous tiny book, *What is life*[2][7] (Box 4).

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[Part 1] ... a living organism continually increases its entropy, or, as you may say, produces positive entropy and thus tends to approach the dangerous state of maximum entropy, which is of death. It can only keep aloof from it, i.e. alive, by continually drawing from its surroundings negative entropy — which is something very positive as we shall immediately see. What an organism feeds upon is negative entropy. Or, to put it less paradoxically, the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive...

[Part 2] ... If *D* is a measure of disorder, its reciprocal, 1/*D*, can be regarded as a direct measure of order. Since the logarithm of 1/D is just minus the logarithm of D, we can write Boltzmann's equation thus:

$$-(\text{entropy}) = k \log (1/D)$$

Hence the awkward expression 'negative entropy' can be replaced by a better one: entropy, taken with the negative sign, is itself a measure of order. Thus the device by which an organism maintains itself stationary at a fairly high level of orderliness (= fairly low level of entropy) really consists in continually sucking orderliness from its surroundings. This conclusion is less paradoxical than it appears at first sight. Rather could it be blamed for triviality. Indeed in the case of higher animals we know the kind of orderliness they feed upon well enough, viz. the extremely well-ordered state of matter in more or less complicated organic compounds, which serve them as foodstuffs. After utilizing it they return it in a very much degraded form — not entirely degraded, however, for plants can still make use of it (These, of course, have their most powerful supply of negative entropy in the sunlight)...

Box 4. Two parts of the book *What is life*. The underlined sentences constituted the three viewpoints of Schrödinger's notion.

Schrödinger's negative entropy notion was proposed in the era when in the field of biological sciences, genetics was evolving, but the nature of genes and the mechanism of storing genetic information were still poorly understood. Gregor Mendel's laws of inheritance and the chromosome theory were established, but DNA as the hereditary material had not yet been universally recognized. Consequently, the mechanisms of the order and disorder of organisms were elusive at that time.

Schrödinger's negative entropy notion contradicts Boltzmann's statement that animals struggle for entropy (see Section 3.3). Schrödinger's notion is based on the change of the quantity *W* in the Boltzmann equation with disorder (*D*) (Box 4) and the notion that entropy represents disorder, both have been challenged in Section 3.4. Nevertheless, Schrödinger's notion has garnered widespread acceptance for nearly 80 years, with only a few criticisms[7][46][47]. For instance, Google Scholar showed that Schrödinger's book, *What is life*, had been positively cited over 11,000 times, mainly due to the inclusion of the negative entropy notion. In 2023, this book was cited nearly 600 times, as exemplified by six references[8][9][10][11][12][48], with few doubts about this notion.

Coinciding with the popularity of this notion, English Wikipedia and other academic websites deliberately added "negative" with brackets in Boltzmann's statement before "entropy"[13][49] (Box 2). However, it is unlikely that Boltzmann neglected the word "negative" because: (1) the concept of negative entropy was coined after his death; (2) "negative entropy" is distinct from "entropy"; and (3) Boltzmann's statement is correct, as elucidated in Section 3.3.

Schrödinger's notion contained three viewpoints (Box 4), which are all questionable and challenged below.

Its first viewpoint, that entropy represents disorder and is thus detrimental to animals, has been challenged in Section 3.3.

Its second viewpoint is that animals rely on food to reduce their entropy and generate order to offset the spontaneous increase in their entropy or disorder. This viewpoint assumes that animal food contains less entropy than animal excreta, so animals can obtain order due to entropy decline (i.e., negative entropy) because the entropy they dissipate into the surroundings is greater than the entropy they obtain from low-entropy food. This viewpoint is questionable because the order of life is encoded and provided by genes inherited from parents and accumulates through long-term natural selection[50]. The order of life is neither provided by food nor suddenly emerges due to entropy decline or negative entropy. Furthermore, food provides animals with energy and, thus, entropy to support their lives (see Section 3.3) (Fig. 1). The assumption that animal food contains less entropy than animal excreta is questionable because food metabolism dissipates heat, and hence animal food contains more entropy than animal excreta. Additionally, during the developmental process from a fertilized egg into a prenatal baby of a human, the entropy of the life system increases by millions of times because entropy is an additive property, and the increased entropy is from the food consumed by the baby's mother.

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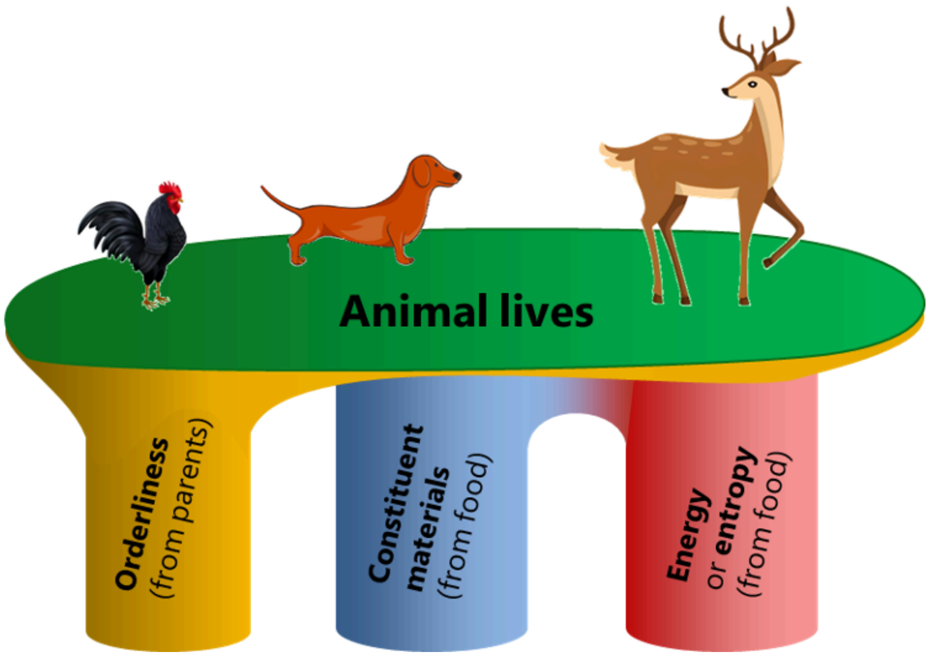

Figure 1. Three pillars of animal lives and their origins.

The third viewpoint of Schrödinger's notion is that sunlight provides negative entropy to plants. This viewpoint is incorrect because, according to the OFU nature of entropy, the entropy of plants, stones, ices, and any other objects increases rather than reducing when they absorb heat from sunlight. Some of the energy or entropy absorbed by plants is stored as chemical energy in carbohydrate molecules through heat-absorbing photosynthesis[28][29]. Furthermore, in biology, sunlight or any type of energy cannot directly provide order to plants, and the order in plants is also encoded and provided by inherited genes and accumulates through long-term natural selection rather than from the environment, food, and entropy decline[50].

Schrödinger himself commented on his negative entropy notion: "...The remarks on negative entropy have met with doubt and opposition from physicist colleagues. Let me say first, that if I had been law catering for them alone, I should have let the discussion turn on free energy instead[2]" Schrödinger's comments showed that he knew his negative entropy notion was questionable and the targeted issue should be elucidated with free energy rather than entropy or negative entropy. Free energy is a pivotal thermodynamic quantity that serves to predict the spontaneity of processes, determine chemical equilibrium, and guide the optimization of energy conversion in biological and industrial systems. Here we did not discuss free energy because the misconceptions challenged by this article were not derived through free energy, and free energy does not change consistently with order or disorder, either[18][19][20].

In recent decades, negative entropy has also been employed to represent information[51], which is also controversial in its calculation[52].

3.6. A prevailing misuse of the second law of thermodynamics

The second law of thermodynamics can be mathematically expressed as the entropy of an isolated system increasing over time until all parts of the system reach the same temperature (see Section 3.1). Since entropy is widely accepted to be a measure of disorder, it is widely assumed by researchers from various fields, such as physics, chemistry, biology, medicine, and social sciences, that many natural or social systems tend to become increasingly disordered due to entropy, or the second law of thermodynamics[4][5][8][9][10][11][12][18][20][30][31][32][33][34][35][48]. As elucidated in Section 3.4, entropy cannot be a measure of disorder, so the above assumption is incorrect.

The second law is on the direction of heat transfer, and the mechanisms of heat transfer, namely heat conduction associated with unordered molecular vibration and collisions, heat convection associated with mixing of the molecules in a fluid (gas or liquid), and electromagnetic radiation, have been revealed by modern physics[6][7][22]. Accordingly, the second law of thermodynamics can be so expressed: heat energy can spontaneously exchange between a hot object and a cold object, and more heat energy, including the energy of random molecular collisions and the energy of electromagnetic radiation, is transferred from the hot object to the cold object than vice versa. This explanation clarifies that the second law does not indicate a natural progression from order to disorder, and thus it does not contradict evolution. This explanation also clarifies that the heat transfer according to the second law of thermodynamics does not coincide with changes of order or disorder, which can also

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challenge the notion that entropy is a measure of disorder and life relies on negative entropy.

Furthermore, it could be a fact that many systems tend to become increasingly disordered. This possible fact results from certain statistical probabilities because many systems are more likely to stay in a disordered state than in an orderly state. However, these statistical probabilities are barely associated with heat transfer. Therefore, the possible fact is not due to entropy or the second law of thermodynamics, a law that only states heat transfer direction.

The reasoning errors of the three notions challenged above are summarized in Fig. 2.

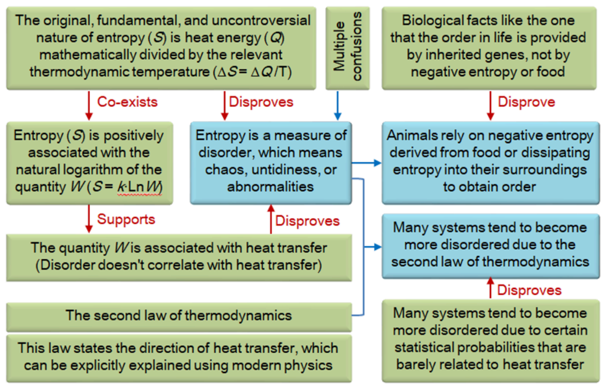

Figure 2. The flawed reasoning steps (shown with blue arrows) of the three misconceptions are challenged by this article and shown in blue rectangles here. The flawed reasoning is disproven here by the correct reasoning steps, which are shown with red arrows.

4. Discussion

As mentioned above, although the three notions challenged in this article have encountered challenges for decades[2][6][7][19][39][40][41][53], primarily from a single aspect, they have been widely accepted and frequently applied in life sciences and other disciplines for decades, misleading countless common people and many researchers through numerous mediums such as textbooks, research papers, and online social communications. Consequently, these notions have become a significant stumbling block and have caused severe pollution in science in recent decades.

This article systematically challenges the three notions. The systematic challenge has the potential to eradicate the entrenched misleading effects of the notions in life sciences and beyond. Furthermore, it could reshape the understanding of entropy, energy, disorder, order, life, thermodynamics, and rigorous reasoning among researchers and the general public. It could rectify and facilitate the relevant scientific research on complexity, order, and evolution[6][14][36][37][38][54][55]. For instance, the systematic challenge suggests that the second law of thermodynamics neither correlates with the changes of disorder nor contradicts evolution, a natural process characterized by an increase in order.

This article presents several novel contributions: it elucidates the basic logic in science—that any concepts derived from a valid idea should not conflict with the inherent nature of the original concept—and applies this scientific logic to set the criterion for validating the correctness of entropy-related concepts (Section 2); it explicates the intrinsic nature of entropy (Section 3.1); it enumerates various instances showing how an increase in entropy can lead to a more uneven distribution of energy within a system (Section 3.2); it reveals the contrasting views of Boltzmann and Schrödinger on the relationship between animal life and entropy (Sections 3.3 and 3.5); it categorizes order and disorder into three separate types and demonstrates that none of these types consistently correlates with entropy (Sections 3.4); it systematically challenges three interconnected prevailing concepts, and provides an in-depth analysis of the historical and logical fallacies underlying these notions; it debunks the notion that entropy is a measure of disorder even within the context of ideal gas systems (Box 3); and it introduces a new expression of the second law from the perspective of modern physics, using this expression to challenge the three interconnected prevailing concepts (Section 3.6).

5. Conclusions

This article systematically challenges with multiple novelties three notions prevailing in diverse disciplines: (1) entropy is a measure of disorder; (2) life relies on negative entropy; (3) and many systems tend to become increasingly disordered due to the second law of thermodynamics, using the OFU nature of entropy and numerous compelling facts in physics, chemistry, and biology. The challenge, if widely accepted, could facilitate the eradication of the entrenched misleading effects of the misconceptions in diverse disciplines.

Statements and Declarations

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contribution

Conceptualization: J.-M. C., Investigation: J.-M. C., J.-W. C., R. Z., Writing—original draft preparation: J.-M. C; writing—review and editing: J.-M. C., J.-W. C., R. Z. All authors have read and agreed to the published version of the manuscript.

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References

1. [a], [b], [c], [d], [e] *Boltzmann L. The second law of thermodynamics. In T heoretical physics and philosophical problems: Select writings; McGuinness BF, Ed., Springer: Berlin, Germany, 1974; pp. 13–33.*

 doi.org/10.32388/038909.5

2. a, b, c, d, eSchrodinger E. What is life; Cambridge University Press, Cambridge, UK, 2012; pp. 67–75.
3. ^Dewar RC. Maximum entropy production and plant optimization theories. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 2010;365:1429–1435.
4. a, b, c, d, eZivieri R, Pacini N. Entropy Density Acceleration and Minimum Dissipation Principle: Correlation with Heat and Matter Transfer in Glucose Catabolism. Entropy 2018;20(12):929.
5. a, b, cPrigogine I. Time, structure and fluctuation (Nobel Lecture). Science 1978;201:777–785.
6. a, b, c, d, eKleidon A. Life, hierarchy, and thermodynamic machinery of planet Earth. Phys. Life Rev. 2010;7:424–460.
7. a, b, c, d, e, fBejan A. Evolution in thermodynamics. Appl. Phys. Rev. 2017;4:011305.
8. a, b, cMoberg C. Schrödinger's What is Life?-The 75th Anniversary of a book that inspired biology. Angew. Chem. Int. Ed. Engl. 2020;59:2550–2553.
9. a, b, cPortugali J. Schrödinger's What is Life?-Complexity, cognition and the city. Entropy 2023;25:872.
10. a, b, cZivieri R, Pacini N. Is an entropy-based approach suitable for an understanding of the metabolic pathways of fermentation and respiration? Entropy 2017;19(12):662.
11. a, b, cSwenson R. A grand unified theory for the unification of physics, life, information and cognition (mind). Phil. Trans. R. Soc. A 2023;381:20220277.
12. a, b, cCushman SA. Entropy, ecology and evolution: Toward a unified philosophy of biology. Entropy 2023;25:405.
13. a, b, cEntropy and life. Available online: https://en.wikipedia.org/wiki/Entropy_and_life (accessed on 27 Aug 2024).
14. a, b, cRoach TNF. Use and abuse of entropy in biology: A case for caliber. Entropy 2020;22:1335.
15. a, bNegentropy. Available at: https://en.wikipedia.org/wiki/Negentropy (accessed on 27 Aug 2024).
16. a, bBejan A. The principle underlying all evolution, biological, geophysical, social and technological. Philos. Trans. A. Math. Phys. Eng. Sci. 2023;381:20220288.
17. a, b, c, d, e, f, gClausius R. Ueber eine veränderte Form des zweiten Hauptsatzes der mechanischen Wärmetheoriein. Annalen der Physik und Chemie 1854;93:481–506.
18. a, b, c, d, e, f, g, h, i, j, k, l, m, n, oBorgnakke C, Sonntag RE. Fundamentals of Thermodynamics; Wiley: Hoboken, NJ, USA, 2022.
19. a, b, c, d, e, f, g, h, i, j, k, l, m, nDeVoe H. Thermodynamics and Chemistry. Available online: https://www2.chem.umd.edu/thermobook/v10-screen.pdf (accessed on 27 Aug 2024).
20. a, b, c, d, e, f, g, h, i, j, k, l, m, nZhang SH, An Y, Ruan D, Li YS. College Physics—Mechanics & Thermodynamics; Tsinghua University Press: Beijing, China, 2018.
21. a, b, c, d, e, fEntropy in physics. Available online: https://www.britannica.com/science/entropy-physics (accessed on 27 Aug 2024).
22. a, b, c, d, e, f, gEntropy. Available online: https://en.wikipedia.org/wiki/entropy (accessed on 27 Aug 2024).
23. ^Freeland S. Undefining life's biochemistry: implications for abiogenesis. J. R. Soc. Interface 2022;19:20210814.
24. a, b, cPlanck M. On the law of distribution of energy in the normal spectrum. Annalen der Physik 1901;4:553-562.
25. a, bvon Helmholtz H. The Thermodynamics of Chemical Processes. Meeting reports of the Akademie der Wissenschaften zu Berlin, 2 Feb 1882.
26. a, b, cBaierlein R. Thermal Physics; Cambridge University Press: Cambridge, UK, 1999.
27. a, bTolley HD, Woodfield BF, Hansen LD. Counting microstates via heat capacity and implications for the third law. J. Chem. Thermodyn. 2022;171:106807.
28. a, b, c, dKabo GJ, Blokhin AV, Paulechka E, et al. Thermodynamic properties of organic substances: Experiment, modeling, and technological applications. J. Chem. Thermodyn. 2019;131:225–246.
29. a, b, cMauzerall D. Thermodynamics of primary photosynthesis. Photosynth. Res. 2013;116:363–366.
30. a, bEntropy. Available online: https://www.oxfordreference.com/search?q=entropy (accessed on 27 Aug 2024).
31. a, b, cEntropy (order and disorder). Available online: https://en.wikipedia.org/wiki/Entropy_(order_and_disorder (accessed on 27 Aug 2024).
32. a, b, cEntropy and disorder. Available online: https://www.britannica.com/science/principles-of-physical-science/Entropy-and-disorder (accessed on 27 Aug 2024).
33. a, b, cSaxberg B, Vrajitoarea A, Roberts G, Panetta MG, Simon J, Schuster DI. Disorder-assisted assembly of strongly corre-lated fluids of light. Nature 2022; 612: 435–441.
34. a, b, cBaker JE. Cells solved the Gibbs paradox by learning to contain entropic forces. Sci. Rep. 2023; 13: 16604.
35. a, b, cAristov VV, Karnaukhov AV, Buchelnikov AS, Levchenko VF, Nechipurenko YD. The degradation and aging of biological systems as a process of information loss and entropy increase. Entropy 2023; 25: 1067.
36. a, bFriston K, Da Costa L, Sakthivadivel DA, Heins C, Pavliotis GA, Ramstead M, Parr T. Path integrals, particular kinds, and strange things. Phys. Life Rev. 2023; 47: 36–62.
37. a, bJennings RC, Belgio E, Zucchelli G. Photosystem I, when excited in the chlorophyll Qy absorption band, feeds on negative entropy. Biophys. Chem. 2018; 233: 36–46.
38. a, bRamstead MJD, Badcock PB, Friston KJ. Answering Schrödinger's question: A free-energy equation. Phys. Life Rev. 2018; 24: 1–16.
39. a, bChen JM. A new evolutionary theory deduced mathematically from entropy amplification. Chin. Sci. Bull. 2000; 45: 91–96.
40. a, bLambert FL. Disorder—A cracked crutch for supporting entropy discussions. J. Chem. Educ. 2002; 79: 187.
41. a, b, cRay S. The solid-gas, – a criticism of the definition of entropy as disorderliness. Proceedings of the Indian Science Congress. 1934; 21: 166–167.
42. a, bDisorder. Available online: https://www.oxfordreference.com/search?q=disorder (accessed on 27 Aug 2024).
43. a, bDisorder (Collins Dictionaries) Available online: https://www.collinsdictionary.com/us/dictionary/english/disorder (accessed on 27 Aug 2024).
44. ^Nicolis G, Prigogine I. Exploring Complexity: An Introduction. W.H. Freeman and Company, 1989.
45. ^Li H, Seugnet L. Decoding the nexus: branched-chain amino acids and their connection with sleep, circadian rhythms, and card

iometabolic health. Neural Regen. Res. 2025; 20(5): 1350–1363.

46. ^*Pauling L. Schrödinger's contribution to chemistry and biology. In Schrödinger Centenary celebration of a polymath; Kilmister CW, Ed., Cambridge University Press: Cambridge, UK, 1987; pp. 225-233.*
47. ^*Chen JM, Chen JW. Root of Science: The driving force and mechanism of the extensive evolution. Science Press: Beijing, China, 2000.*
48. a, b*Roth Y. What is life? The observer prescriptive. Results Phys. 2023; 49: 106449.*
49. ^*Ludwig Boltzmann quotes. https://www.goodreads.com/author/quotes/178457.*
50. a, b*Futuyma DJ, Kirkpatrick M. Evolution (Sinauer Associates USA, Sunderland, 2017).*
51. ^*Brillouin L. The negentropy principle of information. J. Appl. Phys. 1953; 24: 1152–1163.*
52. ^*Wilson JA. Entropy, not negentropy. Nature 1968; 219: 535–536.*
53. ^*Styer D. Entropy as disorder: History of a misconception. The Physics Teacher, 2019; 57: 454–458.*
54. ^*Chen JM, Chen JW. Carbon-Based Evolutionary Theory. Preprints. 2024, https://www.preprints.org/manuscript/202010.0004/v21.*
55. ^*Tolley D, Woodfield BF, Hansen LD. Positional microstates and probability fields in real systems. Pure Appl. Chem. 2024, doi:10.1515/pac-2024-0221.*

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