Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 December 2020 doi:10.20944/preprints202010.0004.v6

A comprehensive evolutionary theory deduced from thermodynamics

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Abstract

Studies on evolution have made significant progress in multiple disciplines, but evolutionary theories remain incomplete, controversial, and inadequate in explaining origin of life and macroevolution. Here we create the concept of carbon-based entities (CBEs) which include methane, amino acids, proteins, bacteria, animals, plants, and other entities containing carbon atoms. We then deduce the driving force, the progressive mechanisms, and the major steps of CBE evolution from thermodynamics. We hence establish a comprehensive evolutionary theory termed the CBE evolutionary theory (CBEET), which suggests that evolution is driven hierarchy-wise by thermodynamics and favors fitness and diversity. The CBEET provides novel explanations for origin of life (abiogenesis), macroevolution, natural selection, sympatric speciation, and animal group evolution in a comprehensive and comprehensible way. It elucidates that collaboration, altruism, obeying rules with properly increased freedom are important throughout the CBE evolution. It refutes thoroughly the notion that negative entropy (negentropy) leads to biological order which is distinct from thermodynamic order. It integrates with research advances in multiple disciplines and links up laws of physics, evolution in biology, and harmonious development of human society.

Keywords

carbon-based entity; driving force; energy; entropy; evolution; fitness; mechanism; natural selection; negentropy; thermodynamics; theory

1. Introduction

Charles Darwin's evolutionary theory built on natural selection is a breakthrough in science. However, natural selection defined in this theory as “survival of the fittest” is literally confusing because some individuals less fit can also survive [1-3]. Charles Darwin's evolutionary theory was updated last century with the Modern Synthesis, which reinforced the importance of natural selection. The Modern Synthesis reinterpreted natural selection as “gradual changes in gene frequencies of populations because those individuals carrying adaptive mutations are more reproductively successful”, as per mathematical modelling and advances in genetics and other disciplines [1-3].

In recent decades, paleontologists revealed that evolution of many species showed in the punctuated equilibrium tempo, with little change in long geological periods and significant changes in short geological periods; molecular biologists revealed that many molecular mutations are likely neutral in natural selection, and some mutations occur not randomly; developmental biologists revealed that acquired epigenetic changes are heritable and important for adaption of organisms [1-14]. These research advances challenge the Modern Synthesis which has not well integrated with these challenges. Moreover, the Modern Synthesis remains inadequate in interpreting origin of life and macroevolution (i.e. evolution above the species level) [1-3].

Charles Darwin's theory, the Modern Synthesis, and some other evolutionary theories were largely extrapolated from microevolution (evolution within species) [1-14]. This logic is prone to generate incomplete and controversial views, like using fishes' eyes to reveal the structure of a river, as different fishes could have different views, and no fishes could reveal the panorama of the river.

Here we deduced a comprehensive evolutionary theory, which can integrate with research advances in multiple disciplines and interpret origin of life and macroevolution. This theory relies on deduction from thermodynamics in determining its framework and observation from microevolution in determining its details. This theory is termed the CBE evolutionary theory (CBEET), where CBE denotes carbon-based entity. CBEs include some small molecules (e.g. methane and ethanol), middle organic molecules (e.g. amino acids and nucleotides), large organic molecules (e.g. proteins and nucleic acids), and organisms (e.g. bacteria, animals, and plants). CBEs have hierarchies, and large organic molecules are higher-hierarchy CBEs (HHCBEs) compared with middle organic molecules, but they are lower-hierarchy CBEs (LHCBEs) compared with organisms.

The differences between the CBEET and previous theories are outlined in **Figure 1** and listed in **Table 1**.

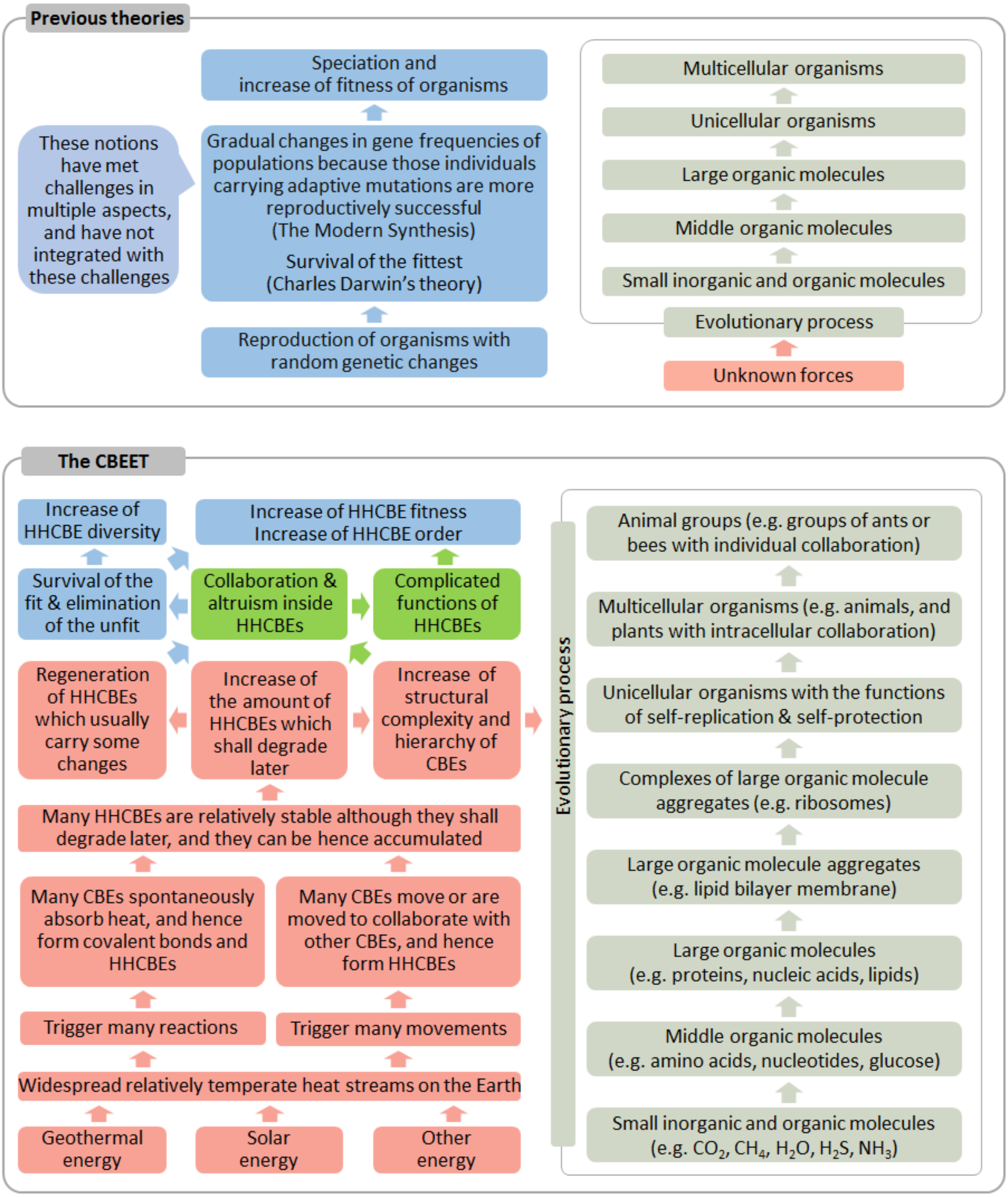

Figure 1. Major views of previous evolutionary theories versus the CBEET. The red, green, and blue arrows represent the driving force mechanism, the structural mechanism, and the natural selection mechanism, respectively.

Table 1. Differences between the evolutionary theory CBEET and previous theories.

Topics	**Previous theories**	**CBEET views**
Logic	Using extrapolation from microevolution, like using fishes' eyes to reveal the structure of a river	Using observation from microevolution (like using fishes' eyes to reveal details of a river) and deduction from thermodynamic laws (like using satellites to reveal the panorama of a river)
The driving force of evolution	Natural selection, genetic drift, mutation, or competition (none of them directly involve energy)	The tendency of carbon-based entities (CBEs) to absorb energy from heat streams on the Earth to form higher-hierarchy CBEs (HHCBEs)
Progressive mechanisms of evolution	Natural selection, sexual selection, and epigenetic changes lead to increase of fitness of organisms; no rational mechanisms have been proposed to interpret macroevolution	The driving force increases the structural complexity and hierarchy of CBEs; CBEs with increased structural complexity and hierarchy can obtain spontaneously some complicated functions; natural selection leads to increase of diversity and fitness of HHCBEs
Natural selection	Defined as "survival of the fittest" or "gradual replacement of populations with those carrying advantageous mutations"; stressing positive selection in one aspect; claiming mutations occur randomly and only inheritable changes are under natural selection	Defined as "survival of fit HHCBEs and elimination of unfit HHCBEs" which leads to increase of fitness and diversity; highlighting the overall fitness constituted by all traits of HHCBEs; highlighting selection from various aspects; accepting that some mutations occur not randomly, and inheritable changes and uninheritable changes (e.g. vaccination) are all under natural selection
Chemical evolution	Neither the driving force nor the mechanisms have been proposed to interpret how large organic molecules evolved into lives; stressing autocatalysis and RNA	The driving force and mechanisms of chemical evolution are revealed; lives originated hierarchy-wise from small molecules with several intermediate hierarchies; stressing collaboration and altruism of various molecules
Biological evolution	Interpreting sympatric speciation with diverging selection targeting different niches in the same area	Proposing a novel sympatric speciation mechanism: different combinations of various traits can all constitute adequate fitness targeting the same niche in the same area
Animal group evolution	Not having established the concept of animal group evolution; difficult to explain altruism and social norms; having negative influence on human society	Establishing animal group evolution as a phase of the evolution; clarifying that collaboration, altruism, and obeying rules with properly increased freedom are important throughout the evolution of CBEs; having positive influence on human society
Biological order and entropy	Organisms have order and low entropy due to negative entropy (input of low-entropy matter and output of high-entropy matter)	Organisms are of high entropy; the notion of "negative entropy" is wrong; biological order is contrary to thermodynamic order; order should not be always hooked with low entropy
General features	Incomplete, elusive, unable to integrate with recent discoveries, separated from physics and social sciences	Comprehensive, comprehensible, able to integrate with recent discoveries in multiple disciplines, bridging laws of thermodynamics and social sciences

2. Methods

2.1 Definitions

Autocatalysis: the phenomenon that the product of a reaction has the activity to catalyze the reaction to produce the product itself.

Multiple other concepts including altruism, CBE, HHCBE, LHCBE, the extrapolation logic, the deduction logic, the backstepping logic, microevolution, macroevolution, natural selection, positive selection, negative selection, punctuated equilibrium, chemical evolution, animal group evolution, and cultural evolution are defined at relevant sites in the main text.

2.2 Fundamentals of thermodynamics [17,18]

The first law of thermodynamics: increase of internal energy of a closed system is equal to the work the surroundings gives to the system plus the heat the surroundings gives to the system.

The second law of thermodynamics: heat can spontaneously flow from a hotter body to a colder body, and cannot spontaneously flow from a colder body to a hotter body; the entropy of an isolated system never decreases over time.

The third law of thermodynamics: the entropy of a system approaches a constant value as its temperature approaches absolute zero, and the entropies of perfect crystals at absolute zero temperature are zero.

The Boltzmann formula of entropy: $S = k \cdot Ln\Omega$, where S, k, and Ω denote entropy, a constant, and microstates (i.e. possible microscopic configurations), respectively. This formula suggests that the entropy of a closed system is only determined by its microstates which are related to the physical and chemical states of the system, particularly the temperature of the system, as higher temperature means more rapid thermal motion of molecules, more microstates, and greater entropy.

The Clausius inequality of entropy: $dS \geq \delta Q/T$, where dS, δQ, and T denote changes of the entropy of a closed system, heat absorbed by the system from the surroundings, and absolute temperature, respectively. This inequality suggests that: first, the entropy of a closed system shall increase if the system absorbs heat from the surroundings, and the entropy of a closed system shall decrease if the system dissipates heat to the surroundings; second, the increase of the entropy of a closed system shall be greater if the system is colder when it absorbs the same amount of heat from the surroundings.

2.3 Deduction and Validation

Deduction of the driving force, the progressive mechanisms, and the major process of CBE evolution was detailed below. The major views of the CBEET are validated through one or two ways: whether the views can explain some phenomena which have not been well explained; whether the views reflect the reality better.

3. Deduction of the driving force of evolution

The earth’s surface has widespread relatively temperate heat streams flowing from the solar, geothermal, and other energy sources. The earth, as a rare habitable planet in astronomy, is in a suitable orbit and receives temperate sunlight, which leads to temperate heat streams on the Earth for billions of years [14]. Meanwhile, many sites on the Earth, particularly at hydrothermal vents, have emitted geothermal energy for long periods [15,16]. The huge amount of water on the Earth and the atmosphere of the Earth regulate these energy flows through evaporation, diffusion, and rainfall, making them more temperate, last longer, and distributed more widely.

The widespread relatively temperate heat streams on the Earth trigger many physical or chemical changes. According to the second law of thermodynamics (i.e. heat can spontaneously flow from a hotter body to a colder body) [17,18], stones can spontaneously absorb heat from these heat streams and increase their temperatures, and many CBEs can spontaneously absorb heat from these heat streams to form HHCBEs through covalent bonds, partially because carbon atoms are prone to form covalent bonds after absorbing heat [19].

The widespread relatively temperate heat streams on the Earth trigger movement of many materials. Many CBEs can hence meet and collaborate with other CBEs to form HHCBEs not through covalent bonds. For example, lipid molecules can form bilayer membranes and ants can form ant groups in this way, where energy required for the movement of these CBEs is directly or indirectly from the widespread relatively temperate heat streams on the Earth. The mechanisms for these CBEs to collaborate to form HHCBEs are given at **Section 4**.

Although all HHCBEs shall degrade sooner or later, many HHCBEs are relatively stable and can be accumulated. HHCBEs have hence been formed, degraded, regenerated, and accumulated at a myriad of places for billions of years, due to the widespread relatively temperate heat streams on the Earth, which constitutes the evolution of CBEs (**Figure 1**). Therefore, the tendency of CBEs on the Earth to absorb energy to form HHCBEs, is the driving force of evolution.

Initially, the driving force of evolution was from solar energy and geothermal energy. Later, with the increase of organisms on the Earth, biological energy became a source of the driving force of evolution. This is of paramount significance for animals which can actively obtain energy and materials from other organisms. Energy from coal, petrol, water flow, and even nuclear power has been utilized by humans for the development of human society.

The above driving force can explain why non-living organic molecules evolved to lives, and why unicellular organisms evolved to multicellular organisms, and why ectotherm animals evolved to warm-blooded animals, because all these three macroevolution events were the processes where CBEs absorbed energy and formed HHCBEs, as driven by thermodynamics. They cannot be well explained with previous theories including natural selection, because none of the processes added fitness to CBEs [3-5,10,20,21].

During the whole history of the Earth, the amount and the diversity of HHCBEs including organisms on the Earth are generally increasing [22]. However, meteorite impacts, huge volcano eruptions, long glacial periods, and other catastrophes can destroy the temperate heat streams on the Earth and structures of many organisms [23-25]. Consequently, the amount and the diversity of organisms could decline greatly for these catastrophes, sometimes leading to mass extinctions [23-25].

4. Deduction of the progressive mechanisms of evolution

Three progressive mechanisms of evolution were deduced from the driving force of evolution. The first is termed the driving force mechanism shown with the red arrows in **Figure 1**, where the driving force of evolution directly raises the amount of HHCBEs and increases the structural complexity and hierarchy of CBEs. The second is termed the structural mechanism shown with the green arrows in **Figure 1**, where CBEs with increased structural complexity and hierarchy spontaneously obtain some complicated functions, due to collaboration and altruism of the components inside HHCBEs (altruism is the action supporting the production, existence, and functions of other entities). For example, when green fluorescence protein is formed by amino acids, it obtains spontaneously the function of emitting green fluorescence, due to collaboration and altruism of its amino acid components, which all “sacrifice” their freedom to support the function of the protein. The third mechanism is termed natural selection shown with the blue arrows in **Figure 1**, which leads to increase of the diversity and the fitness of CBEs, as detailed below.

As shown in **Figure 1**, the driving force of evolution leads to formation and accumulation of HHCBEs. The formed HHCBEs shall degrade into LHCBEs sooner or later, due to outer factors (e.g. fire burning) or inner factors (e.g. natural aging) [1,2]. Therefore, lots of CBEs on the Earth are in the cycle of formation and degradation of HHCBEs, leading to regeneration of HHCBEs. Regenerated HHCBEs usually carry some changes. These changes influence collaboration and altruism of the components inside HHCBEs, which further influence the fitness of HHCBEs. Some regenerated HHCBEs are formed faster and/or degrade more slowly than some other HHCBEs, resulting from the overall fitness of HHCBEs.

Natural selection is defined in the CBEET as survival of fit HHCBEs and elimination of unfit HHCBEs. Whether an HHCBE is fit, or whether an HHCBE is of adequate fitness, is determined not only by collaboration and altruism of its component, but also by its environment. For example, an HHCBE having great fitness in a hot rainforest can be unfit in a cold desert. Moreover, when the environment is comfortable, the fitness threshold of natural selection is low, which allows survival of HHCBEs carrying various changes. This could lead to rapid divergence of HHCBE including species explosion [26]. When the fitness threshold of natural selection is low, some

HHCBEs with reduced fitness could survive if they have adequate overall fitness. In contrast, the fitness threshold of natural selection increases greatly when a catastrophe occurs, which can lead to mass extinction of organisms including those quite fit previously [23-25].

The CBEET definition of natural selection maintains the core feature of the concept of natural selection in Charles Darwin's evolutionary theory and in the Modern Synthesis [3-5]: fitness of organisms increases over time because natural elimination of unfit organisms.

The CBEET definition of natural selection is also different from previous definitions in multiple aspects.

First, the CBEET definition covers non-living CBEs and can be extended to origin of life, while natural selection in previous theories are largely restricted to evolution of organisms.

Second, as shown in **Figure 1**, regeneration of HHCBEs is deduced from thermodynamics, and the changes carried by regenerated HHCBEs influence collaboration and altruism of its component, which further influence the fitness of HHCBEs and are thus under natural selection. Therefore, unlike that natural selection in previous theories is supported by itself and hence suspected of tautology [27], natural selection in the CBEET is supported by structures of HHCBEs and laws of thermodynamics.

Third, the CBEET definition (survival of fit HHCBEs) is less harsh and more inclusive than "survival of the fittest" in Charles Darwin's theory and "gradual replacement with those carrying advantageous mutations" in the Modern Synthesis [1-4], and the CBEET definition reflects the reality correctly because research advances in molecular biology suggest that most genomic changes are likely neutral without increase in fitness [3-5,10,12,28].

Fourth, the CBEET definition of natural selection highlights the overall fitness because the reality is that the existence of an HHCBE is determined by its overall fitness, although a certain trait may play a leading role in the overall fitness of an HHCBE. Therefore, the CBEET allows an organism to have disadvantageous traits, if its overall fitness is adequate. For example, antelopes are less strong than buffaloes to fight against carnivores, but they run fast and have other advantages, making them have adequate fitness in general. This suggests a novel mechanism of sympatric speciation, because multiple combinations of various traits can all constitute adequate overall fitness in occupying the same ecological niche in the same area. Previously, only the mechanism for sympatric speciation targeting different ecological niches in the same area has been proposed, as different ecological niches exert different selection pressures which render organisms evolving towards different directions [3].

Fifth, genetic mutations, epigenetic changes, and uninheritable changes all influence the overall fitness of HHCEBs, and they are thus all under natural selection. For example, vaccination which is uninheritable makes many animals survive viral infections and pass the relevant natural selection.

Sixth, previous definitions usually assume that mutations under natural selection occur randomly. Now it has been known that many organisms have the complicated function which makes many mutations occur not randomly, as evidenced in the evolution of microbial genomes and mammalian immunoglobulin genes [9,29].

Organisms accumulated much fitness through long geological periods. Therefore, organisms are under both positive selection (i.e. natural selection supports those changes which add fitness) and negative selection (i.e. natural selection inhibits those changes which reduce fitness) [30]. Because natural selection "selects" organisms as per their overall fitness which is influenced by all genomic sites and all traits, all genomic sites and all traits are under both positive selection and negative selection [30,31]. Accordingly, natural selection functions extensively in evolution. Moreover, a conserved trait or genomic site without change during a long geological period does not mean that the trait or site is not under natural selection, but likely under strong negative selection [30].

Previously geographical isolation was employed to explain the evolutionary tempo of punctuated equilibrium. Here co-action of positive selection and negative selection provides a more comprehensive explanation for punctuated equilibrium, as detailed in **Figure 2**, which suggests that both geographical isolation and climate or ecological changes can trigger significant changes in traits in short geological periods.

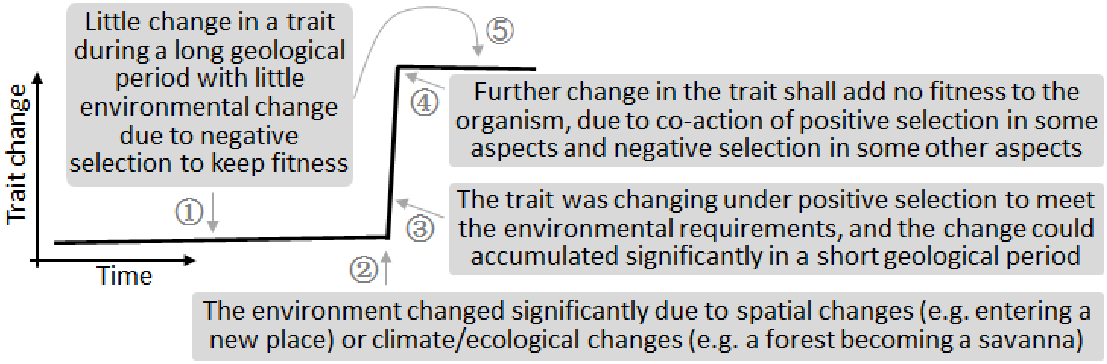

Figure 2. Reasons for the evolutionary tempo of punctuated equilibrium

Natural selection in the CBEET targets all hierarchies of CBEs. For example, giraffe groups, giraffe individuals, and cells, large organic molecules including genes in giraffes are all under natural selection along with giraffe groups. If a giraffe group is favored by natural selection, the LHCBEs involved in the formation of the giraffe group, including genes of the giraffe group, are also favored by natural selection.

Natural selection, mutation, genetic drift, and competition were claimed to be the driving force of evolution [3-5,20,28,31]. These "driving forces" are not directly related to energy, and so they are largely mechanisms or processes of evolution, not the driving force of evolution. The role of energy in biological evolution was highlighted previously [32,33], but energy has not been associated with the driving force of evolution. Here the driving force of evolution from thermodynamics provides energy for the evolution of CBEs. Moreover, all the three progressive mechanisms of evolution are derived from the driving force of evolution (**Figure 1**). Therefore, the driving force of evolution plays the first leading role in evolution, although natural selection functions extensively in evolution and remains a leading role in evolution.

5. Deduction of the process of evolution

The driving force of evolution from thermodynamics leads to formation and accumulation of HHCBEs hierarchy by hierarchy. For example, amino acids, nucleotides and other middle organic molecules could not bypass the intermediate hierarchy of large organic molecules to form unicellular organisms, and large organic molecules could not bypass the intermediate hierarchy of unicellular hierarchy to form multicellular organisms. Accordingly, as per the backstepping logic (i.e. if hierarchy A exists, the hierarchies lower than hierarchy A should have existed in advance), there should be the following seven major steps constituting the whole evolution of CBEs on the Earth (**Figure 1**).

Step 7, many animal individuals of the same species collaborate with each other and form animal groups, which include groups of bees, ants, humans, and many other animals. Animal groups have novel functions which cannot be fulfilled by animal individuals. For example, some ant groups plant fungi for food, which cannot be fulfilled by ant individuals [34]. Some animal groups are eusocial, where some individuals reduce their own lifetime reproductive potential to raise the offspring of others. Many other animal groups are presocial, where the parents take care of their own progenies [46]. Although presocial species are much more common than eusocial species, eusocial species have disproportionately large populations [35].

Step 6, many cells collaborate with each other and form multicellular organisms, which include fungi, plants, and animals. Multicellular organisms have novel functions which cannot be fulfilled by any cells (e.g. birds can fly faraway which cannot be fulfilled by any cells).

Step 5, many complexes of large organic molecule aggregates collaborate with each other and form the first batch of unicellular organisms, which are the units having the complicated functions of self-replication via catalysis (for efficiently generating HHCBEs) and self-protection (for efficiently maintaining HHCBEs). The first batch of unicellular organisms emerged at a tiny possibility, and this tiny possibility was realized through the effect of vast spaces and vast time.

Step 4, many large organic molecule aggregates collaborate with each other and form complexes of large organic molecule aggregates which, like organelles in the unicellular organisms, have some complicated functions (e.g. synthesis of proteins).

Step 3, many large organic molecules collaborate with each other and form large organic molecule aggregates (e.g. lipid bilayer membranes and channels allowing ions to pass lipid bilayer membranes) [36]. From this step to the seventh step, energy is not always required to form chemical bonds, but is required for the movement of CBEs to meet and collaborate with other CBEs.

Step 2, many middle organic molecules (e.g. amino acids, nucleotides, glucose) collaborate with each other and form proteins, nucleic acids, polysaccharides, and other large organic molecules. Before origin of life, few mechanisms were available to direct the synthesis of large organic molecules according to certain orders, and so proteins, nucleic acids, lipids, polysaccharides were produced with few repetitions, and thus the products were of a myriad of diversity. These highly diversified large organic molecules could provide abundant candidates for forming HHCBEs in **Steps 3–7**. This was beneficial for complexes of large organic molecule aggregates to form unicellular cells at a tiny possibility.

Step 1, many small molecules (e.g. CO_2, CH_4, H_2O, H_2S) collaborate with each other and form middle organic molecules (e.g. amino acids, nucleotides, glucose). This step has also occurred on other planets, and lots of middle organic molecules were sent to the Earth by meteorites [37].

Box 1. How could live emerge at a tiny possibility through abiogenesis?
The Earth about 3.8 billion years ago could be much warmer than the current Earth, and most of the then Earth could be covered with warm water containing abundant of small, middle, large organic molecules, large organic molecule aggregates, and complexes of large organic molecule aggregates. If these CBEs on the whole Earth tried to form unicellular organisms for one billion times every hour, and the successful possibility was only 10^{-15}, then over 8 million unicellular organisms could emerge through abiogenesis within one billion years.

Steps 1–5 constitute chemical evolution which is also termed abiogenesis or origin of life. **Steps 5–7** constitute biological evolution excluding abiogenesis. **Step 7** constitutes animal group evolution including the development of human society.

Steps 1–5 suggest that, before origin of lives, there were five successive and overlapping worlds: the world of small molecules, the world of middle organic molecules, the world of large organic molecules, the world of large organic molecule aggregates, and the world of complexes of large organic molecule aggregates. Compared with previous theories which emphasize the special role of RNA and some organic molecules with the function of autocatalysis [38,39], the CBEET highlights collaboration and altruism of various molecules.

Components of HHCBEs should obey certain rules. This is embodied throughout the evolution of CBEs. For example, molecules should obey some rules in cells, and cells should obey some rules in multicellular organisms. Individuals in animal groups should obey some rules, including that lion kings should take their responsibility to fight against invaders, and worker bees should work diligently all days for their groups, and drivers should obey traffic rules. Obeying rules is the basis of collaboration and altruism of inside HHCBEs which, in turn, determine the overall fitness of HHCBEs.

As for the seven steps given above, components of HHCBEs are restricted within molecules (**Steps 1 and 2**), within molecular aggregates or complexes (**Steps 3 and 4**), within cells (**Step 5**), within multicellular organisms (**Step 6**), or within certain areas (**Step 7**). Therefore, freedom of components of HHCBEs should be restricted, and their freedom increases along with the increase of CBE hierarchies.

6. Significance for human society

The CBEET aids the harmonious development of human society. First, previous evolutionary theories stress selfishness, competition, and elimination of those less fit in certain traits [1-5,24]. These notions have been employed to justify authoritarianism, racism, fascism, and Nazism [40]. In contrast, the CBEET not only emphasizes selfish (self-reproduction and self-protection), fitness, and competition, but also emphasizes increase of diversity and co-existence of many differences and changes. This suggests that we should respect diversity in races, culture, and management systems. Second, previous evolutionary theories stress genetic differences, while the CBEET not only emphasizes genetic differences, but also emphasizes the effects of endeavor to increase fitness, even if the effects are uninheritable. Third, previous evolutionary theories stress advantages of a certain trait, while the CBEET emphasizes overall fitness and all traits. This is important for humans in making correct decisions. Moreover, the CBEET demonstrates that collaboration, altruism, obeying rules with properly increased freedom are all embodied throughout the evolution of CBEs including development of human society.

7. Significance in physics

The CBEET refuted the notion that negative entropy (i.e. negentropy) leads to biological order. Evolution leads to increase of biological order, which seems contrary to the second law of thermodynamics leading to increase of entropy in isolated systems, because entropy represents chaos in thermodynamics [17,18,41]. Some scientists assumed that organisms are systems with low entropy because organisms have much order, and organisms keep low entropy through absorbing low-entropy matter and discharging high-entropy matter, and hence the controversial notion of “negentropy” was established [41,42].

We believe that this notion negentropy is wrong as per the definitions of entropy [17,18], and it is incorrect to hook all kinds of order with low entropy (this mistake prevails in common people and scientists [41-44]). For example, we take a dog as a close system herein, and this dog is dying in the snow with heat being lost from the dog to the surroundings, the biological order of the dog declines as it is dying, and the thermodynamic order of the same dog increases because the entropy of the dog declines, as per the Clausius inequality of entropy [17,18]. Live dogs are warm and moving systems with many microstates, and they have hence high entropy, compared with perfect crystals at absolute zero temperature which have the lowest entropy and the highest thermodynamic order, as per the Boltzmann formula of entropy and the third law of thermodynamics [17,18]. As deduced in **Section 4**, biological order is established through billions of years' evolution, rather than a short-time metabolic effect of negentropy. During the period that fertilized eggs grow into mature dogs, the biological order of these dog change little, while their entropies increase billions of times, as per the additive property of entropy [17,18]. Contrary to the notion of negentropy, the entropy of what we absorb is greater than the entropy of what we discharge, which is clear by this example: the materials absorbed by a fetus for rapid growth in the uterus are much more than the materials discharged by the fetus, and thus the entropy of the materials absorbed by the fetus is much more than the entropy of the materials discharged by the fetus.

In effect, lives rely on entropy rather than negentropy, because lives rely on movement of their inner components. Ludwig Boltzmann, who created the Boltzmann formula of entropy, also pointed that animate beings struggle for entropy which becomes available through the transition of energy from the hot sun to the cold earth [44]. Interestingly, this view was inherited and detailed by the CBEET.

Under certain inherent mechanisms, some high-entropy systems, such as organisms, choruses, armies, airplanes, and skyscrapers, can demonstrate some kinds of order. Although negentropy which has polluted science widely for decades was criticized previously [41,45], the facts elucidated here that all kinds of order should not be simply hooked with low entropy refuted negentropy thoroughly and clearly.

Box 2. Another widespread notion pertaining to entropy is also incorrect.

The entropy of a pile of books placed neatly is frequently claimed to be less than the entropy of the same pile of books placed messily. In effect, the entropy of the pile of books changes little no matter whether they are placed neatly or messily, as the books do not absorb heat from the surroundings or dissipate heat to the surroundings through the arrangement. The chaos of the books we observe is different from the chaos of the pile of books at the level of microscopic particles (i.e. microstates, which determine the entropy of the pile of books).

Acknowledgements: This study has not been supported by any funds so far. The author thanks many friends of his for providing precious comments on this study.

Author contributions: This study is completed by Ji-Ming Chen.

Competing interests: The author declares no conflict of interest.

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