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The Carbon-Based Evolutionary Theory (CBET)

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Abstract: Why and how did simple and unordered substances on Earth evolve into complex, orderly, and diverse organisms and social organizations? Here we propose the Carbon-Based Evolutionary Theory (CBET) to provide an explicit and comprehensive answer to this fundamental scientific question. The CBET is based on the integration of the principles of physics and chemistry (e.g., laws of thermodynamics), the features of Earth (e.g., having abundant water and energy), and the features of carbon-based materials (CBMs) using rational logic and abundant evidence from a panoramic view. The integration reveals the driving force mechanism, the structure-function mechanism, and the natural selection mechanism, which underpin evolution with energy supply, function generation, and structural optimization, respectively. These three mechanisms escalate the hierarchy of CBMs, augment the quantity, diversity, and orderliness of high-hierarchy CBMs, and lead to chemical, biological, and social evolution. The CBET uncovers the natural roots of multiple pivotal and seemingly paradoxical social notions, such as inclusiveness versus elimination, cooperation versus competition, and altruism versus selfishness. It advocates for the balanced, harmonious, and peaceful development of human society. The CBET could unify biology with physics and chemistry, bridge the natural sciences and the social sciences, and guide the rational development of human society.

Keywords: carbon; chemistry; evolution; logic; mechanism; natural selection; theory; physics; society

1. Introduction

Why and how did unordered, simple substances on Earth evolve into numerous, complex, and diverse organisms and social organizations? This is a fundamental question in science that has captivated humans for millennia [1]. Creationists claim that humans, life, Earth, and the whole universe were created by one or more supernatural powers [2].

In physics, some notions, such as negative entropy proposed by Nobel laureate Erwin Schrödinger [3], the dissipative structure theory proposed by Nobel laureate Ilya Prigogine [4], and the maximum entropy production hypothesis [5], have been proposed to interpret the natural origin of orderliness. These notions, which were based on abstract concepts, did not provide explicit explanations for evolution.

In chemistry, in the 1920s, Alexander Oparin proposed a hypothesis suggesting that life on Earth originated through a gradual chemical evolution of organic molecules [6]. Since the 1950s, numerous experiments have been conducted to investigate how various organic molecules, such as amino acids, monosaccharides, nucleotides, proteins, and nucleic acids, could be synthesized naturally on the prebiotic Earth [7–15]. The concept of chemical evolution has been widely accepted, although the mechanism has not been revealed. In the 1970s, the hypercycle theory proposed by Nobel laureate Manfred Eigen assumed that some autocatalytic macromolecules are interconnected in a way that each of them catalyzes the production of its successor, with the last molecule catalyzing the first one [16]. To date, no macromolecules have been identified to support the hypercycle theory.

In biology, various evolutionary theories have been proposed, including the natural selection hypothesis proposed by Charles Darwin in the 19th century and its updated version, the Modern Synthesis, which emerged in the 20th century [17]. Darwin's theory elucidated the importance of natural selection, and the Modern Synthesis elucidated the genetic basis underlying it [17]. These two theories cannot explain some macroevolution issues, such as the origin of life and multicellular

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organisms, because organisms are no fitter than inanimate materials, and multicellular organisms are no fitter than unicellular organisms [17].

In the social sciences, some social evolution theories, inspired by Darwin's theory, led to notorious notions like social Darwinism, which highlighted fierce competition and justified colonialism, slavery, racism, and massacre [18–20]. These theories have not revealed the natural roots of some key social notions, such as inclusiveness, altruism, and cooperation.

In general, previous evolutionary theories are either confusing (e.g., some theories in physics and the hypercycle theory) or incomplete (e.g., Darwinism, the Modern Synthesis, and some social evolutionary theories). Here we propose the Carbon-Based Evolutionary Theory (CBET) in order to provide an explicit and comprehensive explanation for evolution.

2. Definitions

Driving force refers to the energy that propels changes. For instance, gasoline provides the driving force for fuel-powered cars.

Mechanism refers to the reason for the change of things. For instance, airplanes have two mechanisms for flying: one is that they have a sophisticated structure supporting the flight, and the other is that burning of fuel generates energy or driving force for the flight.

Carbon-based materials (CBMs) refer to those substances in which carbon atoms play a major role at the atomic level. There are eight hierarchies of CBMs, as defined below.

H0-CBMs refer to carbon atoms.

H1-CBMs refer to small carbon-containing molecules (CCMs), such as methane and carbon dioxide.

H2-CBMs refer to intermediate CCMs, such as lysine and glucose.

H3-CBMs refer to large CCMs, such as proteins and nucleic acids, composed of H2-CBM residues and some functional groups.

H4-CBMs refer to individual cells, such as bacteria, composed of various H3-CBMs and other molecules.

H5-CBMs refer to multicellular organisms, such as pines and rabbits, composed of some H4-CBMs (cells) and other materials.

H6-CBMs refer to social collectives with only one hierarchy in management, such as ant colonies, bee colonies, and departments of a university, composed of some animal or human individuals that closely cooperate for the collective good and have distinct roles within the collectives.

H7-CBMs refer to human social collectives that have multiple hierarchies in management, and low-hierarchy collectives closely cooperate with different duties for high-hierarchy collectives. For instance, a university is an H7-CBM as it possesses the hierarchies of departments, colleges, and university in management. Also, an army and a country are H7-CBMs, as they have multiple hierarchies in management.

Notably, no clear lines separate these CBM hierarchies. For instance, some peptides are between H2-CBMs and H3-CBMs, viruses are between H3-CBMs and H4-CBMs, and lion groups are between H5-CBMs and H6-CBMs.

High-hierarchy CBMs (HHCBMs) and **low-hierarchy CBMs (LHCBMs)** are defined by comparing their hierarchies. For instance, H4-CBMs are HHCBMs compared to H3-CBMs, but they are LHCBMs compared to H5-CBMs.

Simple CBMs and **complex CBMs** are defined by comparing their structural complexity. For instance, eukaryotic paramecia are complex CBMs compared to prokaryotic staphylococci, but they are simple CBMs compared with multi-cellular ants.

Chemical evolution refers to the evolution from small CCMs to intermediate CCMs and large CCMs, or from H1-CBMs to H2-CBMs and H3-CBMs.

Biological evolution refers to the origin and evolution of life, namely H4-CBMs and H5-CBMs.

Social evolution refers to the origin and evolution of animal or human social collectives, namely H6-CBMs and H7-CBMs.

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The evolution of CBMs refers to the entire evolution process from H1-CBMs to H7-CBMs, covering chemical evolution, biological evolution, and social evolution.

3. Features of Earth and CBMs

3.1. Features of Earth

Feature 1: Earth has abundant energy sources, such as sunlight, lightning, geothermal energy, volcanoes, fires, water flow, wind, and the degradation of organic materials [21].

Feature 2: Earth has abundant water, which weighs around 1.35×10^{18} tons [22].

The energy released from the energy sources on Earth is regulated by the atmosphere, which is over 1,000 kilometers thick, and the abundant water on Earth. This regulation helps to maintain a moderate, widespread, and persistent distribution of energy on Earth and renders Earth an exceptionally rare and hospitable celestial body in astronomy [21].

Water and energy are essential to the synthesis of organic molecules, the growth of plants, the movement of animals, the reproduction of organisms, and the development of human societies. Besides adjusting the energy on Earth, water participates in the formation of all hierarchies of CBMs as an important constituent component and the environment of the formation. Water is also important to maintain the structures and functions of numerous CBMs. Given the crucial role of water and energy, tropical rain forests boast a greater abundance and variety of organisms compared to tropical deserts or cold regions.

3.2. Features of H0-CBMs (carbon atoms)

Feature 1: Carbon is abundant on Earth. The atmosphere, water bodies, and biosphere on Earth could contain 9×10^{11}, 36×10^{11}, and 5.5×10^{11} tons of carbon, respectively [23,24]. Stones, coals, petroleum, natural gas, and methane hydrates on Earth also contain abundant carbon.

Feature 2: Carbon atoms can form numerous intermediate CCMs via chemical bonds with many other atoms. This is because carbon atoms are smaller than the other atoms (silicon, germanium, tin, and lead) that have four electrons in their valence shells [23,24].

Feature 3: Among all elements, carbon is unique in its ability to form long, relatively stable chains of interconnected bonds, which serve as the backbone for numerous large CCMs that are soluble in water. These backbones can bond with atoms such as hydrogen, oxygen, nitrogen, sulfur, phosphorus, halogens, metals, and various groups of atoms known as functional groups. The length, shape, and chirality of the chains all play a role in determining the properties of these large CCMs. No other atoms, including boron and silicon, are capable of forming the backbones of chains in large molecules that are as long, complex, or stable as carbon-based large organic molecules in water [23,24]. Because stable, complex, and water-soluble large molecules are essential for the construction of organisms, it is widely accepted that only CBMs have the potential to evolve from simple structures into life [23,24].

3.3. Features of other CBMs (H1-CBMs to H7-CBMs)

Feature 4: Many CBMs are relatively stable on Earth. For instance, some proteins have been well preserved in fossils for millions of years [25], and various H2-CBMs have been preserved longer than proteins in meteorites [26]. Human individuals can usually live for decades, and some plants can live for millennia.

Feature 5: Many CBMs, along with other materials, can form CBMs one hierarchy higher after energy absorption. For instance, CO_2 (belonging to H1-CBMs) and water, after absorbing energy from sunlight, are able to form glucose (belonging to H2-CBMs) in plant leaves, and glucose can form polysaccharides (which belong to H3-CBMs) after absorbing heat under the catalysis of amylase. This is further elaborated below in Sections 4 and 7.

Feature 6: Almost all complex CBMs are degradable. Typically, an external factor such as fire, collision, or radiation can degrade a complex CBM by disrupting its component interactions. High temperatures, such as those from mountain fires or asteroid impacts, can accelerate the degradation

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of complex CBMs [17]. Usually, it is easier to destroy a complex CBM than to generate it. For instance, it takes only minutes with electricity to kill a pig that has been nourished for months. Additionally, HHCBMs cannot be directly formed from CBMs that are two or more hierarchies lower, while HHCBMs can be degraded into CBMs that are two or more hierarchies lower. For instance, a living tree (an H5-CBM) can be directly decomposed into carbon atoms (H0-CBMs) and other materials.

Feature 7: Organic synthesis reactions of many H2-CBMs and H3-CBMs are complex, with products varying based on different starting materials and reaction conditions. Even when using the same starting materials under identical reaction conditions, the products of these reactions are usually diverse. Furthermore, H4-CBMs to H7-CBMs, are multifarious because they result from the recombination of various LHCBMs.

4. The Driving Force Mechanism

As shown in Section 3, Earth possesses abundant energy sources. Many CBMs and other materials, such as water, stones, and organisms, can spontaneously or actively absorb energy from these sources under the principles of physics and chemistry that apply to the hierarchies from atoms to the solar system where the evolution of CBMs occurred. For instance, under the laws of Newtonian mechanics animals can actively seek and take food, and under the second law of thermodynamics many materials can spontaneously absorb heat on Earth, which can further lead to the spontaneous synthesis of various H2-CBMs and H3-CBMs [27,28]. This constitutes the driving force mechanism of the evolution of CBMs. This mechanism provides the energy required for the structural changes of CBMs [29], as elucidated below.

CBMs can undergo various changes upon absorbing energy, such as an increase in temperature and the formation of more complex CBMs (Figure 1). Certain H1-CBMs, such as HCN, CO_2, and CH_4, along with other materials, can form H2-CBMs, like amino acids, nucleotides, and monosaccharides, through some energy-absorbing organic synthesis reactions under the laws of thermodynamics and organic chemistry [6–15]. Similarly, certain H2-CBMs, along with other materials, can form H3-CBMs, like proteins, nucleic acids, and lipids, through some energy-absorbing organic synthesis reactions under the laws of thermodynamics and organic chemistry [7–9]. Some H3-CBMs and other molecules can form H4-CBMs (unicellular organisms like bacteria) through some energy-absorbing organic synthesis reactions and energy-consuming physical movements. Some H4-CBMs and other materials can form H5-CBMs (multi-cellular organisms like birds and trees) through some energy-absorbing organic synthesis reactions and energy-consuming physical movements. For instance, some fertilized eggs and related materials develop into adult elephants through many energy-absorbing organic synthesis reactions and many energy-consuming physical movements. Some animal individuals (e.g., ants and bees) can form animal social collectives (H6-CBMs) with energy primarily derived from their food metabolism through organic decomposition reactions. Some human H6-CBMs can form multi-hierarchy social collectives (H7-CBMs), such as universities and armies, with energy from food and other sources, such as electricity, fossil fuels, and wind energy.

Complex CBMs formed through the above energy-absorption processes are usually subject to degradation due to the sixth feature of CBMs listed in Section 3.3. Complex CBMs can be established hierarchy by hierarchy from H1-CBMs to H7-CBMs, and they can be degraded into CBMs one or more hierarchies lower, and the degradation usually releases energy and some relatively simple CBMs and other materials (Figure 1). The degraded complex CBMs and some other materials can form new complex CBMs through the above energy-absorption processes again. Regenerated complex CBMs usually carry some structural changes due to the seventh feature of CBMs listed in Section 3.3. Therefore, there are cycles of formation and degradation of complex CBMs, and many complex CBMs carry some structural changes over these cycles. The cycles constitute a major part of the carbon cycle on Earth between the atmosphere, land, oceans, biosphere, and human society [23,25].

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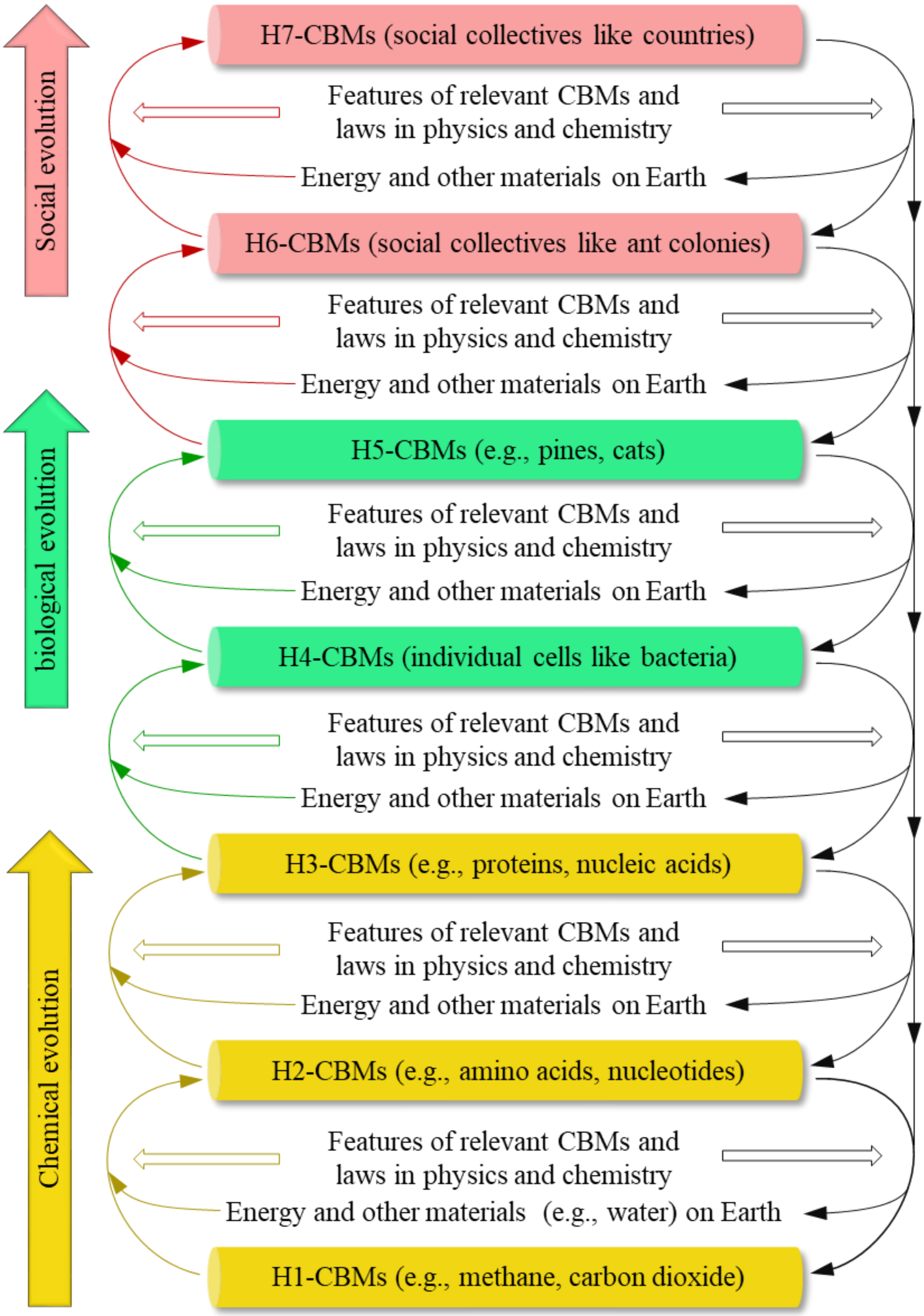

Figure 1. Formation and degradation of complex carbon-based materials (CBMs). Complex CBMs can be formed hierarchy by hierarchy from H1-CBMs to H7-CBMs due to energy absorption, and they can be degraded into CBMs one or more hierarchies lower.

5. The Structure-Function Mechanism

Some complex CBMs formed through the above energy-absorption processes can obtain new functions. For instance, bird cells cannot fly, but birds can. This aligns with the core principle of systems theory: the whole is greater than the sum of its parts [30].

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Some complex CBMs that have changed their structures during their aforementioned cycles of formation and degradation can obtain some new functions. For instance, genomic mutations can change the running rates of goats, the chemical communication within insect colonies, and the intelligence of humans.

The above two facts stem from the logic that structural changes can generate new functions. They constitute the structure-function mechanism of the evolution of CBMs, and this mechanism generates some new functions that can facilitate the formation and maintenance of complex CBMs, as shown by the following examples.

(1) Some CBMs can catalyze chemical reactions. For instance, various H2-CBMs (e.g., proline [31]) and H3-CBMs (e.g., many peptides or enzymes [32,33]) can catalyze the synthesis or degradation of certain H2-CBMs and H3-CBMs.

(2) Some CBMs can capture constituent materials for themselves. For instance, some bacteria can actively absorb water and organic molecules to construct the structures of themselves and their offspring.

(3) Some CBMs can actively absorb energy. For instance, some bacteria can actively absorb energy from sunlight to maintain themselves and reproduce offspring.

(4) Some CBMs can protect themselves or other CBMs. For instance, liposomes can safeguard H2-CBMs and H3-CBMs that are water-soluble from certain degradation enzymes.

(5) Some CBMs can provide direction for the precise synthesis of some H3-CBMs. For instance, nucleic acids (DNA or RNA) can serve as the template to direct the synthesis of DNA, RNA, and proteins, ensuring their precise extension according to specific sequences.

(6) Some CBMs can reproduce. For instance, some H4-CBMs can integrate the above five functions to reproduce their offspring.

(7) Some organisms can conduct sexual selection. For instance, female lions mate with male lions who have demonstrated their dominance through fighting.

(8) Some organisms can encounter non-random mutations. For instance, bacteria can reduce random mutations at important genomic sites, and human bodies can enhance the mutation frequencies of immune genes [34,35].

(9) Some organisms can encounter epigenetic changes. Some epigenetic changes in gene functions are heritable and can result in alterations to biological traits, despite the fact that the sequence of the relevant genes remains unchanged [36].

(10) Humans can accumulate knowledge. This function is due to the high intelligence of humans, which stems from the intricate structure of their brains.

(11) Humans can manufacture silicon-based lives that can be extremely powerful in intelligence and significantly shape the evolution of human societies and the environment.

The above 11 examples also demonstrate that many features of CBMs mentioned in Figure 1 are generated through the structure-function mechanism.

6. The natural selection mechanism

As elucidated in Section 4, there are cycles of formation and degradation of complex CBMs, and many complex CBMs carry some structural changes over these cycles. These cycles hold the following three mathematical logics.

Logic 1: If the total formation of a complex CBM exceeds its total degradation, this complex CBM persists on Earth.

Logic 2: If the ratio of the formation to degradation of a complex CBM exceeds 1 (or falls below 1), the quantity of this complex CBM is increasing (or decreasing) during the relevant period.

Logic 3: If the ratio of the formation to degradation of complex CBM A is greater than that of complex CBM B, the ratio of CBM A versus CBM B in quantity is increasing during the relevant period.

The above three mathematical logics constitute the natural selection mechanism, which has the following features.

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(1) Natural selection stems from mathematical logics, which are the essence of its operation. Natural selection in previous theories stems from the survival competition of organisms, which is a phenomenon of the mathematical logics within the biosphere.

(2) Natural selection not only applies to biological evolution as assumed by previous theories but also applies to chemical and social evolution.

(3) The overall performance of the formation and maintenance (OPFM) of a complex CBM determines its fate in natural selection according to the three mathematical logics. The OPFM is not fully determined by any single component, trait, or hierarchy of the complex CBM but is a product of the collective contribution of all components, traits, and hierarchies of the complex CBM [37]. This implies that all components, all traits, and all hierarchies of a complex CBM are subject to natural selection. Meanwhile, certain traits of complex CBMs, such as the running ability of antelopes, the cooperative behavior of wolves, or human individual expertise, can significantly enhance a CBM's OPFM. Consequently, natural selection underscores both all-round development and specialized development.

(4) Natural selection in the CBET exhibits inclusiveness. According to Logic 1 stated above, a complex CBM can persist on Earth if its total formation exceeds its total degradation, even if its OPFM is lower than that of its predecessor or other CBMs. Consequently, natural selection permits organisms to have some disadvantages. For instance, many people carry gene mutations linked to genetic diseases, and human neonates are more vulnerable than those of some other mammals. This further suggests that some biological traits, like the long necks of giraffes, can be beneficial, neutral, or detrimental in natural selection. The inclusiveness of natural selection aligns with the prevalence of neutral mutations in genomes, as these mutations have minimal impacts on the OPFM of the relevant organisms [17]. In contrast, previous theories emphasized the fierce competition in natural selection, which was expressed as “survival of the fittest” in Darwin's theory and “gradual replacement of populations with those carrying advantageous mutations” in the Modern Synthesis [17]. The inclusiveness of natural selection, along with the aforementioned driving force mechanism and the structure-function mechanism, can interpret the increasing biodiversity on Earth and certain macroevolution events. For instance, organisms, multicellular organisms, and endothermic animals are not inherently fitter than inanimate materials, unicellular organisms, and ectothermic animals, respectively, yet they can all maintain sufficient OPFM (i.e., their total formation exceeds their total degradation) due to some functions generated by the structure-function mechanism and the energy supplied by the driving force mechanism.

(5) Natural selection in the CBET is influenced by both inheritable and non-inheritable factors. For instance, some genetic factors can enhance the OPFM, while non-heritable factors such as education and vaccination can also increase humans' OPFM. This underscores innate advantages and acquired strengths. Additionally, epigenetic changes, whether heritable or not, can affect an organism's OPFM and, consequently, affect natural selection [38].

(6) Whether an HHCBM has sufficient OPFM in natural selection depends not only on its own characteristics but also on the environment. Therefore, organisms must adapt to their environment or migrate to suitable environments, and humans should balance between resource exploitation and environmental protection.

(7) Natural selection involves competition, as suggested by Logic 2 and Logic 3 stated above. The competition results in the accumulation of structural changes (positive selection) that are beneficial in functions to the OPFM of complex CBMs and the elimination of structural changes (negative selection) detrimental in functions to the OPFM of complex CBMs. The synergy of positive selection and negative selection leads to a continuous process of optimizing inner structures, fostering inner cooperation, and thereby accumulating inner orderliness within the relevant complex CBMs.

(8) Natural selection underscores both selfishness and altruism. Selfishness is essential for animals to obtain adequate materials, energy, suitable environments, and mating opportunities to make their total formation exceed their total degradation. Meanwhile, altruism is critical for the success of many complex CBMs in natural selection and is widespread throughout the evolution of

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CBMs. For instance, many molecules are catalyzers, energy-providers, or constituent materials for the synthesis of other molecules in organisms. Many molecules in H4-CBMs (e.g., bacteria) facilitate the passage of nucleic acids to the next generation. Many cells in H5-CBMs (e.g., humans) facilitate the passage of reproductive cells to the next generation. Many animal individuals in H6-CBMs (e.g., ant colonies) support the reproduction of a few reproductive individuals in the collectives; and many human individuals in H7-CBMs (e.g., soldiers, policemen, and firefighters in a country) sacrifice themselves for the benefit of the collectives or other individuals.

(8) Natural selection underscores both restriction and freedom. Restriction of the behaviors of LHCBMs in HHCBMs is common because HHCBMs depend on the cooperation of their constituent LHCBMs, which sacrifices some freedom of LHCBMs for the cooperation. However, the freedom of LHCBMs tends to increase with the hierarchical complexity of CBMs. For instance, atoms within H1-CBMs and H2-CBMs can hardly conduct relative motion, but they can conduct nanometer-sized relative motion in H3-CBMs. Molecules inside cells can move over micrometer distances, and some cells within multicellular organisms can move over meter distances. Many animals can move freely to seek food, resist predators, obtaining mating opportunities.

7. The Evolution of CBMs from the Lens of the CBET

7.1. The Core Viewpoints of the CBET

Sections 3–6 suggest that the CBET have the following core viewpoints (Figure 2).

(1) Many substances on Earth spontaneously or actively absorb energy from some energy sources like sunlight or geothermal energy on Earth, under the principles of physics and chemistry. This constitutes the driving force mechanism that provides energy for structural changes of CBMs on Earth.

(2) Some relatively simple CBMs, along with some other materials, can form relatively complex CBMs after energy absorption, due to the features of the relevant CBMs. Some of these relatively complex CBMs, along with some other materials, can form more complex CBMs after energy absorption, due to the features of the relevant CBMs. The increase in the structural complexity of CBMs can provide complex CBMs with some new functions.

(3) Due to the features of the relevant CBMs, most complex CBMs formed through the above energy absorption processes will be degraded due to some features of CBMs, and the degraded complex CBMs can form complex CBMs again through the above energy absorption processes. The regenerated complex CBMs usually carry some structural changes due to some features of CBMs. Therefore, there are cycles of formation and degradation of complex CBMs with structural changes in complex CBMs. The structural variations can provide some complex CBMs with some new functions.

(4) Some complex CBMs can obtain new functions due to the above two types of structural changes. This constitutes the structure-function mechanism. Some new functions generated through this mechanism can aid the relevant CBMs or other CBMs to form and maintain more complex CBMs through energy absorption.

(5) In mathematics, the aforementioned cycles of formation and degradation of complex CBMs with structural changes in complex CBMs lead to the accumulation of the changes or functions beneficial to the formation and maintenance of complex CBMs and the depletion of changes or functions detrimental to the formation and maintenance of complex CBMs, which constitutes the natural selection mechanism. This mechanism simultaneously demonstrates competitiveness, inclusiveness, and cooperativeness.

(6) The synergy of the above three mechanisms results in the progression from chemical to biological and social evolution. They escalate the hierarchy of CBMs and augment the quantity, diversity, and orderliness of HHCBMs.

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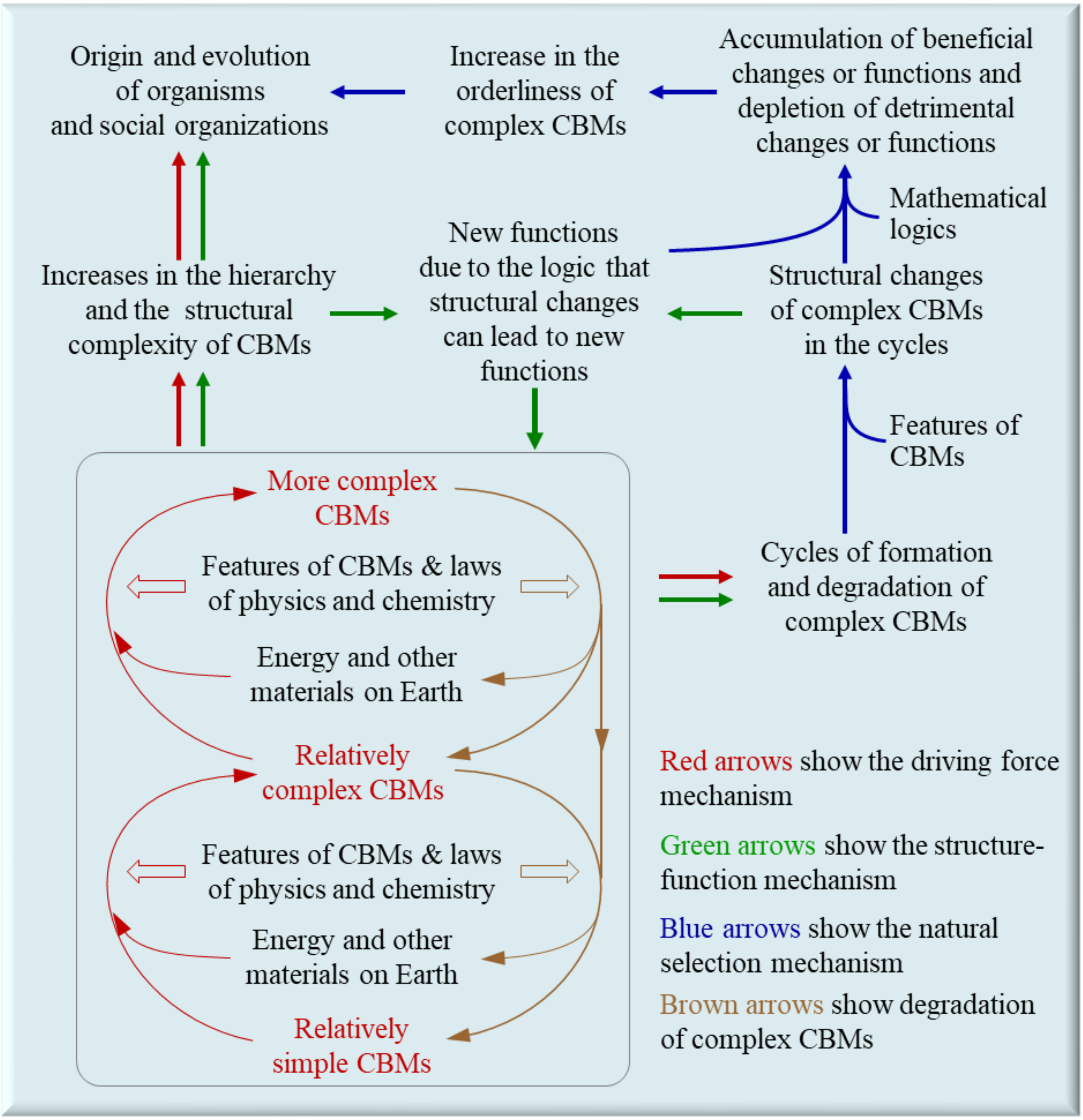

Figure 2. The three mechanisms of the evolution of carbon-based materials (CBMs) on Earth.

The driving force mechanism directly arises from the features of Earth (e.g., having abundant energy sources) and the principles of physics and chemistry (Section 4). This mechanism, along with the features of CBMs, leads to increases in the hierarchy and structural complexity of CBMs (belonging to structural changes) and the cycles of formation and degradation of complex CBMs in which complex CBMs undertake structural changes (Figure 1). The above two types of structural changes result in the structure-function mechanism due to the logic that structural changes can generate new functions (Section 5), and the above cycles result in the natural selection mechanism due to mathematic logic (Section 6). Therefore, among the three mechanisms, the driving force mechanism is the most important and takess actions before the two other mechanisms (Figure 1).

The driving force mechanism and the structure-function mechanism co-determine that CBMs on Earth tend to absorb more energy to form CBMs with more complex structures and higher hierarchies [5,39]. By contrast, the natural selection mechanism determines that CBMs on Earth tend to utilize the absorbed energy to form and maintain complex CBMs more efficiently. However, these two tendencies are restricted by the inner structures of the relevant CBMs, whose major optimization could require long time. For instance, it could take 1.6 billion years for prokaryotes to evolve to

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eokaryotes [17]. These two tendencies are also restricted by various environmental factors, such as the abundance of water and energy. Furthermore, these tendencies could be interrupted by major environmental changes, such as asteroid impacts, volcanic eruptions, glacial periods, and severe ecosystem destructions [17,40].

The evolution of CBMs significantly impacts itself. It stores energy, prepares constituent materials, produce catalyzers, and generate novel functions for its subsequent stages (Figures 1 and 2). Furthermore, the evolution of CBMs substantially modifies the Earth's surface and environment, leading to opportunities, competition, or disasters for certain CBMs [41]. For instance, the increase in photosynthetic bacteria around 2.5 billion years ago likely resulted in a significant increase in the concentration of oxygen in the air, posing a disaster for anaerobic bacteria and opportunities for aerobic bacteria [17,42].

Earth was formed 4.6 billion years ago. Its history has been divided into four eons: Hadean, Archean, Proterozoic, and Phanerozoic [43] (Figure 3). Earth has experienced chemical, biological, and social evolution, as elucidated in the following sections.

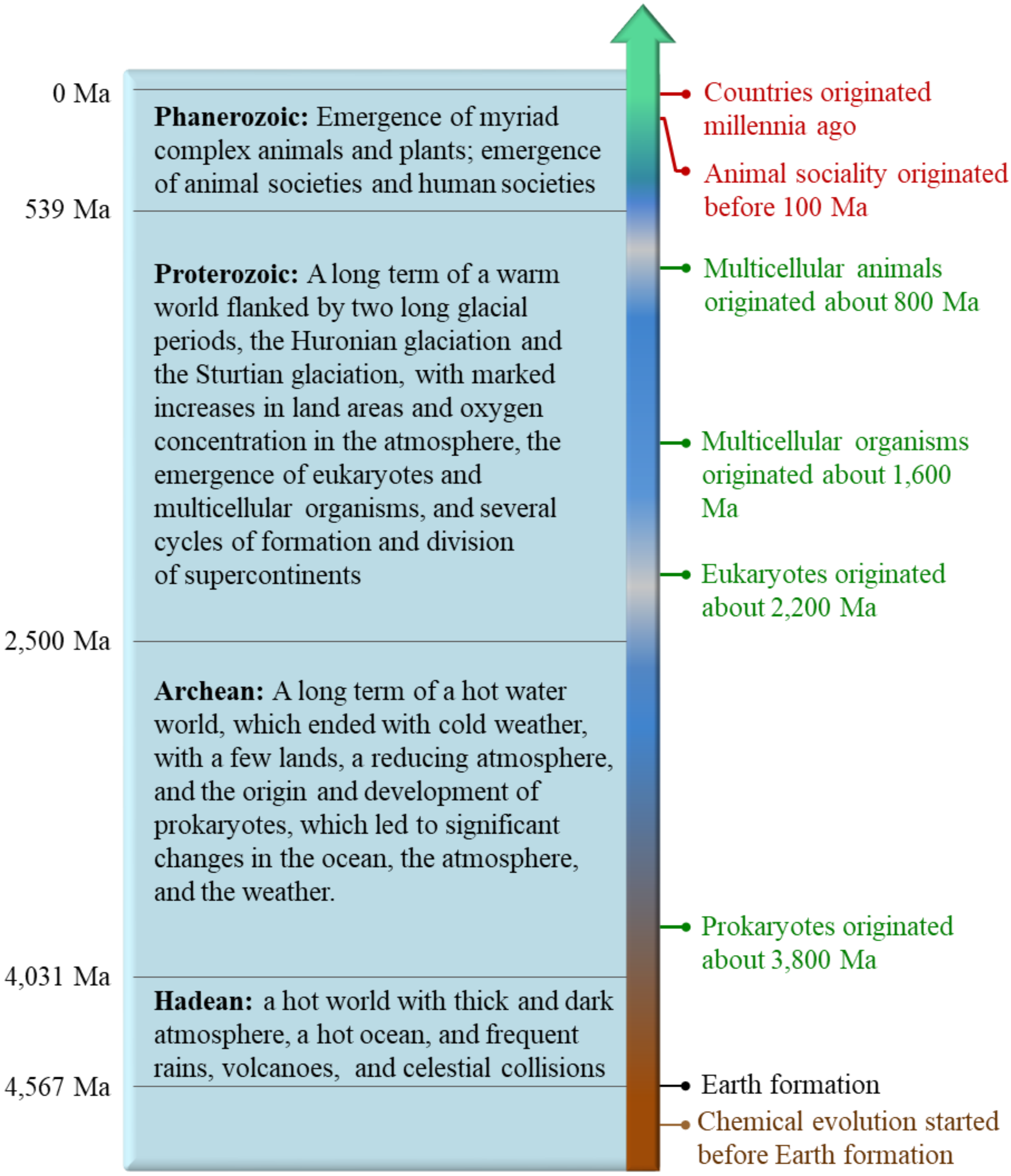

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Figure 3. Four eons of Earth and a few key events of evolution. The brown, green, and red words are related to chemical, biological, and social evolution, respectively. The brown, blue, white, and green hues in the arrow represent hot weather, warm weather, cold weather, and rich terrestrial vegetation, respectively. Ma: a million years ago.

7.2. Chemical Evolution from the Lens of the CBET

Chemical evolution began before the formation of Earth and continues to the present day. According to current cosmological understanding, H0-CBMs (carbon atoms) on Earth were formed within the interiors of giant or supergiant stars. These atoms were scattered into space as dust during the explosive deaths of these stars in the form of powerful and luminous supernovae. The dust from these supernovae events eventually coalesced to form the Sun, Earth, and other celestial bodies within our solar system [24].

During and after the formation of Earth, some H0-CBMs formed H1-CBMs (e.g., carbon dioxide, methane, and hydrogen cyanide) through inorganic or organic chemical reactions, and some H1-CBMs formed myriad distinct H2-CBMs through heat-absorbing organic chemical reactions [6–15]. The prebiotic chemical synthesis of various H2-CBMs found in organisms, such as amino acids, nucleotides, and monosaccharides, has been experimentally validated in laboratories [10–15]. Furthermore, myriad distinct H2-CBMs have been identified with mass spectrometry analysis of the Murchison meteorite, which fell in Australia in 1969 [44], which supports the possibility that myriad distinct H2-CBMs were formed through heat-absorbing synthesis reactions prior to Earth's formation.

Studies have shown that high pressure, some inorganic molecules like boric acids, and some H1-CBMs or H2-CBMs such as N-phosphoryl amino acids can facilitate the abiotic synthesis of some small H3-CBMs [6–8]. In organic chemistry, residues of the same or different types of H2-CBMs could form myriad distinct small H3-CBMs through abiotic energy-absorption approaches. Some small H3-CBMs composed of the same or different types of residues could be more powerful in catalyzing the synthesis of intermediate or large H3-CBMs, such as proteins, nucleic acids, lipids, and polysaccharides, than inorganic molecules, H1-CBMs, and H2-CBMs, because small H3-CBMs have relatively more complex structures.

As a result of the structure-function mechanism, there should have been an evolution of catalyzers for the polymerization of H3-CBMs, from small inorganic or organic molecules to H2-CBMs, small H3-CBMs, and then to intermediate or large H3-CBMs, with an increase in the efficiency and specificity of the catalyzers due to the increase in their structural complexity. Consequently, a multitude of distinct intermediate or large H3-CBMs could have accumulated on Earth before the origin of life due to the catalysis of more and more powerful catalyzers.

7.3. Biological Evolution from the Lens of the CBET

The myriad distinct H2-CBMs and H3-CBMs that emerged on Earth before the origin of life could spontaneously form numerous multi-molecular structures due to the actions of wind, water flow, evaporation, and other factors. Among these structures, some had one of the first five functions listed in Section 5, and a very few exhibited the reproduction function due to the complicated cooperation of various molecules (Section 5). These rare CBMs constituted the first batch of H4-CBMs, which might have originated at seabeds near hydrothermal vents in the ocean [45]. One of these H4-CBMs passed natural selection and became the Last Universal Common Ancestor (LUCA) of all living things. LUCA could possess hundreds of genes [46]. The possibility of the abiogenesis of H4-CBMs, including LUCA, has been supported by successful experiments regarding the abiotic synthesis of viruses and H4-CBMs [47,48]. However, the precise process by which LUCA originated, particularly the steps involving the origin of codons for protein synthesis [49], remains unknown.

Billions of years after the origin of LUCA, myriad variants of H4-CBMs accumulated on Earth, and some of them became eukaryotes during the early Proterozoic eon [50]. In the middle Proterozoic eon, myriad variants of eukaryotes accumulated on Earth, and some of them became multicellular organisms (H5-CBMs) [51].

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Among the thousands of catalytic molecules in an organism, only a few, such as prions, thrombin, and hammerhead ribozymes, are autocatalytic, catalyzing a step in their own production process. No large organic molecules that can catalyze all steps of their own synthesis have been found. For instance, prions catalyze the formation of themselves, but they only catalyze their incorrect folding and do not catalyze the many steps involved in their synthesis from amino acids. In biology, H4-CBMs are the hypercycle systems formed by the cooperation of various allocatalyzers (refer to those catalyzers that do not catalyze their own synthesis or degradation) and many other molecules, including those providing energy, guiding the precise synthesis of specific molecules, and protecting the relevant molecules. The complex cooperative relationships between these molecules achieve the function of reproducing the offspring of H4-CBMs. The large organic molecules in the hypercycle system hypothesized by Manfred Eigen, capable of both autocatalytic and allocatalytic actions and capable of undergoing mutations [16], have not yet been discovered. For the same reasons, the RNA world hypothesis, which overestimates the autocatalytic property of RNA and overlooks the cooperation of various molecules in the origin of life [52], is questionable.

Some features of biological evolution, like the one that natural selection of organisms is both competitive and inclusive, have been clarified in Sections 5 and 6.

7.4. Social Evolution from the Lens of the CBET

Animal or human social collectives (H6-CBMs and H7-CBMs) have the features of the cooperation of animal or human individuals with different duties working for the collectives. Such closely cooperative collectives can be viewed as superorganisms, while multicellular organisms can be viewed as social collectives of cells and unicellular organisms as social collectives of molecules.

Fossils and molecular clocks both suggested that multicellular animals possibly emerged on Earth 800 million years ago [53]. Animals actively search for and consume food, which provides them with constituent materials and heat or energy. Possibly 100 million years ago, some insects established their social collectives [54,55]. The increased complexity in gene regulation and chemical communication is important to the origin of sociality in insects [54–56], which coincides with the structure-function mechanism of the CBET.

Sociality has been established in around 24,000 species of insects and some species of crustaceans and mammals, which constitute separate events in social evolution [54,55]. Sociality is widespread in *Hymenoptera* (ants, bees, and wasps) and *Blattodea* (termites). A typical social collective has a queen and a few reproductive males, who take on the roles of the sole reproducers, and other individuals act as soldiers and workers who work cooperatively to create a living situation favorable for the brood.

Animal social collectives have complex functions stemming from their complex structures. They significantly reduce intra-population competition and struggles, as well as utilize collective advantages to obtain relevant materials and energy to reproduce and maintain them and confront natural selection. Consequently, although sometimes social animals require individuals to sacrifice their freedom and even their lives for the benefit of others, social animals have strong natural selection advantages due to the cooperation within animal social collectives, and they typically have significantly longer lifespans compared to their counterparts without sociality within the same taxa [54–57]. For instance, the naked mole rat (*Heterocephalus glaber*) living in society has a lifespan of up to 30 years, several times longer than that of other rodents. On the other hand, the natural selection advantages of animal social collectives also lead to sometimes intense competition or conflicts between animal social collectives. For instance, battles between ant colonies often result in the slaughter of numerous ants [58].

H6-CBMs have a single management hierarchy. For instance, no ant controls multiple ant colonies in the same location.

Due to the complex brains, bipedal bodies, unique vocal cords, and other special structures of humans, humans possess high intelligence, language and written communication, knowledge accumulation, and cooperation capabilities. Building upon these advantages, humans have

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established universities, armies, banks, countries, and various other social collectives (H7-CBMs) that have multiple hierarchies in management.

In H7-CBMs, low-hierarchy social collectives adhere to the laws of physics, chemistry, and biology, as well as the rules of social collectives, serving high-hierarchy social collectives. High-hierarchy social collectives benefit from the cooperation between low-hierarchy social collectives, enabling them to acquire resources, defend themselves, reproduce, and decrease internal competition and conflicts more efficiently. Therefore, although sometimes human collectives may need to sacrifice individual freedom or even the lives of certain individuals (such as soldiers, policemen, or firefighters) to protect social collectives and other individuals, humans generally have longer lifespans compared to other primates.

The natural selection advantages of human social collectives usually increase with the hierarchies of the collectives. This is why most humans worldwide have established multi-hierarchical social collectives, from clans to tribes, tribal alliances, nations, and national alliances. However, the natural selection advantages of human social collectives can also intensify competition and conflicts between high-hierarchy human societies, such as wars between countries. In 2022, global military spending reached $2.2 trillion, and 238,000 people died as a result of wars [59]. Advances in technology, such as the development of nuclear weapons and artificial intelligence, have significantly augmented the destructive potential of international conflicts, posing a threat to humanity and Earth. These enormous military expenditures and casualties, as well as the threats to humanity and Earth, could be circumvented if a global and harmonious human social collective were established. This is similar to the scenario that there are no economic losses or human deaths due to internal wars in a harmonious country. Therefore, one of the rational ultimate objectives of the evolution of CBMs could be unifying all countries into a single harmonious social collective, which could be referred to as H8-CBM. Accordingly, the CBET advocates for the peaceful and harmonious development of human society.

8. Novelties of the CBET

Previous research primarily investigated some details of evolution using an introspective methodology. In contrast, the CBET investigates the entirety of evolution using a unique "bird's-eye" methodology in addition to the introspective methodology and achieves the following novelties.

In general science, the CBET explicitly and comprehensively elucidates that the entire evolution of CBMs arises from the synergy of three mechanisms. In contrast, chemical evolution, biological evolution, and social evolution were usually investigated separately in previous theories, although there were a few exceptions [5,42,60]. Furthermore, only a single mechanism, such as natural selection in Darwin's theory [17], entropy dissipation into the surroundings in Schrödinger's negative entropy notion [3], self-organization in Prigogine's dissipative structure theory [4], the constructal law [60], the maximum entropy production principle [5,61], or the free-energy principle [62], has been proposed to explain the evolution of CBMs. These one-mechanism theories could not comprehensively explain the evolution of CBMs. Furthermore, the crucial role of natural selection was overlooked or even rejected by these theories, except for Darwin's theory and the Modern Synthesis. Although Darwin's theory and the Modern Synthesis emphasized natural selection, they did not clarify why and how organisms can exist. Additionally, they posited that natural selection, genetic drift, competition, or mutations are the driving forces of evolution [63–67], but these factors require energy and do not provide energy for the evolution of CBMs. This is analogous to the fact that an engine is essential for a fuel-powered car to run, but the engine itself cannot provide the driving force for the car. It is fuel that provides the driving force.

In physics, the CBET challenges a widely accepted notion regarding thermodynamics and evolution. The second law of thermodynamics, which states that heat can spontaneously flow from hotter to colder objects and not the reverse, can also be mathematically expressed as the entropy of isolated systems increasing over time. Since entropy is commonly accepted to be a measure of disorder and the entire universe can be considered as an isolated system, the law indicates that the universe tends to become more and more disordered, which seemingly contradicts evolution

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[3,4,61,62,68], a natural process characterized by an increase in orderliness. Creationists (including some scientists) have exploited this perceived contradiction to argue for the existence of divine entities [2]. Some influential theories, such as Schrödinger's negative entropy theory and Prigogine's dissipative structure theory, accepted the notion that entropy represents disorder and reconciled this contradiction by suggesting that open systems (like organisms) can gain orderliness through the dissipation of entropy into their environment [3,4]. In contrast, the CBET embraces the new notion that entropy cannot represent disorder [39,69], so the second law of thermodynamics does not contradict evolution. Furthermore, the CBET clarifies that the second law of thermodynamics is highly associated with the driving force of evolution (Section 4), which aligns with some other research [5,60,68]. Additionally, the intricate relationships among the five basic concepts associated with evolution: materials, energy, structures, functions, and orderliness, which have been frequently interpreted with some elusive notions associated with the elusive concept of entropy, are explicitly elucidated with the three mechanisms in the CBET (Figure 2).

In biology, as elucidated in Sections 4–6, the CBET reveals the driving force of biological evolution and the mathematical essence of natural selection, and it provides more comprehensive explanations regarding the targets of natural selection, biological altruism, biodiversity, and some macroevolution issues, such as the origin of life, multicellular organisms, and endothermic animals. Furthermore, natural selection, non-random mutations, neutral mutations, epigenetic changes, and acquired strengths, which cannot be integrated into any previous evolutionary theory, can be integrated into the framework of the CBET, as elucidated in Sections 5 and 6.

In the social sciences, the CBET reveals the natural roots of multiple pivotal and seemingly paradoxical social notions, such as inclusiveness versus elimination, cooperation versus competition, altruism versus selfishness, freedom versus restriction, all-round development versus specialized development, resource exploitation versus environmental protection, innate advantages and acquired strengths (Section 6). Accordingly, the CBET advocates for the balanced development of human society. For instance, cruel exploitation of the people or excessive welfare policies are both unreasonable. It is also unreasonable to prohibit citizens from traveling and to allow criminals to escape from prison. Over human history, countries that have more effectively incorporated the concept of balanced development into their social rules and management have often demonstrated greater competitiveness in international competitions. The CBET also elucidates the necessity of integrating all countries into a single harmonious social collective (Section 7.4). In contrast, previous evolutionary theories highlight selfishness, competition, and the elimination of those less advantageous in certain traits [1]. These biases have historically been used to justify colonialism, slavery, racism, and genocide [18].

9. Reasonability of the CBET

(1) The factors emphasized in the CBET, such as the features of Earth, the features of carbon atoms and other CBMs, the principles of physics and chemistry, energy, chemical reactions, new functions stemming from structural changes, and natural selection, are all critical for the evolution of CBMs. In contrast, previous theories only addressed a subset of these critical factors.

(2) The CBET is established through the integration of the above critical factors, rational logic, and abundant evidence using a unique "bird's-eye" methodology. The CBET is neither based on any novel hypotheses, observations, or experiments nor espouses any elusive concepts, viewpoints, or mathematical formulas. To our knowledge, the CBET aligns with numerous facts across physics, chemistry, biology, geology, astronomy, and the social sciences and does not contradict any facts in these fields.

(3) As shown in Section 8, the CBET provides more explicit or comprehensive explanations for some issues in general science, physics, biology, and the social sciences. It also accommodates multiple evolutionary facts that cannot be integrated into any previous theories. These bolster the reasonability of the CBET.

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10. Prospects

This article creates the concepts of eight hierarchies of CBMs and establishes the CBET, which provides an explicit, comprehensive, and reasonable explanation for the evolution of CBMs on Earth from simple to complex and from unordered to ordered. The CBET reveals three key mechanisms shared by chemical evolution, biological evolution, and social evolution, reiterates the absence of conflict between the second law of thermodynamics and evolution, clarifies the intricate relationships among materials, energy, structures, functions, and orderliness in inanimate, biological, and social systems, and uncovers the natural roots of multiple crucial social notions, so it could unify biology with physics and chemistry and bridge the natural sciences and the social sciences.

As a new theory, the CBET is subject to further validation and optimization. If widely accepted, the CBET, which could constitute the top architecture of evolutionary biology, will be edited in global textbooks and applied frequently to interpret some basic evolutionary issues, such as the origin of life and the widespread altruism of multiple types of CBMs.

The CBET can guide scientific research. For instance, on the origin of life, this theory suggests searching for some small H3-CBMs that could be naturally synthesized on the prebiotic Earth and effectively catalyze the synthesis of proteins, nucleic acids, or other organic macromolecules within organisms. It also suggests investigating cooperative relationships among some molecules in the context of life's origin. It recommends research on natural selection, macroevolution, speciation, social behaviors in animals, and the future development of human societies from the panoramic view of the entire evolution of CBMs. On the other side, the CBET cannot provide details for the evolution of each organism during the past billions of years, which should be investigated using some approaches from physics, chemistry, biology, and geology.

The CBET can guide the rational development of human society because it advocates for the balanced, harmonious, and peaceful development of human society, as well as the integration of all countries into a single harmonious social collective.

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