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ARTICLE

Living Matter and the Laws of Thermodynamics for the Biosphere

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ABSTRACT

The laws of thermodynamics have been developed for inert matter, and living matter has not been considered as a variable in these laws. Living matter possesses properties that have had major effects on biosphere evolution with time. The zeroth property is "Living matter is produced from living matter only." The first property may be summarized as "Living matter occupies the available spaces to the maximum extent when environmental conditions are favorable and no obstacles are present." And the second property is " Living matter mutates, changes, and adapts to maintain the continuity of life and size as large as possible when environmental conditions are unfavorable." While the zeroth property is objective in nature, the first and second properties are subjective, in that they are driven by internal stimuli characterizing living matter. Their interaction with the laws of thermodynamics may be thought of as "philosophy intertwining with science." Accordingly, the laws of thermodynamics are revised to factor in life as a variable. Mathematical expressions of the first and second laws are derived and some of their applicability to the biosphere and climate is explained and discussed. The main conclusion is that life changes climates and the fabric of the biosphere.

1. Introduction

Planetary motion is characterized by conservation of the angular momentum and infinitesimal variation of orbital eccentricity. These characteristics yield a constant annual solar energy exchanged with any planet, regardless of orbit shape. A planet thus reaches thermodynamic equilibrium. Seasonal or orbital variations induce thermodynamic transformations displaced differentially from equilibrium. They are, therefore, reversible based on the laws of thermodynamics, and lifeless planets may not have relevant directional thermodynamic transformations.

This is not what is observed on planet earth. The geological record is rich with data revealing steady evolution of living matter, surface geology, and climate. Clearly, life on earth has made a difference, and the first and second laws of thermodynamics must be revised for the biosphere. This sphere includes living and inert matters that interact with each other, and this interaction was not accounted for in the original formulation of the laws of thermodynamics. They were developed for practical applications, where systems' surroundings are part of the biosphere such as land, air, and water. The entire system and its surroundings were made of inert matter. Conversely, biosphere thermodynamic transformations are interactions between living and inert matters, and they changed climates of the past as well as present-day climates.

The biosphere as a thermodynamic system where living and inert matters interact comprises land, surface water,

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living matter in the sea and on the land, and atmospheric air. These biosphere subsystems observe biological, chemical, and thermodynamic changes with variation in the size of life. Because the size of the non-green living matter depends on the size of the green matter, variation in the size of life is equal to variation in the chemical energy of photosynthesis. An increase in the size of photosynthesis converts more solar energy into chemical energy in plant tissues and the surroundings receive less solar energy and vice versa. Consequently, photosynthesis exchanges heat that is in transit in the biosphere and may be treated as such. Therefore, the first property of living matter intertwines with the first law of thermodynamics. So does the second property: Unlike lifeless planets, biosphere thermodynamic transformations have a steady direction, irreversible, and the second law of thermodynamics must be revised as well.

In this work, the interactions of the basic properties of living matter and the laws of thermodynamics are discussed, derivation of the revised laws of thermodynamics to account for life in the biosphere is provided, and the significance of the derived laws is explained.

2. Background Information

The zeroth and first properties of living matter were proposed and thoroughly discussed by [1]. There is overwhelming evidence of their validity. Not a single living cell that eats, secretes, and multiplies has been produced in laboratory experiments. Nor is there evidence of living cells being a product of purely inert matter. Such overwhelming evidence is a reasonable basis to claim that "Living matter is produced from living matter only." Similarly, our basic observations indicate that living matter has an inherent and intrinsic nature to multiply and increase in number when the conditions are favorable and no obstacles are present. This is true for single living cells as well as complex organisms, and there is overwhelming proof of the validity of this conclusion as well.

The innate nature of living matter to adapt, change, and mutate when environmental conditions are unfavorable or vary is observed throughout the geological record. Bacteria mutation in response to medicine and subsequent resistance maintains the continuity of life and bacteria count to the maximum extent. Also, this is true for plants, insects, animals, and humans. Plants adapt, change, produce venoms, lignin, and rise above the ground to occupy the available spaces as much as practically possible. Variation in climates with latitude has produced fauna and flora characteristic of each latitude. Plants shed their leaves in cold climates to maintain the continuity of their existence. The evidence that "Living matter mutates, changes, and adapt to maintain the continuity of life and size as large as possible when environmental conditions are unfavorable" is overwhelming as well. These inherent natural properties of living matter exchange energy that interacts with the thermodynamics of the biosphere. Therefore, they must be accounted for in the laws of thermodynamics.

Thermodynamics is an established branch of science that addresses transformations where heat and work are exchanged between thermodynamic systems and their surroundings. Reference [2] presents the current understanding of thermodynamics applicable to systems involving inert matter only. " Postulate 1: *There exists a form of energy known as internal energy U, which for systems in equilibrium states is an intrinsic property of the system, functionally related to the measurable coordinates which characterizes the system.* Postulate 2: *the total energy of any system and its surroundings is conserved*. (First law of thermodynamics)." Mathematically, this law may be written as follows:

$$dU=dQ-dW \quad (1)$$

Where Q is heat crossing the boundary of the thermodynamic system. The convention is to consider the heat as positive if added to the thermodynamic system. The symbol, W, denotes the work exchanged between system and surroundings. It is energy in transit as well, typically assumed as positive if produced by the thermodynamic system. Therefore, Q and W have opposite signs.

"Postulate 3: *There exists a property called entropy S, which for systems in equilibrium states is an intrinsic property of the system, functionally related to the measurable coordinates which characterize the system. For reversible processes changes in this property may be calculated by the equation*

$$dS=dQ_{rev}/T \quad (2)$$

Where T is the absolute temperature of the system and Q_{rev} *is the reversible heat.*

Postulate 4: *The entropy change of any system and its surroundings, considered together, resulting from any real process is positive and approaches a limiting value of zero for any process that approaches reversibility.* (Second law of thermodynamics)."

Equations (1) and (2) apply for closed thermodynamic systems where the system and surroundings exchange energy only and matter is not exchanged. The mass of system or surroundings remain constant. If the system in thermodynamic equilibrium gains heat, it undergoes a spontaneous thermodynamic transformation until a new equilibrium is reached. In the process, heat and work are

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exchanged between system and surroundings. Thermodynamic characteristics such as system pressure, temperature, and concentrations may be used as coordinates to define states of thermodynamic equilibrium. A thermodynamic transformation differentially displaced from equilibrium may be considered as a reversible transformation, in that the system may spontaneously return to its original characteristic coordinates when the cause of displacement ceases.

The biosphere as defined in the introduction section has a constant mass and exchanges energy with its surroundings. Therefore, it may be considered as a closed thermodynamic system and the first and second laws of thermodynamics thus apply. However, living matter is not considered in these thermodynamic relationships. The size of green matter is a coordinate of the biosphere thermodynamic system, and the energy exchanged resulting from the variation in its size is heat in transit that must be accounted for. Therefore, for the biosphere the first and second laws of thermodynamics should be revised to account for life in the biosphere. The subject is important because variation in the size of photosynthesis varies the heat content of the biosphere and changes climates. Similarly, deforestation is a reversed process of photosynthesis and it produces heat in the climate. Therefore, deriving the first and second laws of thermodynamics for the biosphere is important for research and society.

3. Revising the First and Second Laws of ThermoDynamics for the Biosphere

Publications [3,4] discuss the present state of photosynthesis understanding. It is a chemical reaction where water and carbon dioxide are converted into sugars, cellulose, carbohydrates and other plant constituents. Solar radiation and chlorophyll are required for the chemical reaction; it is an endothermic and non-spontaneous reaction. The solar energy is ultimately converted into chemical energy stored in plants' tissues, and biosphere subsystems loose this energy. While an increase in the size of photosynthesis removes heat from the biosphere, deforestation, decay, or combustion of green matter add heat to the biosphere because it is the reversed process of photosynthesis. If the chemical energy of green matter is indicated by Q_g, the first law of thermodynamics may be revised for the biosphere

$$dU=dQ_g-dW$$

Where U is now equal to the internal energy of the biosphere and W is the work exchanged in the biosphere. Not considered in this last equation radiative terms of biosphere subsystems. The reason is that life-dependent thermodynamic transformations are states differentially displaced from each other and the original starting thermodynamic state. Should this state be assumed to be in thermodynamic equilibrium, which is a reasonable assumption, radiative terms cancel out and may be eliminated from the equation. The same is true for all other thermodynamic states differentially displaced from the state of equilibrium.

The main biosphere subsystems are surface and atmosphere. Therefore

$$dU_s+dU_a=dQ_g-dW_a$$

Where the subscript "s" denotes surface and "a" for atmosphere. Because atmospheric air is surrounded by outer space whose pressure is negligible, variation in the internal energy of the atmosphere, dU_a, is equal to variation in its enthalpy, dH_a. The internal energy of the surface is equal to the heat of the surface Q_s. The work, W_a, is mainly potential energy of the atmosphere. Therefore, the first law simplifies.

$$dQ_s=dQ_g-(dW_a+dH_a)$$

The term (dW_a+dH_a) is energy exchanged between atmosphere and surface. It is equal to the opposite sign of the heat of carbon conversion to carbon dioxide, dQ_c, based on [5]. Consequently

$$dQ_s=dQ_c+dQ_g \quad \text{(1-r)}$$

The sum of surface heat and chemical energy of the biosphere is conserved.

Not mentioned in this form of the first law for the biosphere is the word surroundings. The reason is that the surroundings of the biosphere as defined in the introduction section are outer space and solid earth underneath the biosphere. Outer space is empty and no chemical energy, potential energy, or heat may be exchanged with outer space. The same is true for the solid earth; it is thick and rigid and the amount of energy exchanged with the solid earth may be neglected. The sign of dQ_g is negative if the size of the green matter increases and positive if the size decreases. Also, variation in the heat of carbon conversion dQ_c changes sign. It is positive when the content of carbon dioxide in the atmosphere increases and negative if the content decreases.

It should be noted that the chemical energy defined in this work is the energy associated with thermodynamic processes that exchange carbon in the biosphere. This energy interacts with the laws of thermodynamics according to Equation (1-r). Carbon free processes do not produce

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energy interaction and must exit the biosphere and climate system. Examples of these processes include but not limited to generation of earth's internal heat, transmission of energy of geological activities, and production of carbon-neutral energy.

On the other hand, the thermodynamic transformations caused by life are small displacements from each other. For instance, the present warming trend is less than one degree Kelvin in approximately 250 years. If compared with biosphere temperature of 288 K, the current climate change is in fact an incremental displacement from equilibrium. On an annual basis, biosphere transformations are infinitesimal processes. The same is true for all of past changes in climate. Even though they are infinitesimal displacements from equilibrium, they may not be assumed to be reversible, in that life adapts, evolves, and resists death and annihilation when environmental conditions are unfavorable. As a result, the second law of thermodynamics for the biosphere may be written as follows:

$$dS>0 \quad (2\text{-r})$$

The entropy of the biosphere increases with time.

Here, too, the word surroundings is removed for the same reasons discussed earlier. Equation (2-r) reveals that biosphere thermodynamic transformations are irreversible.

4. Discussion and Conclusions

The zeroth property of the living matter announces the resilience and strength of living matter as a continuous and unbreakable chain extending throughout eons. Living matter is indestructible; however, it may mutate or assume different shapes or forms. The first property on the other hand states that the size of life can never reach a steady value, it is inherently variable. As a result, the energy produced by life is energy transient in the biosphere that exchanges heat and work, Equation (1-r). The biosphere can never reach a thermodynamic equilibrium that characterizes thermodynamic systems of inert matter alone. Thermodynamic transformations driven by life in the biosphere are infinitesimal displacements around equilibrium. Yet, they are irreversible as the revised second law of thermodynamics for the biosphere reveals, Equation (2-r). This fundamental difference between thermodynamic systems where life is a variable and thermodynamic systems made of inert matter is of paramount importance. All life driven thermodynamic transformations have a direction. They are irreversible, and steady evolution of the biosphere is a natural outcome as a result that cannot come to a halt.

These thermodynamic conclusions for the biosphere are in agreement with the geological record. Life and biosphere has had a steady and uninterrupted evolution throughout geological time. The geological record is rich with overwhelming fossil samples supporting simultaneous evolution of life and biosphere. The age of surface rocks are predominately much younger than the age of the earth, and younger rocks are in the making at the present time. Living matter produced these younger rocks through biosynthesis of calcite, phosphate, and the large number of minerals that can be obtained from them such as chalk, gypsum, dolomite, fossil fuels, and others. Life has produced beautiful surface landscapes and majestic mountains made of sedimentary rocks around the world, thus testifying to the continuity, resilience, and power of living matter.

As Equation (1-r) reveals, variation in the size of life can change surface temperature and climates. The size of life depends on the size of the green matter. When the environmental conditions are favorable, an increase in the size of photosynthesis is an inherent nature of the green matter. The surface of the earth cools down, and a cooling cycle is initiated. These cooling periods are characterized of having severe cold and dry climates [6]. Colder surface temperature, reduced carbon dioxide content in the atmosphere, glaciers cover of land, and decreased water availability; all are unfavorable to life. The cooling cycles cannot continue indefinitely, there comes a time when the temperature in the biosphere is too cold for living matter. A large segment of life perishes as the cooling cycle progresses, which provides sediments for building continents and lands. Photosynthesis contracts in the process and the decay, oxidization, and combustion of living matter warms the biosphere and a warming or interglacial cycle is initiated. Environmental conditions become favorable for life to expand again. Only the species that adapt during the cooling cycle continue the journey of life. The warming and cooling cycles repeat throughout the geological history of the earth.

A warming cycle is much shorter than a cooling cycle. These cycles provide favorable conditions for life, and life tends to occupy the available spaces left from the devastation of the cooling cycle to the maximum extent and as quickly as possible. Figure 1 is a picture of Near Island, Alaska supporting this conclusion. The historical record [7] indicates that the island was not covered with dense spruce trees in the late eighteenth century. Apparently, climate change has provided favorable conditions for the trees to occupy the available spaces to the maximum extent including hard floors and solid rocks. There is, of course, death and decay of living matter during warming cycles as well. However, there is more growth than decay. Consequently, the mass of sediments pro-

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duced in cooling cycles is considerably greater than that of warming cycles. These sediments ultimately accumulate at ocean floors and are accreted to the continent margins by tectonics. In addition, ocean floor spreading increases during warming cycles and decreases during cooling cycles [8, 9]. During cooling cycles, tectonics thus builds mountains and during warming cycles tectonics build valleys, and these mountain ranges are observed around the world. Figure 2 is a satellite picture of the Andes near Bolivia. The early mountains, farthest inland, are visible, apparently due to the building of new mountains westwards. These in turn may have arrested the destructive power of winds and water from the sea and preserved some of the mountains farther inland. Mountain ranges in other parts of the world reveal these cycles as well. Generally, they have been severely eroded by rain, glaciers, and rivers. The number and duration of the cycles may be roughly estimated using map scale and extrapolating to the subduction zone. Those that appear to be preserved mountain ranges may be used to calculate the number of complete interglacial and glacial cycles and age of the mountains. Using the image of Figure 2, the average length of a complete cycle is about 4.9 kilometers. At ocean floor spreading of nearly 8.0 centimeters annually [10], the average cycle duration is nearly 122 500 years. The number of cycles may be estimated by dividing the total distance to the subduction zone, about 1 000 kilometers, by cycle length, which yields to nearly 204 cycles. This is approximately the number of cycles needed to add all of the sedimentary or soft rocks to the platform of South America. The age of the rocks may be estimated as well by knowing the actual lineal length of the material accreted to the margins of this continent. The lineal length is hard to estimate with accuracy given that much of the mountains has eroded over the years and formed the surrounding landscapes. Assuming the angle of repose of the lithified sediments as 45 degrees, the original lineal length may be estimated at 2 830 kilometers. The Andes therefore began to form approximately 71 million years ago based on these simple observations. References [11, 12] estimate is between 40 and 60 million years ago.

The ongoing climate change supports the derived Equation (1-r). Present deforestation and fossil fuel burning has decreased the chemical energy of the biosphere. Simultaneously, the surface of the earth has accumulated heat. Clearly, the effects of the discussed properties of the living matter are embedded in the fabrics and tissues of the biosphere. These basic properties of life apply for small samples of single cell culture to complex organisms and animals and plants. The most relevant aspect of these properties is heat exchange in the biosphere, which interacts with the laws of thermodynamics. As a result, life has changed climates and surface geology.

5. Figures

Figure 1. Picture taken by the Author of Near Island off the east coast of Kodiak Island, Alaska, U.S.A. at 57.7900° N and 152.4072° W

Note: Spruce trees occupy the available spaces to the maximum extent.

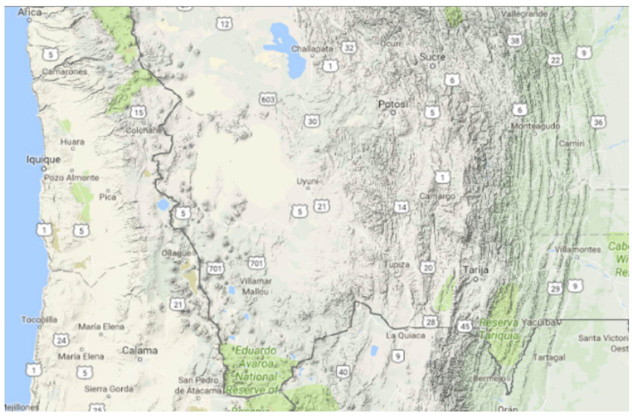

Figure 2. Satellite image of the Andes near Bolivia, about -20° Latitude and -65° Longitude

Note: The mountain chains farther inland recorded the process with which sedimentary rocks were added or accreted by tectonics. Cooling cycles provided sedimentary rocks to build mountains, and the succeeding warming or interglacial periods left valleys behind. In the direction to the ocean, cycle fingerprints have been destroyed by the elements. The picture is a courtesy of U.S. Geological Survey.

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