Artículo de Investigación

Life and Earth Environment from an Entropic Point of View

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ABSTRACT

At a first glance it seems that the Second Law of Thermodynamics, the Fundamental Law of Physics, is inapplicable to a system of life and to the environment of Earth. It is understandable, however, if one takes into account that both systems represent themselves non–equilibrium stationary open systems. A deeper understanding to these systems becomes possible if one considers them from an entropic approach. Such considerations could provide interesting educational materials for the beginners of thermodynamics.
Key Word: Thermodynamics, physics, entropy, living organism.

RESUMEN

A primera vista La Segunda Ley de la Termodinámica, la Segunda Ley de la Física, parece no ser aplicable a un sistema de vida ni al medio ambiente de la Tierra. Esto se debe a que La Segunda Ley de la Termodinámica esta formulada en un marco de trabajo de un sistema de equilibrio cerrado, mientras que ambos representan, por sí mismos, sistemas estacionarios abiertos no equilibrados. Usualmente éstos no se tratan en el curso introductorio de termodinámica. Un entendimiento profundo de estos sistemas es posible si los consideramos desde el punto de vista entrópico. Tales consideraciones deben proveer interesante materia educativa para principiantes de la termodinámica.
Palabras Claves: Termodinámica, física, entropía, organismo vivo.

1.LIFE AND ENTROPY

The structure order of a living organism might appear rather mysterious from a naive point of view in physics. Its entropy does not increase and never comes to a thermal equilibrium state, i.e., to a disorder. Actually, the entropy is kept at a low level and apparently does not increase in various biological phenomena such as maintenance and growth of an individual living body, as well as a self–reproduction. In contrast, after death the decomposition of a body starts to diffuse as usual substances do and hence the entropy increases, approaching to a disordered state. Thus it seems as if the second law of thermodynamics were inapplicable to a living organism [1,2]. The difficulty arising from this physics viewpoint cannot be saved by a biological explanation such as metabolism and/or assimilation of plants. E. Schrödinger gave the following explanation [1]:

1.1 Explanation by Schrödinger

Schrödinger argued in his book "What is life?" as "A living organism takes negative entropy (negentropy)", and emphasized the importance of consideration based on an entropy concept. Since a living organism is in a stationary state, the flow of outgoing energy E_{out} must be equal to that of the incoming energy E_{in}. Thus on average one has

$$\frac{dE_{in}}{dt} = \frac{dE_{out}}{dt}$$

(Ec. 1)

The incoming energy carries the entropy with it as well. He paid attention to the difference of the incoming entropy S_{in} and the outgoing one S_{out} and noticed that:

$$DS = S_{in} - S_{out}$$

(Ec. 2)

A living organism is in a non-equilibrium state, and because irreversible processes take place therein, entropy should be generated. Consequently the net entropy accepted by a living organism has to be negative. Thus a living organism maintains its living state by taking "negentropy", i.e., by compensating the entropy generated through the irreversible processes.

After all, the living organism throws the entropy to the surrounding and thereby increases the entropy of the surrounding. As a result it preserves its entropy at a lower level hence its oredered (molecular) structures in an ordered state.

1.2 Entropic Income and Expenditure in a Living Organism.

A living organism constitutes an open system that exchanges heat and substances with the environment. Moreover it is a stationary system that does not change much in a long period of time. In order that a living organism can maintain its stationarity, it has to discharge outside the same amount of the substances and the energy taken in from outside. They become excretions and abolition heat, respectively, which go out to the environment. Since entropy is newly generated due to the irreversible processes within the system, a living organism has to throw a necessary amount for compensation. As a result, the entropy in the system is preserved at a lower level.

1.3 What is the Mechanism by Which Entropy is Thrown Away?

There are two kinds of ways. One way is throwing entropy by attaching it to waste and the other way is attaching it to abolition heat. One cannot throw entropy alone without attaching to anything. A living organism burns, for instance, the carbohydrate in the body and transforms substances such as carbon dioxide and steam into high entropy, and exhausts them outside of the body mainly by breathing. Thus the entropy generated by the activity of a living organism is partly thrown away outside of the body as high entropy waste. The entropy can be thrown away as well in the form of the thermal energy transfer such as the evaporations and/or sweat. In this way a living organism maintains its stationarity.

After all, what are useful for a living organism are those substances possessing not only high energetic states but also low entropic states. In order that a living organism can function, it is necessary not only to take such low entropy substances but also to discharge high entropy substances and heat into the environment. For this purpose it is necessary considering a mechanism of entropy abolition from the environment surrounding living organisms.

1.4 Low Entropic Sunlight

The sunlight energy plays a crucial role in maintaining life. The fact that it possess a low level of entropy is physically more important than an energetic aspect. Let us consider here a physical mechanism of photosynthesis in a plant. The photosynthesis of a plant is the assimilation in which glucose is synthesized from carbon dioxide together with water. In photosynthesis reactions sunlight plays an important role. Photosynthesis process in which the energy with low entropy carried by the sunlight is fixed proceeds as:

$$6H_2O + 6CO_2 + 48hv(\text{photon}) \rightarrow C_6H_{12}O_6 + 6O_2$$

(Ec. 3)

In general, in the chloroplast of the plant, photosynthesis can proceed by the light with the wa`velength of less than 700 [nm]. Namely in the photosynthesis only a part of the visible light of sunlight is used. This is because in order to make the absorption band of the chlorophyl into excited states it has to absorb such photons having energy higher than certain value. In creating one molecule of glucose, 48 photons are needed. In this photosynthesis reaction, approximately 1/3 of the energy of the photons (with lower entropy) is fixed in glucose. The rest is thrown away into the steam coming from the leaves, together with the entropy generated by the irreversible processes. A plant is alive by throwing outside high entropy of waste by the transpiration of water.

Glucose and oxygen, being the products of the reactions have higher energies compared with those of the raw materials, i.e., carbon dioxide and water, since they have received the energy of light. Although the entropy of raw materials and that of the products do not change very much, the products have higher energy than the raw materials. Thus the ratio of entropy to energy is comparatively low in the products' case. The conversion efficiency of energy is considerably high for such photosynthesis reactions.

In nature animals seek for energy with low entropy in glucose, which is synthesized by plants. The negentropy taken from vegetables and fixed partially by herbivorous animals is used by carnivorouses. In this way the lowness of sunlight entropy is being used one by one through the food chain. Since entropy is generated additionally at each stage, smaller number of living organisms can be supported at later stages. A part of these living organisms changed into fossil fuels such as coal and oil after their deathes. Thus, the lowness of sunlight entropy was fixed therein, though only partially.

2. ENVIRONMENT AND ENTROPY

2.1 Earth is a Stationary Open System.

In the surface layer of Earth, various vital phenomena and social activities are taking place whereby entropy is created. Although entropy continues increasing on Earth, we never reach to a "thermal death". The reason is that Earth, moving within the space of the solar system, receives heat and light from the sun constituting an open system that discharges heat into space. Such an open system maintains "non-equilibrium stationary state far from the thermal equilibrium one" by taking negentoropy from the environment and, at the same time, throwing the generated entropy into the environment. By environment we mean the one extended from the surface of Earth and up to the atmosphere. Since it throws entropy to space it constitutes a non-equilibrium stationary open system as well.

2.2 Circulation is Important in the Maintenance of Earth Environment as well as for Life.

In general there are two kinds of stationary open systems. One is a system wherein a simple diffusion process takes place. This type is called first kind open system. The examples for this type are such as flows of falling down water, electric conduction and heat conduction. In this case the system is locally almost equilibrium, and entropy does not increase any more. Such system is not related to any form of life.

Another one is a system where a circulation exists. Such system is called the second kind of open system, and is deeply related to life. In fact life consists of various circulations. In the case of a human body various types of circulations such as blood circulation, lymph circulation, and metabolisms of substances are functioning in mutual harmony.

While maintaining a stationary open system on Earth, circulation plays an important role as well. Three types of circulations can be mentioned, i.e., the one of atmosphere, the one of water, and the one of living creatures.

2.3 How does Earth Maintains its Stationary Open System?

First of all, it exists an atmosphere kept by gravity linked to the surface of Earth wherein the circulations of atmosphere and water take place constantly by convection. The extra entropy is carried to the upper layer of the atmosphere by the convection of air together with thermal energy against gravity. Earth throws heat entropy to space as well. Water circulation is responsible for such processes. Heat entropy on the ground is absorbed by the water evaporation. The steam rises to the upper layer of the atmosphere because it is lighter than air (the molecular weight of water is smaller than that of nitrogen). Then heat is radiated to space together with entropy and the water returns back to the ground as it rains.

On the other hand, matter entropy such as the one discharged by living organisms of Earth and corpses of living creatures are transformed into carbon dioxide and steam, through decomposition, by microorganisms such as bacteria, as well as by small creatures. These carbon dioxide and water are reused for photosynthesis. That is the circulation of living organisms. Finally, the generated entropy of the abolition heat is radiated from clouds in the atmosphere to space as infrared rays by water circulation and by the mechanism of entropy emission from the Earth. The reason why we can survive in such an environment polluted by entropy is by virtue of the strong purification ability of such environment.

2.4 How Much Entropy is Thrown Away out of the Earth Sphere to Space?

Among the solar energy that reaches Earth, the thermal energy Q that remains on Earth surface is on average, approximately 77 [kcal] at 1 [cm^2] per year [3]. Average temperature T_1 on Earth surface is about 288 [K]. Therefore the entropy received by Earth from the Sun at 1 [cm^2] per year is

$$\frac{Q}{T_1} = 266 [cal/K] \qquad \text{(Ec. 4)}$$

On the other hand, the residual heat Q is thrown away to space under an infrared ray form. The temperature T_2 in the upper layer of the atmosphere is about 250 [K], and therefore the entropy discharged out of the Earth sphere is

$$\frac{Q}{T_2} = 308 [cal/K] \qquad \text{(Ec. 5)}$$

Thus, the net entropy thrown by Earth at 1 [cm^2] per year is

$$DS = \frac{Q}{T_1} - \frac{Q}{T_2} = 42 [cal/K] \qquad \text{(Ec. 6)}$$

through water circulation and convection in the atmosphere. This way Earth maintains a low entropy level. Of course, the above-mentioned was restricted to the case of solar energy alone, and if we burn coal, oil, and nuclear fuels too, excessively, water circulation and convection in the atmosphere cannot throw the amount of excessive entropy, and thus entropy will increase in the Earth environment.

3. CONCLUDING REMARKS

In concluding we stress that the considerations based on the concept of entropy help us to understand life and the global environmental problems much deeper. It is needless to say that the cause of present global environmental problems is due to excessive economic activities of mankind. On discussing such global environmental problems, the considerations from the energetic viewpoint alone are not sufficient and the ones based on the entropic viewpoint are indispensable. The considerations on life from the entropic viewpoint are also useful in such field as food sciences.[4]

The concept of entropy is one of the most difficult for beginners of thermodynamics to understand, because of its abstract character. Adopting concrete examples such as life and/or global environmental problems treated in this article may help to grasp this concept better and feel it more familiar, as the one of energy.

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