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Entropy, a Measure of Order Degradation in the Universe

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Abstract

This writing directly connects the thermodynamic function *entropy* with the degradation of ordered energy and of ordered structures in the Universe. Entropy manifests itself not only in physical, chemical or biological systems, but also in social and economic systems. The cosmological enunciation of the second principle of thermodynamics, according to which the entropy of the Universe increases, brought in the foreground the thermic death of this because of the degradation of ordered energy in thermic energy. If the Universe has an ending, this means it had a beginning. And if it had a beginning, we may admit that it had a creator, the theologians say, but also many scientists. All these aspects are analyzed through the thermodynamic function *entropy* in the following study.

Phenomenology

Among all the natural laws, there are no other two laws which can have so many implications in the evolution of cosmological, physical, chemical, biological, economic and social systems or in informatics, psychology and especially in religion as the two laws or principles of thermodynamics.

The first principle postulates equivalence of all forms of energy: mechanical, chemical, nuclear, electric, radiant, biological and thermic. This aspect involves the reversibility of transformation of a energy form into another and vice versa.

On the contrary, the second principle decrees that the transformation of a energy form into another and vice versa is achieved with a certain degree of irreversibility, the rest is lost as thermic energy (heat). A measure of the irreversibility degree of any process is entropy[1].The source of the irreversibility of processes is represented by the interaction between the constituents of the system in evolution. Entropy manifests itself only in systems which evolve far from thermodynamic equilibrium. At state of equilibrium, entropy reaches maximum value and remain constant because irreversible processes are not achieved any longer.

In 1865 Clausius formulates the two principles of thermodynamics through a cosmological enunciation.

I. The energy of the Universe is constant (Die Energie der Welt ist Konstant)

II. The entropy of the Universe tends to maximum (Die Entropie der Welt strebeinem maximum zu)

The enunciation of the first principle represents an irrefutable truth. The validity of this principle was and has been reconfirmed by high energy physics. Isaac Asimov states that this principle "represents the most founded generalization about the Universe which scientists have ever been able to formulate". It is so perfect that the theologians surnamed it "The Principle of Conservation of Divine Creation".

The enunciation of the second principle, as formulated above, gave rise to arguments because this enunciation implies an ending of the Universe because of the degradation of the ordered energy forms (chemical, nuclear, radiant, biological, etc.) into thermic energy, the only form of degraded energy. Clausius draws the conclusion that the Universe will eventuate in thermic death. For the first time in the history of humanity, a problem mooting arose, if not about the existence of the Universe, then, surely, on the existence of our biosphere.

Between the two enunciations given by Clausius there is a fundamental connection which can be easily highlighted through the molecular interpretation of these two physical measures, energy and entropy[2].

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[1] P. Glansdorff and I. Prigogine, *Thermodynamic Theory of Structure*, Willey Interscience, 1978, p.12

[2] I. Prigogine, *De la existență la devenire, [From being to becoming]*, Stiintifica Publishing House, Bucharest, 1992, p. 24

Energy represents a measure of ordered motion of a system's molecules whereas entropy is a measure of degradation of ordered energy or, saying in other words, a measure of disordered motion of molecules. Historical experience of human societies allows a generalization: entropy represents a measure of order degradation; of ordered energy and of ordered structures. No physical, chemical, biochemical, biological process develops without the manifestation of entropy. Sir Arthur Eddington asserted that the law of entropy is the most important among the natural laws.

The connection between these two measures, energy and entropy, for an isolated system, is given by the equation:

$$U=F+TS \quad (1)$$

In this equation, U represents the internal total energy of the molecular system, F represents ordered energy which corresponds to the ordered motion of molecules and the result between temperature T of the system and entropy S represents the energy due to the disordered motion of molecules which is exactly the thermic energy, a form of degraded energy. The degradation of the ordered motion is caused by the molecular collisions. Generalizing, we can state that the degradation of order is due to the interaction between the constituent parts of the system (molecular collisions, friction, etc.).

In accordance with the equation (1), for an isolated system, the sum between the ordered energy, F, and the disordered energy, TS, remain constant. However, as the system evolves towards the state of equilibrium, the ordered energy decreases and the disordered energy increases, and implicitly so does entropy, but, as it can be seen from equation (1), their sum stays constant (the essence of the first principle of thermodynamics). Let's take notice on the fact that the entropy of the system increases at the expense of the degradation of the ordered energy (the essence of the second principle). At state of thermodynamic equilibrium, entropy reaches maximum value and ordered energy F has minimum value. The system is worn-out, unable to carry out a mechanical work, electric or chemical.

Helmholtz, one of the creators of phenomenological thermodynamics, acknowledged that the principle of energy conservation represents a *sine qua non* condition to understand nature. ”In nature there is a fundamental invariance above all natural transformations”. The invariance is exactly the constancy of the energy of the Universe.

The irreversible processes (heat transfer, substance transfer, chemical and biochemical reactions, etc.) produce entropy. As concerns irreversible processes, time reveals its unidirectionality. The direction of time flow is the same as the direction of entropy increase, the same as the direction of irreversible processes.

Entropy and Thermodynamic Probability

Irreversibility of physical and chemical processes was in total contrast with the reversibility of the motion of planets. Newton’s classical dynamics, later developed by Lagrange, Laplace and Hamilton, does not make the difference between past and future. The direction of time flow has no preferences.

Boltzmann elaborates a statistical interpretation of the increase of entropy in evolving systems in which irreversible processes develop such as the mixing of two ideal gases or of two miscible liquids in any proportion at constant temperature and pressure.

The increase of entropy due to mixing, a fully an irreversible process, is given by the Boltzmann equation[3],

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

where W represents the maximum number of arrangements of molecules, at a state of equilibrium. W is also called thermodynamic probability.

Let’s assume that into a recipient separated through a wall there are N_1 gas molecules 1 on the left side and N_2 gas molecules 2 on the right side, at the same temperature and pressure. If the separating wall is removed, the molecules from the two different gases start mixing because of the molecular collisions. As time passes, the mixing of the two different gases

[3] G. Nicolis, I. Prigogine, *Self organization in Non-Equilibrium Systems,* John Wiley, New York, 1977, p. 4

is more and more definite. At the state of equilibrium, when the mixing is complete, the number of arrangements, equal to thermodynamic probability, W, takes the maximum value and has the expression:

$$W_{eq} = \frac{N!}{N_1! N_2!} \tag{3}$$

with $N = N_1 + N_2$. It is obvious that in the first phase of the mixing the number of arrangements is smaller. This increases as the degree of mixing increases and in accordance with (2) the entropy of the system increases. At the state of equilibrium, when the disorder is reaches a maximum, W_{eq} and S_{eq} have maximum values. Extrapolating to other isolated physical and chemical systems, this means that their evolution towards the equilibrium state is always achieved by passing from an ordered state to a less ordered state. As heat is given by the disordered motion of molecules, we can understand why all forms of ordered energy have the tendency to change into thermic energy (heat) which is a degraded form of energy. Through statistical interpretation of entropy the phenomenological aspect of this physical measure was revealed that is the universal tendency of degradation of order, leading to less ordered structures, with larger thermodynamic probability in isolated systems.

Entropy and Alive Systems

For open systems, such as biological systems, Prigogine showed that their entropy could vary only for two reasons:

a) because of the irreversible processes inside the system, $d_i S_{sist}$;

b) because of the flux of entropy from the system towards the medium ($sist \rightarrow m$) and vice versa, from the medium towards the system ($sist \leftarrow m$), $d_e S_{sist}$. Therefore:

$$dS_{sist} = d_i S_{sist} + d_e S_{sist} \tag{4}$$

The second principle of thermodynamics involves $d_i S_{sist} \geq 0$ (=*0* at the state of equilibrium). The second term $d_e S_{sist}$ is given by the equation:

$$d_e S_{sist} = d_e S_{(sist \to m)} + d_e S_{(s \leftarrow m)} \qquad (5)$$

and can be positive, negative or zero, according to the value of the two fluxes in the right term. Conventionally, the flux $d_e S_{(sist \to m)} < 0$ and the flux $d_e S_{(sist \leftarrow m)} > 0$.

In order that the living systems should maintain at a high degree of organization, it is necessary that:

$$d_i S_{sist} = \left| -d_e S_{sist} \right| > 0 \Rightarrow dS_{sist} = 0 \qquad (6)$$

Equality (6) suggests that the (alive) open systems in evolution reach a stationary state in which their entropy is constant, therefore $dS_{sist} = 0$. In accordance with (5), the conditions (6) are achieved if $\left| d_e S_{(sist \to m)} \right| > \left| d_e S_{(sist \leftarrow m)} \right|$, that is the flux of entropy which leaves the system towards the medium, $d_e S_{(sist \to m)}$ is greater than the flux of entropy which the system gets from the medium, $d_e S_{(sist \leftarrow m)}$.

Starting from this balance of entropy, Schrödinger and Prigogine (Nobel Prize laureates) show that the mechanism through which a living organism remains at a high degree of organization, characterized by low entropy, consists in continuous absorption of order from the external the medium; indeed, the man, as the most structurally and functionally developed, biological species, feeds on food having a high degree of organization and low entropy, such as animal proteins. After metabolism, these give back to the medium products of high entropy[4].

The ordered structures which appear and maintain because of the exchange of energy and substance with the medium, therefore far from equilibrium, were named by Prigogine dissipative structures. Alive systems are examples of dissipative structures.

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[4] E. Schrödinger, *Ce este viața - Spirit și materie [What is life & Mind and Matter]*, Politica Publishing House, Bucharest, 1980, p.96,

The entropy balanced equation of ensemble (dS_{univ}), system and medium, is:

$$dS_{univ} = dS_{sist} + dS_m \tag{7}$$

A similar equation to (4), written for the system, can be also expressed for the variation of entropy of medium, dS_m ,that is

$$dS_m = d_i S_m + d_e S_m \tag{8}$$

where $d_i S_m$ represents the variation of entropy of medium because of the irreversible processes within the medium which provides food for the biological species and $d_e S_m$ is the flux of entropy changed between the medium and the system. With (4) and (8),the equation (7) becomes:

$$dS_{univ} = d_i S_{sist} + d_i S_m + d_e S_{sist} + d_e S_m \tag{9}$$

However $d_e S_{sist} = -d_e S_m$ and (9) becomes

$$dS_{univ} = d_i S_{sist} + d_i S_m > 0 \tag{10}$$

In as much as it has been considered that the ensemble-system + medium -is isolated, in accordance with (10), the global entropy of this, dS_{univ} increases. We can imagine an infinitude of such ensembles such as the one discussed above. The natural result we come to is that expressed by Clausius, namely, the entropy of the Universe increases at the expense of the degradation of ordered energy. Indeed, the equation:

$$\Delta S_{univ} = -\frac{\Delta F}{T} > 0 \tag{11}$$

directly connects the degradation of ordered energy of the system, given by $\Delta F < 0$, to the increase of the entropy of the Universe given by $\Delta S_{univ} > 0$ [5].

[5] N.C. Craig, *Entropy Analysis*, Ed. VCH Publishers', Inc., New York, 100110, 1992, p. 99

In accordance with the inequality in (10), the evolution of biological systems towards structures that are more and more ordered structurally and functionally is in accordance with the second principle of thermodynamics, the principle of the increasing entropy of the Universe. Biological structures maintain at a high degree of organization absorbing order from outside

Entropy, Technology and Economy

The greatest part of the energy used by the human society, at least during the last one hundred years, is chemical energy stored in fossil fuel (coal, hydrocarbons) and nuclear fuel. The ordered chemical energy is delivered through combustion under the form of thermic energy (heat), the efficiency being 100%.

The imperative problem from a technical point of view and also from an economic point of view, which was raised at the beginning of the 19^{th} century, was the following:

How can heat, a form of disordered energy, be changed into mechanical work, a form of ordered energy? Sadi Carnot gave the answer through the thermodynamic cycle wearing his name. The real efficiency of transformation of thermic energy into mechanical energy is 30%. The rest thermic energy is lost in the medium, leading to the increase of its entropy.

The development of thermic engines led to the growth of economic activity, but also to people's comfort. In his book *The Entropy Law and the Economic Process*, the mathematician Nicolas Georgescu – Roegen states that thermodynamics is, to a great extent, a kind of economical physics and, partly has, therefore, an *anthropomorphic* character. There is not a mechanical, physical, chemical, biochemical, or biological process which does not obey the law of entropy, or, in other words, which can develop without a partial degradation of the ordered energy into disordered energy. A definition of entropy, in a wider meaning, is the following: *Entropy represents a measure of degradation of ordered energy into disordered energy within systems in function*. Only within systems in function are there interactions between the constituent parts of the system, interactions which cause the degradation of order and, consequently, the increase of entropy.

Low entropy reserves or, more precisely, the reserves of substances with low entropy (hydrocarbons, ores, etc.) are exhaustible. Moreover, these reserves are not regenerable. Even if the population and the rate of exploitation of natural reserves remain constant, eventually the reserves would be exhausted and the existence of the human species would be endangered, unless it ends sooner because of other factors such as pollution. If the land reserves are noted by R and the rate of consumption by *r*, then[6]:

$$R = r \,.\, t \qquad (12)$$

In (12) *t* represents the amount of time the human species will survive. It is obvious that technical progress and the growth of population will lead to the growth of consumption and, consequently, to a shortening of the life span of the human species, "Any child born at present represents a less child in future. In the same time any Cadillac produced now represents less lives in future".

Cosmological Time, Thermodynamic Time and Psychological Time

The redshift of radiations emitted by galaxies, set off by Hubble (1924), proves that the Universe is expanding and it is not static, as it was believed. If at current time, *t*, the Universe in expansion has volume, *V*, results that it had a smaller volume in the past. When time *t = 0*, the whole energy was concentrated into an extremely small volume, in which density and the curvature space-time were infinite (point of singularity). Expansion began through an initial explosion, Big-Bang[7]

"The conclusion which seems to be imperative is that the initial explosion was the beginning itself of all physical things: space, time, energy. Obviously, it is useless to ask ourselves what happened before

[6] N. Georgescu-Roegen, *Legea entropiei si procesul economic [The Entropy Law and the Economic Process]*, Politica Publishing House, Bucharest, 1979, p.491

[7] S. W. Hawking, *Scurta istorie a timpului [A Brief History of Time*], Humanitas Publishing House, Bucharest, 1994, p. 145

the initial explosion or what caused the explosion. There is no "before". And where there is no time, it can't be causality" (Paul Davis "The Last Three Minutes of the Universe")

The Theory of Universal Expansion introduced *cosmological time*. The direction of flow of cosmological time coincides with the direction of the Universe expansion, with the growth of its volume (Figure 1).

As far as thermodynamic systems are concerned, we have shown that the direction of time flow is identical with the direction of development of irreversible processes, with the direction of entropy increase. The entropy of the Universe increases not only because of the degradation of ordered energy, but also because of the Universe expansion. When the volume of the Universe increases from V_1 to V_2, the increase of its entropy is:

$$\Delta S \approx R \ln \frac{V_2}{V_1} \quad (14)$$

The increase of the Universe entropy introduced *thermodynamic time*. The direction of flow of cosmological time coincides with the direction of flow of thermodynamic time.

Like in the case of the Theory of Universe Expansion which admits, by a natural logic, a beginning of the Universe, the second principle of thermodynamics, by means of formulation *the entropy of the Universe increases,* enforces a beginning of the Universe, too, when entropy had minimum possible value, even zero in the point of singularity (Figure1).

Hawking shows that there is also the psychological time that derives from the thermodynamic time. The way of perceiving time flow by human species induces certain psychology. *We can remember the past, but not the future.*

It is necessary that psychological time should have the same direction as the thermodynamic time so that intelligent beings can exist. In order to survive, as we have already shown, human beings have to consume food with a high degree of organization and low entropy, from the medium. After metabolism, these eliminate heat and substances with higher entropy so that $dS_{univ} = d_i S_{sist} + d_i S_m \rangle 0$. Whereas the entropy of the Universe increases, it results that life would not be possible but only in the phase of expansion, expansion which is achieved from a more ordered state to a less ordered state. All three times, cosmological, thermodynamic and psychological have the same direction of flaw.

Entropy and religion

The content of the first principle "The energy of the Universe is constant" expresses, undoubtedly, an absolute truth, but without any predictability about the future. This principle, implying the reversibility of transformations of all forms of energy, reveals a static Universe, without becoming, a Universe without beginning and ending, a Universe without ambitions. Obviously, such a Universe did not need a creator. Instead the content of the second principle "The entropy of the Universe increases" enforces a beginning of the Universe, when entropy had an extremely low value, maybe even zero at zero time. The theory of Universe expansion admits a beginning, as well.

As long as the Universe has a beginning, we can assume that it had a creator, said Hawking.

A created Universe needs much information, many initial conditions. It seems that charges and the masses of elementary particles, which were about to form after the explosion, were "thought of" from the initial conditions, before the birth of the Universe. The expansion was achieved with such a rate so that the chemical elements, indispensable for any living creature such as H, C, N and O, can have time to produce. At an atomic level, energy is quantified. The smallest quantum of action, named the Planck constant, has the value $h = 6,67 \cdot 10^{-34}$ J· s. If energy hadn't been quantified, infinity of chemical compounds would have formed, but they would have been unstable. The formation of proteins or of nucleic acids, without which life would not exist wouldn't have been possible[8].

Are the few data presented here are the result of chance, hazard or were they thought of from the initial conditions so as the Universe should look the way we see it today?

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[8] J.M. Maldamé, *Christos pentru întreg Universul [Christos for the Whole Universe]*, Cartimpex Publishing House, Cluj, 1999, p. 102

Even if we limited ourselves to our biosphere, Clausius' enunciation that the entropy of the Universe increases expresses not only a reality, but also a threat in relation to the future of human civilization, as well, threat scientists understood along with Clausius 'enunciation (1865). The degradation of ordered energy stored in hydrocarbons, nuclear fuel etc, into thermic energy, the exhaustion and the lack of regeneration of these resources, the growth of the concentrations of anthropogenic chemical species, which lead to global heating of the planet Earth, emphasize the fact that the future of human species is strongly threatened. *" Maybe the sun will go on shining above the Earth as strongly as today even after the disappearance of mankind, feeding with low entropy other species, those without any ambition. We don't have to doubt that man's nature, being what it is, wanted a dull, but long career; the destiny of human species was to choose a brilliant career, even if short"* Professor Nicolas Georgescu – Roegen stated in 1971 in his book "*The Entropy Law and the Economic Process"*.

No matter how many forms of alternative energy would be discovered, eventually all of them will finish bringing human species to an extremely critical point The threatening of the human species does not come from lack of food, but from the pollution resultant from the production of food, and, especially, of comfort that is extravagant more often than not.

Whereas the conditions for the existence of life on Earth are extremely rigorous, we can believe that the position of the Earth towards the Sun, from which the Earth gets ordered energy, was thought by God from the initial conditions, before the birth of the Universe, so that life should be possible. John Wheeler considers that "The existence of the Universe depended on our existence". The creation of the Universe was not a purpose in itself. God created the Universe to lodge the Man.

Whereas the planet Earth is today in an advanced state of degradation, how will the future of man be? What is God's plan to save His creation?

Has Christ's resurrection already foretold the creation of a new Universe in which the flow and wear of time will be abolished?[9] Maybe theologians really have an answer to these questions to which science, for the first time, seems to be helpless.

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Caption for Figures

Figure 1 a - The direction of flow of cosmological time coincides with the direction of the Universe expansion, with the growth of its volume

- Beginning of the Universe related with entropy

Figure 1