ENTROPY and NEGENTROPY

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This unpublished paper presents a fresh perspective on the nature of entropy, negentropy, and system morphogenesis. LaViolette shows that the concepts of process and form provide a better context for understanding order genesis than do concepts borrowed by convention from the field of thermodynamics.

One term which is perhaps a bit overused by general systems cosmologists is the term "entropy". It is of particular interest because it presents the disturbing paradox that in considering closed physical system entropy is seen to increase over time whereas in open physical systems and living systems it appears to decrease over time. Such distinctions are good because they are helpful in classifying system and lead the initiate to probe deeper into the mysteries of systems metaphysics to discover a reasonable explanation.

However the term "entropy" is borrowed from the field of physics. It is normally defined in thermodynamic terms as $S = dQ/T$, the change in heat (dQ) divided by the prevailing temperature T. Its terminology was originally introduced to describe the workings of the steam engine. Believing the principles to be of general import beyond the realm of steam engines, they were set forth as the laws of thermodynamics. Whereupon, the Second Law, that *entropy is always the same or increases in a closed system*, became philosophically taken as a universal law of existence. The general nature of this principle became more apparent when information science came up with the isomorphic derivation that systems of order tend toward disorder, i.e., from states of lesser to greater probability.

It soon became obvious that entropy, whether it was increasing or decreasing or staying the same, was an important concept for the general system theorist. The fact that the concept was borrowed from physics or information theory does not seem to disturb the average theorist since he can feel that he will be above criticism if he uses a term that is mathematically well documented in respectable fields. When asked by the layman what is meant by entropy (i.e. positive entropy), the systems theorist gives general examples like: 1) the experiment where a sugar cube dissolves in coffee, 2) the decaying of living matter, i.e., catabolism, or 3) the running down of a wound-up clock.

Yet, in bringing up a variety of qualitative examples such as these, it no longer makes same to restrict the definition of entropy just to thermodynamics and information theory. A universal conceptual symbol must be utilized. Such a symbol has already been formulated, indeed, long ago. In fact, it dates back to antiquity. It is the esoteric meaning behind the astrological sign Aries (♈), the meaning of the first arcanum of the tarot card deck (the Magician), the significance of the male principle, yang.* In modern terminology it is the geometric concept of divergence

* In astrology, the ideogram for Aries can be interpreted either as the rams head or as the fountain, the tremendous outpouring of life force. Astrology holds that Aries is the pioneer. This sign is cardinal, meaning that it initiates or generates activity. It is also a fire sign, i.e.. one expressing dynamic creativity. Aries represents self-expression, self-projection upon the immediate environment, and is characterized by urgency and emphasis. The Magician of the tarot, sometimes symbolized mythologically by Mercury (the messenger) or by the dove, is characterized by similar terms such as: beginning, potential, action, creative force, aspiration, and will power.

(symbolized in modern mathematics by the vector operator $\nabla\bullet$). In the English language the words "dispersion" and "dissemination" express the positive side of this principle, while the word "dissipation" emphasizes the negative aspects.

In contrast to the philosophical implications of the second law of thermodynamics, the ancients took a more or less positive view of the dispersion principle. Indeed, life and death, degradation and creativity are two sides of the same coin. The sun may be regarded as a dying star which is radiating away its mass; on the other hand, it may be regarded as a creative and life-giving force. What the sun loses, life on earth gains. When weeds invade your garden, you could say that your neatly weeded plot goes into a state of disorder and degradation. On the other hand, you could say that this is an example of creativity, or procreativity, plant species propagating their kind. Here we see that dispersion is a characteristic or one aspect of the behavior of open systems in their environment, and in this case may be found to be grounded in biological principles.

To generalize one might say that the principle of dispersion always involves competition for space in one way or other. In the case of compressed gas being released from a cylinder, the cause of dispersion may be-traced to the repulsive forces developed by molecular collisions. In the case of light radiating from a point source, dispersion is caused by the repulsive force developed between photons whose oscillations are out of phase with one another. In the case of catabolism, structural dispersion is caused by physical and chemical forces which organizationally compete with an organism's anabolic processes. Anabolism can be thought of as the building up of biological order and catabolism as the disintegration of that order. However, all is relative. Anabolism also involves the breaking down of physical, inorganic order, and catabolism, the reconstruction or reconstitution of that order. When a company's market share begins disintegrating, this could be thought of as a loss of order, but for the competing companies it seems like just the opposite.

We have demonstrated by example that the dispersion principle, with which positive entropy is usually associated, governs both the building up and breaking down of order. Now, where does that leave the concept of negentropy?

It is said that due to the fact that they are open systems, living organisms are capable of decreasing their entropy, i.e., of increasing their amount of order and theirby growing. This state of affairs, it is claimed, is due to the fact that open systems not only produce entropy, due to irreversible processes, but also import entropy which may be negative. This proposition is illustrated by Prigogine's Theorem,(1) stating that the variation of entropy during a time interval dt takes the form,

$$dS = d_eS + d_iS\ , \qquad \text{where } d_iS \geq 0 \qquad (1)$$

where d_eS is the flow of entropy due to exchanges with the system's surroundings and d_iS is the entropy production due to irreversible processes inside the system such as diffusion, chemical reactions, heat conduction, etc. Moreover, it is maintained that while d_iS must never be negative, d_eS has no definite sign. So, in the case where d_eS is negative and greater than d_iS, a situation may be obtained where $dS < 0$, i.e., where the net entropy of the system is negative. Alternatively, if $-d_eS = d_iS$, then $dS = 0$, i.e., the system is maintained in a steady state.

However this model has some pitfalls. Take the example of an individual who has the choice of eating a steak vs. eating a few hamburgers made from the same steak ground up, vs. drinking a bouillon soup of equivalent nutrient and caloric value. For an individual to satisfy his steady state bodily requirements, according to Prigogine's Theorem, he would not need to eat as much of the former as the latter (in that sequence) since the former has a higher negentropy, i.e., greater order. In actuality, the reverse is true; the individual has to expend more energy to digest the steak, than the hamburger; and the nutrient broth, which can be absorbed directly in the stomach with minimal digestion, places the least burden on the organism. Since it is calories and not entropy which sustains the organism, one would be wiser to choose the soup.

Another problem with equation (1) is that it combines elements of both structure and process, $-d_eS$ being the import of a given quantity of structural negentropy and d_iS being the entropy change due to irreversible processes in the system. While it is thermodynamically legitimate to add these quantities, from a conceptual point of view, it is like trying to add apples and oranges. In the end you are more confused than ever as to how open systems are able to form ordered structures in a spontaneous manner.

The basic question remains unanswered. How does negentropy naturally arise when all spontaneous physical and chemical processes are dissipative, i.e., characterized by entropy increase. A system such as a cell is able to assemble macromolecules of immense complexity creating an ordered macrolevel structure. But, at the microlevel, all the chemical processes involved in this anabolic process are dissipative. While the mechanism of protein synthesis is fairly well understood, the question remains; how did the phenomenon of protein synthesis first arise? Who taught the cell this trick of generating negentropy using common every day positive entropic processes? To avoid the pitfall of vitalism, we must conclude that this phenomenon evolved from simple prebiotic ordering principles, and that in the course of evolution, has become manifest in the preprogrammed and highly complex processes of the cell.

Hence, the spontaneous emergence of order at the molecular level must be a property which is characteristic of simple open systems. Consequently, to come to an understanding of how negentropy arises in open systems, it is best to study simple examples such as the emergence of order in thermal convection and in nonlinear chemical reaction systems.

First, though, I will state some general laws relating to process and structural order.

1) All elemental processes are dispersive (dissipative).

2) Physical order, "negentropy" manifests at a macroscopic level when a macrolevel dispersive process having many degrees of freedom is intersected and dominated by a macrolevel dispersive process having two degrees of freedom. Related to this:
Order is the emergent expression of a cyclically causal phenomenon, i.e., of self-referential causality.

In the case of thermal convection, such as that produced in a pan of water heated on a stove, there are two elemental dissipative processes involved: a) vertical thermal convective dissipation, and b) non-directional spatial dissipation of ordered molecular states. In the near equilibrium regime, the homogeneous steady state condition is stable. Heat is dissipated upward via thermal conduction. Any symmetry-breaking fluctuations, such as the formation of local pockets of water at higher or lower densities, are damped by the random motion of the molecules., i.e., process b) dominates process a).

As the thermal gradient is increased, i.e., as the system is moved further from equilibrium, a threshold is reached beyond which the symmetry of the system is broken and where thermal convection emerges as the dominant mechanism of dissipation, i.e., process a) supercedes process b). The transition from conduction to convection is marked by increased thermal dissipation. Hence, in this particular example the change from one mode to the other is itself governed by the dispersion principle.

The thermal convection process has two mechanical degrees of freedom; see Figure 1. Either a locally hot, low density pocket is moving up ($Y_1 \rightarrow Y_2$), or else a locally cold, high density pocket is moving down ($X_1 \rightarrow X_2$). The motive force for this mechanical transport process must be attributed to gravity. It should be mentioned that density transport implies coherent behavior, i.e., many molecules acting in unison. To completely represent the convective cycle, two thermal steps must also be included in which cold, high density water is transformed into hot, low density water ($X_2 + Q \rightarrow Y_1$), and where hot, low density water is transformed into cold, high density water ($Y_2 \rightarrow X_1 + Q$).

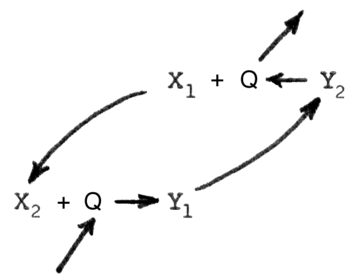

Figure 1

Convective dissipation, involving coherent microlevel behavior (coherent movement of water molecules) is manifest as a macrolevel process having two degrees of freedom (flow up vs. flow down). This-new-pattern overrides the macrolevel structural dissipation process consisting of random microlevel processes having on the order of n directional degrees of freedom (n being the number of molecules in a density fluctuation pocket). Hence the random symmetry of the system is broken; the random motion of molecules is superseded by a nonrandom macrolevel pattern. Negentropy becomes manifest. Were it not for the existence of circular causality (as seen in Figure 1), negentropy, as manifested in the macrolevel cellular convection pattern, would not be present. Hence it could be said that the negentropy that manifests as physical ordering was already preexistent in the circular structuring of causation or process. Therefore, negentropy, structure, and form should be associated with the geometric principle of self-closure (mathematically symbolized by the vector operator $\nabla\times$, or curl). This illustrates how physical form emerges from behavioral patterning.* Floyd Allport[2] has brilliantly developed a theory of behavioral form in his event-structure theory, and this may be usefully applied here.

Nonlinear open chemical system also exhibit ordering properties. Take for example the following reaction scheme suggested by Glandsdorff and Prigogine:[3]

(A held constant)	$A \rightarrow X$	(i)
	$2X + Y \rightarrow 3X$	(ii)
	$B + X \rightarrow Y + D$	(iii)
	$X \rightarrow E$.	(iv)

* Applied to social systems, this approach illustrates how the physical aspects of social systems (such as technological devices, buildings, land use patterns, etc.) emerge from human behavior patterns governed at the symbolic level by values, norms, beliefs, and roles.

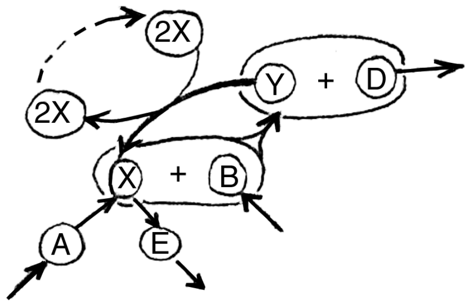

Figure 2

In the near-equilibrium regime, with the input of B maintained at a reduced level, the homogeneous steady state condition is stable. Equations i) and iv) predominate such that A → X → E appears as the primary global reaction. At low concentrations of B the overall reaction B → D remains in the near equilibrium regime, hence the autocatalytic steps, equations ii) and iii), remain insignificant. Any tendency for inhomogeneities to develop due to steps ii) and iii) is damped by the random motion of the molecules, appearing as a dissipative process at the macromolecular level.

However, as the concentration of B is increased, that is, as the reaction B → D moves far from equilibrium, a threshold is reached where equations ii) and iii) become significant. The homogeneous steady state maintained by random motion becomes superseded, wherein, the system begins to exhibit coherent temporal ordering, i.e., concentrations of X and Y at the microlevel coherently oscillate periodically with respect to each other. Due to molecular diffusion, this temporal ordering of chemical composition becomes manifest as spatial ordering in the reaction volume, wherein shells of alternating X, Y concentration expand outward from the location of the initial instability, invading the surrounding homogeneous medium with a spherically symmetric periodic structure. These shells may themselves be static or propagating.* The oscillating reaction system has at the microlevel two degrees of freedom: a state of either more of X and less of Y, or a state of more of Y and less of X. This inherent dichotomy becomes magnified and expressed as coherent behavior at the multi-molecular macro level due to the presence of the autocatalytic step ii) and diffusion.

Unlike the convection example, the existence of circular causality is here not alone sufficient to manifest ordering. This is because the circular causal process here takes place at a *microlevel* uniformly throughout the reaction volume. It is not until this circular causality becomes integrated via diffusion and step ii) to produce coherent oscillations that it is able to become manifest as spatial ordering at the multi molecular level. Hence, a universal criterion for the emergence of order in either type of open system is the emergence of *macrolevel* circular causal behavior, i.e., coherent circular causal behavior at the *microlevel* dominating the tendency toward homogeneity.

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* Note that this reaction scheme is only theoretical, being chemically impossible due to the tri molecular reaction in step ii).
[Update] Nevertheless, Lefever, et al. (1988) later showed that trimolecular reaction (ii) can be expanded into two coupled bi-molecular reactions. [Lefever, R., Nicolis, G., and Borckmans, P. "The Brusselator: It does oscillate all the same." *J. Chem. Soc. Faraday Trans. 1* **84** (1988): 1013-1023.]

What is typically termed positive entropy is simply the tendency for random microlevel behavior, or chaos, to supplant microlevel coherent behavior. This microlevel behavior is so complex by virtue of its numerous degrees of freedom that it appears at the macrolevel as homogeneous order (like "snow" noise on a TV screen). What is typically termed negative entropy is simply macrolevel order, i.e., the replacement of microlevel chaotic behavior by microlevel coherent dichotomous behavior, the latter incorporating circular causality.

Positive entropy, therefore, should be conceptually associated with *process*, the dispersion principle, while negative entropy should be associated with *form*, or the circular causality principle, wherein two or more dispersive processes are organized into a self-closing loop.

References

1) Prigogine, I., *Etude Thermodynamigue des Phenomenes Irreversibles,* Desoer, Liege (1947).
2) Allport, F.,"The structuring of events: Outline of a general theory with applications to psychology", *Psychological Review*, 61, p. 281, (1954).
3) Glansdorff, P. and I. Prigogine, *Thermodynamic Theory of Structure, Stability and Fluctuations*, Wiley, New York (1971).

This paper was written for a systems science class taught by Ervin Laszlo. After reading the paper, Prof. Laszlo wrote at the end of the paper the following comment:

"So, in evolution form is imposed on process -- pure Aristotle. Applications to coupled systems. Implications of "form" as a general category need to be worked out.