THERMODYNAMICS OF CULTURE

THE RELATIONSHIP BETWEEN CLASSICAL ENTROPY AND CHAOS
By Jerome Heath

Systems Theory and Chaos

The systems theory of von Bertalanffy (1962) developed the idea that complex enough systems could be purposeful if the complexity included feedback or cybernetic loops (Wiener, 1961). This "explains" how biological and evolutionary systems can appear to violate the rules of entropy. The chaos theorist have developed the concept of self-organization related to the concepts of chaos, fractals and complexity (Prigogine, 1980; Prigogine and Stengers, 1984). Prigogine in particular indicates that self-organization results from a system being "far from equilibrium." In chaos theories entropy is considered as an important variable in systems that self-organize.

Objective and the Entropy of Chaos

Denbigh and Denbigh (1985) argue that the entropy of classical thermodynamics is objective entropy as contrasted to the entropy of chaos theory (applying the rules of entropy to non-physical systems). The concern is that the classical entropy, although a measure of uncertainty, was also a constituent of physical reality. The entropy of chaos, then, only refers to uncertainty. The entropy of a gas in classical thermodynamics can be integrated from absolute zero and then be included as part of the state equations. This value of entropy is a measure of the relative randomness of the gas and still a measure of uncertainty. According to the Denbighs, the entropy of chaos cannot be integrated from absolute zero, since there is no absolute zero in chaos systems. The problem with defining entropy, in this sense, has to do with the definition of the temperature (and its relationship to entropy) in a given system.

The Grade of the Energy

Kelvin suggested that the second law of thermodynamics demonstrates that there are grades of energy, with heat the lowest grade. Low level energy is energy that is distributed to the subsystems of a system. Because of the rules of entropy (probability) this energy is not as useful as kinetic, potential or electrical energy. As energy degrades into the lowest level, or to heat, the energy is absorbed into activities of the subsystems. In most physical cases this activity is the motion of molecules. This activity can be measured by the expansion of a liquid in a tube. This expansion is caused by the same activities of the molecules of the liquid as they absorb the energy of the system.

Thermodynamic Temperature

Significantly, in thermodynamics, the temperature has a very special definition. Since we need to define temperature without the aid of a thermometer (the thermodynamic definition needs to be more rigorous), it is not an easy task. By ignoring the thermometer and concentrating on entropy and energy, in such a definition, we may explore the possibility of a "T" variable that could also accomplish the integration of entropy that we need in chaos systems. The preliminary definition of the second law of thermodynamics is that all systems will move toward thermodynamic equilibrium. The measure of thermodynamic equilibrium is the temperature.

The process of moving to thermodynamic equilibrium involves the increase in a variable known as entropy. The relationship between the entropy and probability is that entropy measures the necessity for a system to change toward a condition of higher probability. This is the natural or equilibrium direction. In classical thermodynamics, the lowest grade energy of a system is considered to be distributed into molecular energy states. The lowest grade of energy in a chaos system, such as the Denbighs were referring to, may have different origins, but still should demonstrate the distribution of the energy among subsystems. This energy could be quite independent of the molecular energy states. For the sake of our development, wherever there is a probability distribution, and this distribution partitions some kind of energy into subsystems (or the

partition within the subsystems could only be constructed at the expense of energy), the rule of increasing entropy determines the direction in which the system moves toward equilibrium.

The "T" Variable

In order to follow the approach to equilibrium in a particular system we need to define a variable, T, or a temperature degree of freedom (molecular energy will still be present, but may not effect or be effected by this temperature degree of freedom), for that system. For a reversible process, if we have a measure of the change in the lowest grade of energy for the subsets of this system and a measure of the relevant change in the entropy of the system, we know:

$$T = \frac{\delta Q}{\delta S}$$

Where:
- Q = the energy in the system
- S = the entropy in the system
- δ refers to incremental change

This is the fundamental equation of Clausius, and the thermodynamic definition of temperature (Lewis and Randall 1961). This T variable, then, is the thermodynamic temperature, in any situation that is considered to contain entropy and energy. The T variable measures the ratio of the input of low grade energy to the resulting development of entropy. The existence of entropy is based on the partition of a probability distribution among sub-system components. The system moves towards equilibrium, which refers to the system moving towards a more probable state. Changing this to a differential equation with respect to T:

$$T = \frac{dQ/dT}{dS/dT}$$

Transposing we have:

$$\frac{dS}{dT} = \frac{1}{T} \cdot \frac{dQ}{dT}$$

The derivative of S with respect to the T variable is a function of dQ/dT (the temperature coefficient of energy absorption), and an inverse function of the T variable.

Entropic Logistics T Variable Coefficient of Energy Absorption

The logistic equation:

$$\frac{dN}{dT} = C*N*(1 - N/\alpha)$$

describes the growth of populations or the diffusion of innovation (Banks, 1994). It is described as being a basis for evolutionary succession and economic development and related to self-organization in these areas (Prigogine and Stengers, 1984). This equation provides a related assumption for the T variable coefficient of energy absorption in the entropy equation. There are conditions under which the absorption of energy may be limited by a logistic type process. We assume that this occurs in such a way that with increasing S the T variable coefficient of energy absorption will decrease, (that is, the system has a limit to the amount of subsets energy that it can hold) or
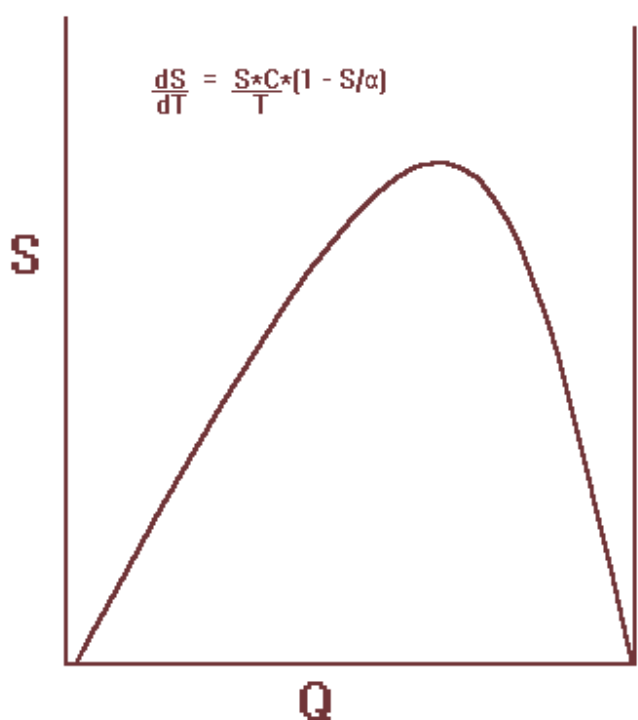
$$dQ/dT = C*(1 - S/\alpha):$$
$$\frac{dS}{dT} = \frac{S*C*(1 - S/\alpha)}{T}$$
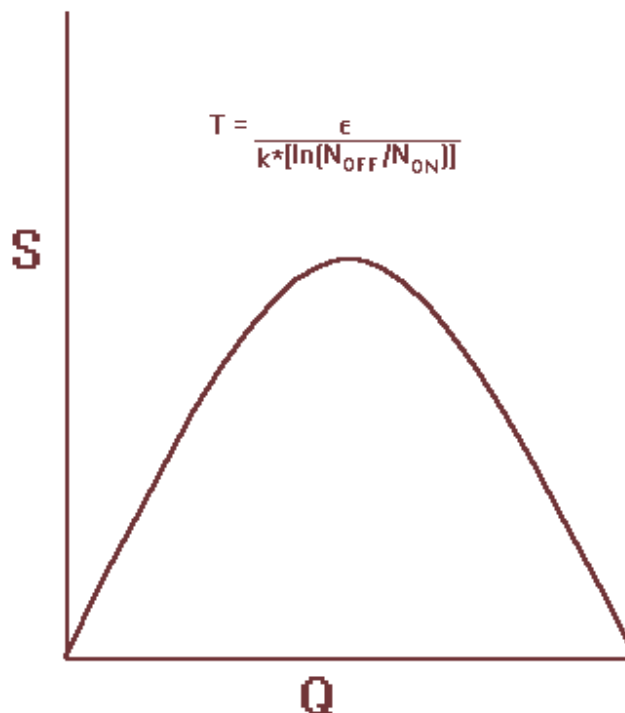$$S = \frac{\alpha}{1 + \beta*T^{-c}} \; ; \; T = [(\alpha/S - 1)/\beta]^{-1/c}$$

Where $\beta = \alpha/S_0 - 1$ (Banks, 1994).

This assumption was chosen because the resulting equation is similar to the logistics equation. Many systems, studied from the chaos perspective, show the "growth curve" character of a logistics equation. The value of S follows the top half of a (here non-exponential) growth function. It appears that there is an upper limit to the energy levels that are applicable in this particular chaos system. This "flattens out" S on the top end. The T variable is discontinuous at $S = \alpha$:

$$\frac{dS}{dT} = \frac{S*C*(1 - S/\alpha)}{T}$$

S

Q

The T variable coefficient of energy absorption, C, relates to how we measure the T variable, and although there are limits, we have some freedom in specifying the T variable. If we can settle on a definition of energy and the T variable such that C = 1, the logistics system, above, behaves quite uniquely. As the system increases in energy, above $S = \alpha$, the T variable becomes indeterminate and then flips to the negative. The laser process is due to such a negative T variable in a similar situation. This process occurs when more upper atomic states are filled than lower states:

$$T = \frac{\alpha}{k*[\ln(NOFF/NON)]} \; ; \; (Atkins, 1984)$$

$$T = \frac{\epsilon}{k*[\ln(N_{OFF}/N_{ON})]}$$

S

Q

Because this is atomic and not molecular, these states are a separate degree of freedom from the molecular energy levels. In describing this degree of freedom, as more of the upper atomic states are filled, T can flip to infinity and then to the negative based on a reduction in S as the energy increases ($T = dS/dQ$) since S is now decreasing with increasing energy. In any process, a negative T value would cause an inversion in the second law of thermodynamics. The fundamental rule of entropy is:

$$\delta S = \delta Q/T = \Sigma^i \, \delta Q_i/T_i$$

With a negative T variable, although overall energy must be conserved, energy is gained from entropy as the process reaches equilibrium. There is also an effect on the work, or usable energy, equation:

$$\frac{w}{q} \leq \frac{(T_h - T_c)}{T_h}$$

With a negative "cold side" T value, w, the useful energy, can be greater than q, the total energy input, again at the expense of entropy. In the laser situation the negative T results in the formation of coherent light. In chaos situations negative T results in a noticeable self-organizing within the system. The outcome appears as though the negative T variable acts like an information source for the process (Brillouin, 1962).

Understanding the negative T variable may help us predict the outcome better than without that knowledge. The negative T variable seems to favor groups of subsystems acting together.

Non-integer values of 1/C produce imaginary results after the discontinuity. This could imply a cyclic process. All even integer values of 1/C produce a return from the discontinuity point on the positive side. All odd integer values produce the flip to the negative after the discontinuity. Since we have not specifically defined energy in these equations, there is some leeway as to how this function works out. The energy we are talking about, here, is not from putting a beaker on a Bunsen burner. This energy is measured in the amount of information, or the amount of food, or the degree of motivation. That this form of energy can be

limited to a maximum level is shown by facts, such as, in most cases a herd does not eat all the grass, or a lecture of more than an hour is too long.

The T variable depends on how the information, the food, the motivation is absorbed. In particular, the equation indicates that a T variable, can have a negative value. Whether we recognize it or not may depend on how we define the T variable scale.

Shannon

The work of Shannon (Shannon and Weaver, 1949) demonstrated the importance of partitioning in entropy. With information the partitioning of the "message" into its components leads to the value of information following the rules of entropy. This leads to accurate prediction about how information is stored in binary on the computer (binary is the computer method of partitioning information) and predicting how much it "costs" to send a message of any transmission medium.

Social Science

It is difficult to define energy with information. So our equations are not readily usable. But in other social sciences the energy is more apparent. A sedentary group has obviously less energy than an active group. Activity is a measure of energy in social science. We also have come to regard much of the social sciences as statistical. What a group does is actually partitioned into the actions of the individuals of the group. We also recognize that the laws of entropy will apply to this partition from the group to the individual. This is the key to the Chaos approach to social science.

Hegel

Hegel (1830) proposed a process of seeing social change as occurring because of a dialectic process. A thesis or new idea is proposed, which prompts a response in the form of a Gegensatz (opposing concept or antithesis). A period of conflict ensues which could involve civil strife or even war. Ultimately there is a new workable result that develops, which Hegel called an Aufhebung (over-reaching concept or synthesis) and this becomes accepted as the solution to the conflict. Hegel is viewing history as a system. The concepts of Hegel are in reality the beginning of the systems view. It is interesting that in politics, today, we can see that the synthesis process is being attempted. Most elected officials listen for the proposals (theses) and counter proposals (antitheses) on various issues. If they find it advantageous, a good politician will choose to offer a solution (synthesis) that can make the most number of his or her constituents happy. The important consideration is that Hegel's synthesis is viable and accepted. It is the base for developing new ideas in the political arena. There is also no question that the approach of Hegel is a form of cultural thermodynamics.

Aufhebung

Hegel's Aufhebung is translated, into English, as "overreaching," "succession," "overcoming." The meaning of Aufhebung is that there is a new higher system which contains all of the old, and not just a compromise. This process results, according to Hegel, from a Gegensatz (antithesis) in the old system. The Gegensatz is unresolvable in the system as it was. The Aufhebung is a "resolution" of the Gegensatz into a higher order system. The Aufhebung is a new level of the system (self- organization), that absorbs (synthesizes, overreaches, succeeds, overcomes) both sides of the Gegensatz. Both sides of the antithesis are present in the new system but resolved by a higher order of the system (both a recognition and a resolution).

Aufhebung and the T Variable

The concept of Aufhebung is a process that comes from a system and there is definitely a limit to the energy of the system. The limit is shown by the Gegensatz. The temperature, here, is the political excitement of the issue being discussed. The value of α (the point of indeterminacy) in the T equation may not be measurable without examining a series of such processes that demonstrate the concept. The system has probability states that relate to the growth of the thesis and the growth of its opponents. As the system progresses, the growth in those who are proponents of the thesis, over those that are neutral, increases S. The growth in the adherents of the antithesis increases the value of S more dramatically. At some point, this will result in a negative T variable:

$$T = [(\alpha/S - 1)/\beta]^{-1/c}$$

The Aufhebung, according to Hegel, is a new order. This is a self-organization of the system. It is the Gegensatz and the negative T value, that gives impetus to the Aufhebung or new self-organized system.

Turbulent Flow
Turbulent flow is a concept that involves a T variable degree of freedom formalized as a steady velocity that occurs over an specific area in a fluid. A velocity is present in the fluid. This velocity is quite steady and can be averaged over a roughly circular area. The area is then measured by its diameter. We take the turbulent system as being of the entropic logistics form:

$$T = [(\alpha/S - 1)/\beta]^{-1/c}$$

Then S, the entropy of this degree of freedom, is the velocity times the (roughly circular) diameter of the area over which such a steady velocity is averaged. Then α is the viscosity of the fluid times about 2,000. In this form we predict the moment of ensuing turbulence as the point where $S \to \alpha$. The limitation, then, on S is related to the point where groups of molecules, in the fluid, are thermodynamically able, under this T degree of freedom, to act together rather than as individual molecules. This T degree of freedom measures a relationship between group and individual molecular entropy. The viscosity measures the relationship of molecules to nearby groups. The negative T results in a self-organization of groups of molecules, that breaks up the laminar flow of the fluid. The molecules can act in groups or individually. The point where groups begin to act is related to the indeterminate point in this T variable. The negative T variable in the viscosity degree of freedom is the pivot point to molecules acting in groups rather than individually. This T variable measures a steady velocity/area degree of freedom in a fluid.

Generalization of Turbulence
Further generalization can be obtained by approximating a viscosity for non-fluid systems. In the dialectic system of Hegel the viscosity would be approximated by social processes that allow for slow but limited and consistent change. Note that this generalization of the turbulence process clarifies the effect of the area. The larger the area over which the velocity of change occurs, the more likely to reach the T discontinuity that produces self-organization. As hurricanes develop over huge areas of warm ocean, and tornadoes develop over broad inland plains, really dramatic political change is more likely to occur if the area of the political process is large. This requires that the velocity of political change is consistent over this large political area. The antithesis is the verbal expression of the tendency to grouping that leads to the new political order.

Predator-Prey System
The Lotka-Volterra equations describe the material changes with respect to time for predator-prey biological systems. The predator-prey system could be characterized as crossed logistics curves of predator and prey. Here we are using S and T as the primary variables, developing differential equations, with, for example, rabbits as herbivores, S_1, and foxes as carnivores, S_2:

$$\frac{dS_1}{dT_1} = \frac{S_1 * C_1 * (1 - \frac{S_2}{\alpha_2})}{T_1}$$

$$\frac{dS_2}{dT_2} = \frac{S_2 * C_2 * (\frac{S_1}{\alpha_1} - 1)}{T_2}$$

With the solution:

$$S_1 = \frac{\alpha_1}{1 + \beta_1 * T^{-C_1} + \epsilon}$$

$$T_1 = [[\alpha_1/S_1 - 1 - \epsilon]/\beta_1]^{-1/C_1}$$

$$S_2 = \frac{\alpha_2}{1 + \beta_2 * T^{C_2} - \epsilon}$$

$$T_2 = [[\alpha_2/S_2 - 1 + \epsilon]/\beta_2]^{1/C_2}$$

This is based on the assumption, as an approximation, that S_1 and S_2 move together with a generational delay, ϵ;

$$\frac{S_1}{\alpha_1} \approx \frac{S_2 * (1 + \epsilon)}{\alpha_2}$$

$$\frac{S_2}{\alpha_2} \approx \frac{S_1 * (1 - \epsilon)}{\alpha_1}$$

The system is divided into two entropy partitions, represented by S_1 and S_2 and two separate T value degree of freedoms, measured by T_1 and T_2. The value of S_1 varies in the range of α_1. The value of S_2 varies in the range of α_2. T_1 and T_2 try to reach equilibrium. S_1 and S_2 are offset by ϵ, because of a generational difference between the two species. The offset is corrected with a factor to allow for differentiation. This generational difference is to guarantee that T_1 flips before T_2. As S_1 approaches α_1, T_1 approaches infinity and flips to the opposite sign. As S_2 approaches α_2, T_2 approaches zero and flips to the opposite sign. These flips in T, prevent equilibrium from occurring, and the values of S_1 and S_2 cycle around α_1 and α_2 indefinitely. The flipping of the T value means that the system is never able to reach equilibrium. The negative T also means that the side of the negative T, and both could be negative, is exerting an organizing influence on the other side of the predator-prey system.

Multiple Degrees of Freedom
If there are more than one T variable degrees of freedom, the system is deemed to be a combination of say T_1 and T_2 variables:

then $dQ/dT = C_1 * T_1 + C_2 * T_2$
etc.:

$$\frac{dS}{dT} = \frac{1}{T} * (C_1 * T_1 + C_2 * T_2)$$

$$S = (T_1 * C_1) * (T_2 * C_2)$$

This indicates that each T variable degree of freedom can act independently when it come to reaching a zero value or a negative value for the particular system.

It's the Temperature, Stupid
Thus, the entropy could be integrated using a number of different assumptions about dQ/dT. This may not completely satisfy the desires of the Denbighs. Absolute zero would be the point where entropy and the T variable would reach zero together. The actual relationship between the entropy (which is related to the probability distribution) and the T variable depends on the characteristics of the system itself.

In each of the chaos systems: living systems, predatory systems, evolutionary systems, economic systems, social systems, cultural systems; the actual character of the relationship between entropy and a given T variable may be quite different. This does not mean that the system does not truly involve entropy. The partitioning of energy among subsystems of the process defines entropy.

There are different possible equations for the relationship between the T variable and S. A given chaos system whether biological, social, economic, or cultural, will have a T variable defining an energy degree of

freedom, and a distribution of entropy. We may know this distribution or we may know the resulting characteristics of the T variable coefficient of energy absorption. With such knowledge we can develop a measure of the T variable and S for the particular case and determine the equation that fits those characteristics. We then have a strong basis for calculating the effect of entropy using thermodynamic principles. The T variable is definitely not measured by the expansion of mercury in a tube.

It is possible that, in some cases, the entropy may work in a reverse direction from our understanding, causing increased order. This is shown as possible, here, because of the "flattening out" of S. This flattening out could cause the T variable to become negative with increases in Q, which causes interesting results in the system's progress. This will only occur when the system is far from equilibrium and near to the capacity of the system for energy absorption, related to a particular T variable degree of freedom. This occurs when both the system is complex enough, as Bertalanffy puts it, and far enough from equilibrium, as Prigogine puts it, to have a negative temperature.

BIBLIOGRAPHY

Adler, P., (1981). Momentum: A Theory of Social Action, Sage Publications: Beverly Hills.

Argyros, A. J., (1991). A Blessed Rage for Order, The University of Michigan Press: Ann Arbor.

Atkins, P. W., (1984). The Second Law, Scientific American Books: New York.

Banks, R. B., (1994). Growth and Diffusion Phenomena, Springer- Verlag: New York.

von Bertalanffy L., (1962). "General Systems Theory: A Critical Review." General Systems, 7, pp 1-20.

Boltzmann, L., (1871). Weiter Studien uber das Warmegleichgewicht unde Gasmolekulen, K. Acad. Wiss.: Sitzb.

Brillouin, L., (1962). Science and Information [2nd Ed], Academic Press: New York.

Cambel, A.B. Applied Chaos Theory: A Paradigm for Complexity, Academic Press, Inc.:Boston.

Carnot, S., (1960). Reflections on the Motive Power of Fire [Edited by E. Mendoza, with other Papers on the Second Law of Thermodynamics by B. Claperon and R. Clausius], Dover: New York.

Chomsky, N. (1972). Language and Mind, Harcourt Brace Jovanovich: New york.

Davies, P., (1983). God and the New Physics, Touchstone: New York.

Davies, P., (1988). The Cosmic Blueprint, Simon and Schuster: New York.

Denbigh, K. G., and Denbigh, J. S. (1985). Entropy in Relation to Incomplete Knowledge, Cambridge University Press: New York.

Dyke, C., (1988). "Cities as Dissipative Structures." In Weber, B. H., Depew, D. J., and Smith, J. D. (Eds.) Entropy, Information, and Evolution, The MIT Press: Cambridge, MA.

Feigenbaum, M. J., (1980). "Universal Behavior in Nonlinear Systems." Los Alamos Science, 1, pp 4-27.

Firrao, S., (1983). The Theory of Self-Organizing Systems in Physics, Biology and Psychology, Via dei Gracchi: Milano, Italy.

Fiske, A. P., (1991). Structures of Social Life, The Free Press: New York.

Forrest, P., (1988). Quantum Metaphysics, Basil Blackwell Ltd: Oxford.

Fraser, J. T. (1978). Time as Conflict, Birkauser Verlag: Basel.

Fraser, J. T. (1987). Time the Familiar Stranger, University of Massachusetts Press: Amhurst.

Giddens, A., (1982). Profiles and Critiques in Social Theory, Berkeley University Press: Berkeley.

Gleick, J., (1987). Chaos: Making a New Science, Viking Penguin: New York.

Greiner, W., (1994). Quantum Mechanics, Springer-Verlag: Berlin.

Han, M. Y., (1993). The Probable Universe: An owner's guide to quantum physics, TAB books: Blue Ridge Summit, PA.

Hawkins, H. (1995). Strange Attractors: Literature, culture and theory, Prentice Hall/Harvester Wheatsheaf: New York

Hayles, N. K., (1989). "Chaos and Orderly Disorder: Shifting Ground in Contemporary Literature and Science." New Literary History, 20 (2), pp 305-322.

Hayles, N. K., (1990). Chaos Bound: Orderly Disorder in Contemporary Literature and Science, Cornell University Press: Ithica.

Hayles, N. K. (Ed.), (1991). Chaos and Order: Complex Dynamics in Literature and Science, The University of Chicago Press: Chicago.

Hegel, G. W. F. (1830). Enzyklopadie der philosophischen Wissenschaften im Grundrisse, Felix Meiner: Hamburg.

Hegel, G. W. F., (1975). Lectures on the Philosophy of World History [trans. by H. B. Nisbet, includes an introduction by Duncan Forbes], Cambridge University Press: New York.

Hofstadler, D., (1980). Godel, Escher, Bach: An Eternal Golden Bird, Vintage Books: New York.

Hofstadler, D., (1985). Metamagical Themas: Questing for the Essence of Mind and Pattern, Basic Books: New York.

Hubert, H. and Marcel, M., (1985). "The Circulation of Sentiments, Magic and Money." In Collins, R. (Ed.) Three Sociological Traditions: Selected Readings (pp 187-197), Oxford University Press: New York.

Laszlo, E. and Bierman, J. (1977). Goals in a global Community: The Original Background Papers for Mankind [A Report to the Club of Rome], Pergamon Press: New York.

Lewis, G. N., and Randall, M., (1961). Thermodynamics [Revised by Pitzer, K. S., and Brewer, L.], McGraw-Hill: New York.

Lotka, A. J., (1925). Elements of Mathematical Biology, Dover: New York.

Mandelbrot, B., (1983). The Fractal Geometry of Nature, W. H. Freeman: New York.

Mosekilde, E. and Mosekilde, L. (Eds.), (1990). Complexity, Chaos, and Biological Evolution [NATO ASI Series], Plenum Press: New York.

Nicolis, G., and Prigogine, I., (1977). <u>Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order Through Fluctuations</u>, Wiley: New York.

Prigogine, I., (1980). <u>From Being to Becoming</u>, W. H. Freeman: San Francisco.

Prigogine, I., and Stengers, I., (1984). <u>Order out of Chaos</u>, Bantam: New York.

Rogers, E. M., (1983). <u>Diffusion and Innovations</u>, 3rd Edition, Free Press: New York.
Seydel, R. (1988). From Equilibrium to Chaos, Elsevier: New York.

Shannon, C. E., and Weaver, W., (1949). <u>The Mathematical Theory of Information</u>, Illinois Press: Urbana.

Shaw, R. S., (1984). <u>The Dripping Faucet as a Model Chaotic System</u>, Aerial: Santa Cruz.

Swinney, H. L., and Gollub, J. P., (1978). "The transition to Turbulence," <u>Physics Today</u>, 31/8, pp 41-49.

Volterra, V. (1931). <u>Theory of Functionals</u> [M. Long Trans.; L. Fantappie Ed.], Blackie & Son Limited: London.

Wiener, N., (1961). <u>Cybernetics</u>, M. I. T. Press: Cambridge, MA.

Yorke, J., and Tien-Yien Li, (1975). "Period Three Implies Chaos." <u>American Mathematical Monthly</u>, 55, pp 583-600.

Ziock, K. (1969). <u>Basic Quantum Mechanics</u>, John Wiley & Sons, Inc.: New York.