CHAPTER 8
THE MYSTIQUE OF ENTROPY[1]

Students of thermodynamics soon learn to appreciate the utility of entropy in making various calculations involving process heat and work effects. These are direct applications found in engineering and physical science. However, in addition to these quantitative applications, one finds qualitative and metaphoric uses of entropy in a wide diversity of fields. The extent to which the concept of entropy has suffused contemporary thought is well illustrated by Lord C. P. Snow's assertion that any definition of culture should include a technical component and that an understanding of the second law of thermodynamics is the cultural equivalent of a familiarity with the works of Shakespeare[2].

Ignoring incidental uses, a few examples will be presented here in which the concept of entropy is central to the development of a theme or is thought to provide insight. The intent is to illustrate the pervasiveness of the fascination evoked by the entropy concept — the entropy mystique.

8.1 COSMOLOGY

Of the many formulations of the laws of thermodynamics, the boldest and most provocative was advanced in 1865 by Rudolf Clausius:

- The energy of the universe remains constant.
- The entropy of the universe tends to a maximum.

Here Clausius has taken concepts arising from limited, earth-bound experience and with a great leap of imagination has vested them with cosmic significance. While both statements are daring, the second law statement has sparked the most interest and controversy because it leads to speculations regarding the birth and death of the universe.

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[1] Most of this chapter is taken from B.G. Kyle, *Chem. Eng. Ed., 22(2),* 92 (1988).

[2] C.P. Snow, *The Two Cultures: And a Second Look*, The New American Library, New York, 1964.

8.1.1 Birth and Death of the Universe. By definition, the universe must be a closed system, and the uncritical extrapolation of our terrestrial experience would suggest that its entropy is increasing toward a maximum. Because an increase in entropy is associated with a decreased ability to perform work, the second law implies that the universe will ultimately reach a dead state referred to as thermal death. This dead state is an equilibrium state in which all thermodynamic potentials have been leveled and processes yielding work are no longer possible.

If one accepts Clausius' statement of the second law with its implication of thermal death, then by the following simple argument one can show that the universe had a beginning. If the entropy of the universe is tending to a maximum, it is doing so at a finite rate and will reach its goal in a finite time. A universe of infinite age would have already reached its equilibrium state of maximum entropy, and since this is not the case, the universe must have a finite age. Thus, the universe had a beginning and we have a position that is at least congenial to the inference of creation and a creator. Undoubtedly, the inclination to draw this inference is strengthened by a scientifically more acceptable theory originated by Lemaitre in 1927 and more recently popularized[3] as the "Big Bang" theory.

The widely published English prelate, William Inge, eagerly accepted the proof of a creator as implied by the "law of entropy"[4]. Inge used the prospect of the thermal death of the universe to argue that God the Creator could not be merely a pantheistic god found only in Nature because such a god would be under an inexorable death sentence. Such would not be the fate of the transcendent god of Christianity.

> "It is not Christianity but modern pantheism and the myth of unending progress which are undermined by the degradation of energy."

Most notable among those espousing the creation view was Pope Pius XII, who stated that Clausius' law of entropy provides "eloquent evidence of the existence of a Necessary Being."[5]

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[3] See, for example, S. Weinberg, *The First Three Minutes*, Fontana, 1978.

[4] W.R. Inge, *God and the Astronomers*, Longmans, Green & Co., London, 1934.

[5] Address to the Pontificial Academy of Sciences, Rome 1951, reprinted in English in *Bulletin of the Atomic Scientists*, *8*, 143 (1952).

An argument against the inference of creation from the laws of thermodynamics was advanced by the Russian physicist, I. P. Bazarov[6], based on the dialectic materialism of Engels. Identifying flaws in the thermal death argument for the existence of a creator, Bazarov points to the unfounded assumption that the laws of thermodynamics apply to the entire universe and to Engels' argument that the creation implied by the second law would be in violation of the first law. In Engels' words, those advocating the pro-creation view saw the universe as winding down and thus assumed that an initial winding up had been provided by "a stimulus from without." However, the process of winding up imparted energy to the universe and hence the total energy of the universe has not always been constant as required by Clausius' first-law statement.

It now appears that Engels' argument of a first-law violation may be vitiated by recent calculations that indicate the total of all energy in the universe is zero[7]. This is possible because energy of motion and the energy equivalent of mass are positive while energy of gravitational or electromagnetic attraction is negative. A zero energy sum would imply that creation could have occurred without an energy input and brings to mind the theological doctrine of creation *ex nihilo*.

Bazarov's criticism regarding the unwarranted extension of the laws of thermodynamics to the entire universe seems well taken. This is especially so considering that on a cosmic scale the predominant energy effects are associated with gravitation and radiation, types of energy which are usually neglected when applying thermodynamics in its usual terrestrial context. In spite of this obvious incongruity, the question is still unresolved for today one finds astrophysicists concerned with entropy changes of various cosmic processes in which quantum and relativistic effects predominate.[8]

<u>8.1.2 Time</u>. Of all the basic quantities in the physical world, time is the most elusive. This is because we not only experience it as an abstraction useful in

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[6] I.P. Bazarov, *Thermodynamics*, Macmillan, New York, 1964, p. 74.

[7] P. Davies, *God and the New Physics*, Simon and Schuster, New York, 1983, Chap. 3.

[8] *ibid*.

physical science, but also in a psychological sense. Because the latter lies beyond the realm of physics, any strictly physical description of time can never be entirely satisfactory.

The theory of relativity shows that time and space are part of the structure of the universe and not, as pictured by classical physics, an empty stage on which physical events are enacted. However, within this purely physical picture there remains the basic question of the direction of time. The equations of classical mechanics, quantum mechanics, and relativity theory are symmetric in time and do not preclude the reversibility of processes. On the other hand, we know that all naturally occurring processes are irreversible and hence travel only in what we have designated as the forward direction of time. For this reason the second law of thermodynamics is said to define the "arrow of time." Time increases in the direction of increasing entropy.

The problem of reconciling the reversibility of the microscopic world of colliding molecules obeying the laws of classical mechanics with the irreversible behavior of the macroscopic world was first undertaken by Boltzmann.[9] This search for the origins of irreversibility provides an interesting chapter in the annals of science[10] and has led to the development of statistical mechanics, an area of science which has proved quite useful in the calculation of thermodynamic and transport properties. However, despite this practical success, the origins of irreversibility have yet to be determined to the satisfaction of scientists of a philosophical bent[11].

8.2 LIFE AND EVOLUTION

At present there is disagreement among scientists as to whether living systems can be completely described by the laws that apply to inanimate matter or whether additional, but as yet undiscovered, laws applying only to living matter are also needed. However, the various identifiable physical and chemical

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[9] See Chap. 6.

[10] S. Brush, *The Kind of Motion We Call Heat*, North Holland Pub. Co., Amsterdam, 1976.

[11] For a review of this problem, see H.B. Hollinger and M.J. Zenzen, *The Nature of Irreversibility*, D. Reidel Pub. Co., Dordrecht, Holland, 1985.

processes occurring within living systems require no additional laws for their explication and therefore conform to the laws of thermodynamics. Additionally, it is known that the laws of thermodynamics are obeyed by each living system as it interacts with its environment. Our present societal obsession with diets and calorie counting serves as a monotonous reminder of our bondage to the first law, but the dictates of the second law are not so obvious and, in fact, may seem counter-intuitive. The conceptual difficulty appears when we regard life as a striving to maintain order and the second law as a principle of degradation. This apparent conflict is due to our failure to recognize living systems as open systems. In an open system the combined entropy of the system and surroundings must increase. Thus, a living system can maintain itself or grow, and thereby decrease its entropy, if the surroundings undergo the appropriate increase in entropy. This leads directly to the statement that life is sustained by the conversion of low-entropy resources into high-entropy wastes. The ultimate origin of lowentropy resources is the sun which drives the photosynthetic mechanism in plants whereby solar energy is converted into chemical energy and stored as carbohydrates.

Despite reconciliation of the life force with the law of entropy, there is still a persistent undercurrent of nagging doubt when the origin and evolution of life are considered. These activities imply purpose, a goal that seems totally opposed by the entropy principle. This contradiction was recognized by Teilhard de Chardin in formulating his grand scheme of evolution towards an Omega Point of pure consciousness and ecstatic union with God[12]. Because of the law of entropy with its opposing tendencies and prospect of thermal death, Teilhard postulated two classes of energy: tangential and radial. Tangential energy is simply the energy identified by physical science and subject to the laws of thermodynamics. On the other hand, radial energy is of a psychic or spiritual nature and is not subject to the laws of thermodynamics. The evolution of life toward the Omega Point is said to be driven by radial energy and thus is free of second-law restrictions. The relationship of the two classes of energy is tenuous and is best illustrated by Teilhard's words:

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[12] P. Teilhard de Chardin, *The Phenomenon of Man*, Harper and Row, New York, 1975. A good summary of Teilhard's arguments is presented in J.D. Barrow and F.J Tipler, *The Anthropic Cosmological Principle*, Clarendon Press, Oxford, 1986, Chap. 3.

> "To think, we must eat. But what a variety of thoughts we get out of one slice of bread! Like the letters of the alphabet, which can equally well be assembled into nonsense as into the most beautiful poem, the same calories seem as indifferent as they are necessary to the spiritual values they nourish."

Teilhard was a Jesuit priest as well as a scientist, but he wanted his work to be judged on the basis of its scientific merit. His *Phenomenon Of Man* is a monumental attempt to meld science and metaphysics to provide an answer to the question of meaning. Despite his heroic effort to fuse faith and reason, science, because it recognizes only reason, could do nothing but render a negative verdict. Nevertheless, his work has wide appeal today, many years after his death. Perhaps this is because the soul of a poet and mystic shows through. After all, who but a poet or mystic would dare address such questions.

8.3 SOCIAL SCIENCE

Henry Adams, the noted American historian and man of letters, was the first to view the course of civilization (i.e., history) from a second-law perspective[13]. In the opening years of the twentieth century he expounded a theory of history in which the Social Energy of civilization is continually dissipated. According to Adams, the second law of thermodynamics required that, "...the higher powers of energy tended always to fall lower, and that this process had no known limit." In the category of energy Adams included the Vital Energy of an individual and the Social Energy of society and stated that, "The law of entropy imposes a servitude on all energies, including the mental." All this naturally resulted in a pessimistic prognosis for civilization where "...the ashheap was constantly increasing in size."

According to one of its most famous practitioners, Claude Levi-Strauss, the field of anthropology could appropriately be called "entropology." Levi-Strauss[14]

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[13] Henry Adams, *The Degradation of Democratic Dogma*, Reprint of the 1919 ed., Harper Torchbooks, New York, 1969.

[14] C. Levi Strauss, *Tristes Tropiques*, translated by J. and D. Weightman, Jonathan Cape, London, 1973.

sees man and his civilizations as "instruments intended to create inertia, at a rate and in a proportion infinitely higher than the amount of organization they involve." He further states

> "Thus it is that civilization taken as a whole, can be described as an extraordinary complex mechanism, which we might be tempted to see as offering an opportunity of survival for the human world if its function were not to produce what physicists call entropy, that is inertia. Every verbal exchange, every line printed, establishes communication between people, thus creating an evenness of level, where before there was an information gap and consequently a greater degree of organization."

We find familiar the concept that the net result of human life is an increase in entropy, but the idea of a leveling of social organization through communication is a bit unexpected and would appear to be a metaphoric extension of the thermal death concept.

The second law of thermodynamics has been shown to provide a realistic perspective for economics[15]. According to Nicholas Georgescu-Roegen, the conventional view of economic process as circular and timeless ignores the increase in entropy accompanying every human endeavor. Georgescu-Roegen sees economic activity as turning low-entropy inputs into high-entropy outputs.

> "All species depend on the sun as their ultimate source of low entropy except man, who has learned also to exploit the terrestrial stores of low entropy such as minerals and fossil fuels. Life feeds on low entropy and so does economic life. Objects of economic value such as fruit, cloth, china, lumber, and copper, are highly ordered, low-entropy structures. For low entropy is the tap root of economic scarcity."

He observes that economic development as presently practiced is based on rapacious consumption of our terrestrial dowry of low-entropy materials and concludes that this can not be indefinitely sustained.

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[15] N. Georgescu-Roegen, *The Entropy Law and the Economic Process*, Harvard University Press, Cambridge, 1971.

Using the entropy-conscious economic views of Georgescu-Roegen, Herman Daly[16] argues persuasively against the fallacy of perpetual growth and even suggests that growth itself may be illusory when measured by the GNP. This closely watched economic indicator includes, besides the value of goods produced and services rendered, all costs associated with production, including pollution control costs. As the richer and more accessible resources are preferentially consumed, the remaining lower-quality resources require higher production costs and thus a rise in GNP may reflect increased cost of production rather than increased level of production. This is the entropic factor largely ignored by conventional economics. As an alternative to growth, Daly has outlined in some detail the workings of a steady-state economy.

The work of Georgescu-Roegen has also inspired Jeremy Rifkin's *Entropy: A New World View*[17] in which the entropy law is credited with singlehandedly undermining the Newtonian-Cartesian mechanistic world view. Rifkin believes that a new world view based on the entropy law would expose the fallacy in our present obsession with growth and would allow us to meet the future with awareness and acceptance of Nature's constraints. This change in outlook would affect practically every area of human endeavor ranging from technology to religion and could move us toward the long-sought but ever-distant utopian dream. There is no doubt that Rifkin has overstated his case in a single-minded and over-simplified manner, but exaggeration is a forensic device which often becomes acceptable when used in passion for a worthy cause. Because the inculcation of an entropy-conscious world view is considered by many to be such a cause, perhaps Rifkin should not be judged too harshly for his excesses.

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[16] Herman E. Daly, *Steady State Economics*, W. H. Freemam & Co., San Francisco, 1977.

[17] J. Rifkin, *Entropy: A New World View*, Bantam Books, New York, 1980.

8.4 LITERATURE AND ART

Metaphoric entropic themes abound in modern fiction[18] as well as in serious science fiction[19]. Most applications are implicit, although several writers explicitly use the term entropy in their work. These writers are predominately American and include John Barth, Donald Barthelme, Saul Bellow, Stanley Elkin, Norman Mailer, Walker Percy, Thomas Pynchon, and John Updike. As expected of fertile imaginations, one finds many variations of the entropic theme whether used explicitly or implicitly. The theme has been applied to either individuals or entire societies, sometimes within the context of a closed system, with ultimate states as extreme as chaos and stagnation.

Norbert Wiener's famous book on cybernetics[20] first appeared in 1950 and was undoubtedly instrumental in popularizing the application of the entropy concept to the many aspects of the human condition as found in modern literature. Moreover, Wiener's identification of entropy as a measure of the information content of messages stimulated writers to examine the very act of writing[21]. In Wiener's words

> "Messages are themselves a form of pattern and organization. Indeed,it is possible to treat sets of messages as having entropy like sets of states of the external world. Just as entropy is a measure of disorganization, the information carried by a set of messages is a measure of organization. In fact, it is possible to interpret the information carried by a message as essentially the negative of its entropy, and the negative logarithm of its probability. That is, the more

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[18] Tony Tanner *City of Words*, Harper and Row, New York, 1971, Chap. 6 and Zbigniew Lewicki , *The Bang and the Whimper*, Greenwood Press, Westport, CT., 1984.

[19] Colin Greenland, *The Entropy Exhibition*, Routledge and Kegan Paul, London, 1983.

[20] Norbert Wiener, *Human Use of Human Beings*, Houghton-Mifflin, Boston, 1950.

[21] See Sec. 4.3.

> probable the message, the less information it gives. Cliches, for example, are less illuminating than great poems."

The idea behind this passage is easily grasped when applied to the transmission of factual data (e.g., a seven-digit telephone number) or a coded message (e.g., one if by land, two if by sea) but quickly becomes fuzzy when considering the transmission of subtle or abstract ideas or the more vital aspects of communication inherent in the sender and receiver. This becomes apparent when the idea is pushed to its limit. The writer, in an attempt to counter the entropic effect of banality, looks for unexpected or improbable ways of using words and thus runs the risk of verbal chaos. The dilemma is articulated by Lewicki[22]:

> "In order to avoid entropy, a writer must therefore walk a narrow path between the danger of producing probable messages of low informational value (such as, for example, new versions of old themes, written in a conventional manner), and the risk of turning out incomprehensible bodies of words that would seem disorderly to the reader."

Rudolph Arnheim[23] has recognized the contradictions in information theory as applied to art:

> "Here order is described as the carrier of information, because information is defined as the opposite of entropy, and entropy is a measure of disorder. To transmit information means to induce order. This sounds reasonable enough. Next, since entropy grows with the probability of a state of affairs, information does the opposite: it increases with its improbability. The less likely an event is to happen, the more information does its occurrence represent. This again seems reasonable. Now what sort of sequence of events will be least

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[22] *ibid*.

[23] Rudolf Arnheim, *Entropy and Art*, University of California Press, Berkeley, 1971.

> predictable and therefore carry a maximum of information. Obviously a totally disordered one, since when we are confronted with chaos we can never predict what will happen next. The conclusion is that total disorder provides a maximum of information; and since information is measured by order, a maximum of order is conveyed by a maximum of disorder."

Arnheim attributes the contradiction to a failure to distinguish order from structure:

> "Any predictable regularity is termed redundant by the information theorist because he is committed to economy: every statement must be limited to what is needed. He shares this commitment with scientists and artists; its meaning, however, depends on whether one chops up patterns into elementary bits or whether one treats them as structures. A straight line reduced to a sequence of dots for the purpose of piecemeal analysis or transmission can be highly redundant; in the drawing of a geometrician, engineer, or artist it is not."

In explaining the creative process underlying a work of art, Arnheim sees an interplay between the anabolic tendency which establishes the structural theme and the entropic principle which is manifested both as a catabolic destruction of patterns, or disordering, and a simplification or ordering due to tension reduction. Here we see the entropy principle invoked metaphorically and identified simultaneously with two opposing tendencies: ordering and disordering.

8.5 COMMENTARY

Of all the properties of matter, entropy is most difficult to conceptualize and seems the most contrived. It cannot be evaluated directly from an experimental measurement, but must be calculated from a somewhat arbitrary computational path and thus its existence and evaluation are closely tied to human activity. It is tainted with a human scent. Perhaps this is a reason this most anthropomorphic of all the concepts of science has fascinated the human mind.

<u>8.5.1 Entropic Insight?</u>. Despite its mystique, entropy actually provides very little insight into the mysteries of Nature. This can be appreciated by recalling the familiar textbook derivations. A Carnot cycle is used to define entropy and demonstrate that it is a state property. Next, an isolated system undergoing a spontaneous process is considered and a simple argument shows that an increase in entropy results. Ramifications of this result are extremely useful for the detailed calculations made by engineers and scientists, but in what way has it improved our general understanding of Nature? Are not the following statements equivalent and equally enlightening?

A. Every spontaneous process tends toward a condition of deterioration or stagnation.

B. Entropy is the measure of deterioration or stagnation. Every spontaneous process results in an increase in entropy

Statement A is a direct statement of experience. Statement B is expressed in the language of an empirically based science and is therefore merely an indirect but more formalized statement of experience.

The idea of things running down, which can now be proclaimed as a decree of science, has been found to be a dominant theme in ancient myths[24]. This condition also has been lamented by Hesiod, the Greek poet of the 8th century B.C., who told of the five descending ages of Man beginning with a pristine age of gold and ending in his own worldly age of iron. Also, somewhat later, we find St. Paul[25] referring to a coming time of glory when "creation itself will be set free from its bondage to decay." These may be regarded as generalizations of statement A and appear more naive than the B-based concept of thermal death. Yet, even though we favor statement B today, let us not be deceived into thinking it more insightful than statement A.

With regard to fixing the direction of time, it is also instructive to consider two alternative statements.

A. In the usual sense of before and after, spontaneous processes proceed in the forward direction of time.

B. All spontaneous processes are accompanied by an increase in

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[24] G. de Santillana, and H. von Dechend, *Hamlet's Mill*, Gambit Inc, Boston, 1969.

[25] Romans 8:21.

entropy. The forward direction of time is the direction in which the entropy increases.

While the practical person would give no advantage to statement B, many philosophers prefer something similar to it because it appears to have eliminated some of the subjective element that clings to statement A. Their object is to define time without reference to the human mind[26]. However, in this respect an obvious problem arises in the actual determination of entropy. This requires a human mind to devise a reversible path between the initial and final states which is essential to the calculation of the entropy change. There is no entropy meter and the invoking of entropy, which is itself a construct of the human mind, does little to remove the human scent from the concept of time.

To place the question of time in perspective we should recognize that it is a construct of the conscious mind. The subconscious mind, the Freudian id, has no awareness of time — a fact known to science and easily verified personally by recalling the particulars of our dreams. What we have done is to construct from the regular rhythms of the universe (e.g., the motion of the earth about its axis or about the sun) a lifeless, linear time scale upon which we can place in monotonic order the events of our physical world. This seems so natural that it comes as something of a shock to learn that it is possible to have a valid and effective world view that does not include the concept of time. An outstanding example of this is the language of the Hopi Indians of the American southwest which contains no reference to "time" either explicitly or implicitly. This language is capable of accounting for and describing correctly, in a pragmatic or operational sense, all observable phenomena in the universe without the mental construct of time[27].

The avowed aim of science is to establish the basis of physical reality. However, two different interpretations exist: external and internal. The external version is the older, traditional view in which the human mind objectively probes and observes Nature and thereby discovers natural laws. Recent developments in physics, however, have cast doubt on the concept of an objective observer

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[26] For lucid and concise discussion of the philosophical problem of time, see K.G. Denbigh, *Three Concepts of Time*, Springer-Verlag, Berlin, 1961.

[27] B.L. Whorf, *Language, Thought and Reality*, M.I.T. Press, Cambridge, 1956.

independent of the system observed[28], and this has led to the view that science merely creates a set of interlocking laws which provides a consistent description of Nature. This description usually involves the use of abstractions and mental constructs far removed from our everyday experience and may thus be termed a view of physical reality internal to the mind[29]. The previous discussion of time and entropy is obviously an argument for the internal view.

One is now left wondering why the entropy concept, which offers so little insight, has been so widely employed outside its narrow scientific context and why any serious artist or writer would even consider the application of scientific principles to the very act of creating. There does indeed appear to be an entropy mystique, although the reasons for it will not be fully explored. The following is merely a suggestion.

8.5.2 Entropy as a Symbol?. A symbol is something that suggests something else. Often, that which is suggested by a symbol is nebulous or impossible to articulate and we are often unaware of the exact correspondence between the symbol and what is symbolized. The origin of symbols is usually not traceable because symbols seem to arise naturally and are accepted because of their power to evoke deep feelings and because of our inner conviction, often not consciously or logically formed, of their validity. For many individuals symbols play a large role in the shaping of their worldviews and historically, shared symbols have always been an important part of a culture. In the past most symbols have been of religious origin, but in western society science has displaced religion as the reliable source of *truth*. Thus, religious symbols have lost their efficacy, and it seems that science is unable to provide us with viable replacements. The poet Stephen Spender[30] has noted the decline in the number of shared symbols and believes that this loss makes the task of a modern poet extremely difficult. Instead of being able to freely use a existing body of generally

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[28] See, for example, F. Capra, *The Tao of Physics*, Bantam Books, New York, 1975.

[29] Both the external and internal views are discussed by Morris Kline in *Mathematics and the Search for Knowledge*, Oxford University Press, Oxford, 1985. The internal view is examined by Roger S. Jones in *Physics as Metaphor*, New American Library, New York, 1982.

[30] Stephen Spender, *World Within World*, H. Hamilton, London, 1951.

accepted symbols available to earlier poets, the modern poet must devote considerable effort to fashioning symbols that he or she hopes will strike a responsive chord in the reader.

Because our need for symbols is unconscious and deep-seated, it could be argued that we have unknowingly made entropy a symbol. As a symbol arising from science, entropy is both authoritative and profound, and there is little doubt that it is cloaked in mystery. In addition to these essential attributes, entropy could be said to be a symbol possessing religious overtones. It is apocalyptic in its dreaded revelation of eventual and inexorable thermal death; it reminds us of our ever-present existential burden($\Delta S > 0$); and it provides a saving grace by showing us the "way"($\Delta S = 0$). If, indeed, entropy has achieved the status of a symbol, it is unconsoling and lacks the richness and inspirational quality of symbols we seem to have forgotten.