Entropy

By Herman F. Greene

The law of entropy has been variously defined. The simplest definition is "a thing once used becomes less useful." Try to burn a log that has been already been burned, or build a house with its ashes. Or who would want to buy an old pair of shoes, if he or she could get new ones? A thing once used is less useful.

More technically entropy is a measure for the quality of the energy in an isolated system. Lower entropy means that more energy is freely available, higher entropy means that less energy is freely available. According to the second law of thermodynamics, the movement from lower entropy to higher entropy is inevitable. At any time in the future, the system must have equal or higher entropy. In addition to being inevitable, this movement is irreversible. So, a log before it is burned has low entropy, but it has high entropy after it is burned. Its energy available to perform work will never be freely available again.

Upon reflection you might ask, "Why does entropy increase?" According to the first law of thermodynamics, the law of the conservation of energy, energy is neither created nor destroyed; it only changes form. So if energy is never lost, how can it be that the amount of energy available to perform work decreases? Where does the available energy go, if it is not lost? A partial answer to this puzzle was formulated by Ludwig Boltzmann more than a century ago, when he interpreted the increase in entropy as the increasing disorganization of matter within an isolated system, an irreversible movement toward maximum disorder and chaotic dispersal.

This interpretation of why entropy increases within an isolated system may also be illustrated with a log. If a log were placed in the corner of a sealed room filled with air, the energy in the room initially would be very unevenly dispersed. Most of the available energy would be in one corner of the room, in the log. If the log were burned, however, its energy would be randomly dispersed throughout the room. Energy would move from an ordered, concentrated state, in the log, to a disordered state dispersed throughout the room. Eventually the room, in theory, would reach its equilibrium state where all the available energy would be randomly dispersed throughout the room. No energy would have been lost in this process, but in the equilibrium state, no energy would be available to perform work. (Interestingly, the theory of entropy requires that this happen over an indefinite period of time even if the log is not burned. The log left alone in the room would decay and its energy would eventually be dispersed with the same ultimate result as if it were burned.)

These characteristics of the second law, the necessary movement from lower entropy to higher entropy within an isolated system and that this movement is irreversible have caused many people to reflect deeply on its meaning. In the scientific world, expressed as a formula, the law of entropy has become a useful tool for measuring the amount of energy wasted in a thermal process, such as an power plant or an automobile engine. Some would argue that this utilitarian use of the concept of entropy is the only useful one. But what we are more concerned about are the larger speculative meanings given to the concept of entropy. These are the ones that have shaped human imagination.

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Perhaps the most famous speculative meaning given to the law of entropy is that it forecasts the coming "heat death" of the universe. According to this view, it is thought that the inexorable workings of the law of entropy will result in the dispersal of all energy in disorderly fashion throughout the cosmos, assuring that, in the words of T. S. Eliot's "*The Hollow Men,*" the world will end "not with a bang, but a whimper."

Another popular meaning given to the law of the entropy is that, leaving the universe aside and looking only at Earth, the progressive increase of entropy will inevitably lead to the exhaustion of the resources of Earth. People espousing this view have concluded that, while there may be no ultimate solution to this problem, later is better than sooner. Thus, they conclude the clear message of the law of entropy is that we should not squander our scarce resources; rather, we should conserve them to prolong life on Earth, as we know it. People of this view criticize modern technology as a force that is rapidly and exponentially accelerating the increase in entropy in Earth's system.

Less dramatic, but perhaps equally provocative thoughts about entropy have included the thought that the law of entropy introduces the concept of the directedness of processes within the universe, and thus of temporal succession. In other words, as Sir Arthur Eddington said, entropy is an "arrow of time." Some have taken this to mean that the flow of time from past to present to future, can be accounted for as a function of entropy. The past is the past because the macroscopic degree of entropy in the universe is lower in each moment of the past than in each succeeding moment. According to this view, it is the progression of entropy that makes time, time. Hence our experience of time is an interior awareness of the progressive increase in the universe's entropy. A correlate of this understanding is that we cannot go back in time (science fiction notwithstanding). The increase in entropy is irreversible, and hence time as well.

Exponents of the entropy-thus-time-irreversibility viewpoint have found support for their position in the big bang theory of the universe. The law of entropy when introduced in the 19th century caused difficulty for cosmologists who had seen the universe as eternally existing (proceeded however momentarily by God). The question for these cosmologists was how could one reconcile a timeless universe, with the inexorable law of entropy and its requirement that over an infinite period of time, the universe (other than in a equilibrium-state or random/chaotic dispersion of energy) cannot exist? The big bang theory seemed to confirm time's arrow and correspondingly entropy and time irreversibility, albeit perhaps with the corollary depressing confirmation that the ultimate meaning and direction of the universe was toward random chaos and loss of all creative energy; *ergo,* in the words of Macbeth, "a tale told by an idiot, fill of sound and fury, signifying [(or, at least tending toward)] nothing."

Caught as we are, in the in-between times, of the present, one other meaning of entropy deserves comment. This is the thought that the law of entropy introduces into our cosmic understanding of the universe the concept of qualitative change, and here we have to depart somewhat from the view that the progression of entropy is simply a matter of particles of matter moving from ordered to disordered states. The meaning given to entropy under this view is that when Humpty-Dumpty falls never to be put back together again, the problem is not that we have a difficult time retrieving and pasting back together the little, chaotically dispersed fragments of egg shell, but that there has been a qualitative change in

Humpty-Dumpty. It is not that it is difficult to put Humpty-Dumpty back together again, it is that we cannot. Thus, in this view, matter is consumed in the inexorable progression of entropy and turns into something that cannot be reconstituted as matter/available energy. Thus, some would say that the laws of thermodynamics require the understanding not only that, in a closed system, we cannot create energy (because the amount of energy is forever fixed and can only change in form), but also that we cannot from dispersed energy create matter (*i.e.*, once energy is dispersed in a high entropy state, in a closed system it remains in its equilibrium state of dispersal).

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This aspect of "qualitative change" is particularly important in its implications. It introduces a third component of the law of entropy, the first two components being (1) the inevitable movement from lower entropy to higher entropy, and (2) irreversibility. The implications of qualitative change are not all negative. Exponents of this view have extended the meaning of entropy from that of responsibility for time, to that of accounting for evolution. Evolution in the universe, it is said, cannot be explained by the laws of mechanics, that is by changes in the position of particles. Evolution involves qualitative change in the universe. What is now is not the same as what was. It is qualitatively different. Thus, entropy is taken to account for novelty, states of matter can come into being that are different from what proceeded them, and, hence, the progression from the big bang, to atoms, to galaxies and stars, to the various elements, to minerals, to life in its various forms, to the human, and even to progression in culture. Each of the qualitative changes in the universe has involved the expenditure/dispersal of energy and cooling of the universe, and correspondingly an increase in entropy. Indeed, all creative activity, all work that we as humans do or that is done by any other plant or animal or by any other force in the universe involves such energy expenditure. While the concomitant increase in entropy might be viewed as the dark side of existence, a malevolent curse, it may also be viewed as grace, the source of all creativity/activity, that our actions and the universe's actions may make a difference—the qualitatively new is possible. According to this view, entropy is the engine of evolution.

So what are we finally to make of our reflections on the second law? What implications does it have for ecology, for human life, for Earth, for the universe? Is the biosphere of Earth a closed system in which the law of entropy requires that we recognize the limitations of our resources and take on a survivor's mentality? Or more subtly, since we know that Earth is an open system at least as regard's the ingression of sun's energy, must we recognize as Nicholas Georgescu-Roegen has said that the limitation we face is not ultimately that of energy, but of the finite stock of mineral resources in the Earth's crust? The sun's energy is a high entropy resource as compared to the low entropy resources of Earth's minerals. Or is it possible, following the apparent logic of Einstein's theory of relativity that, since energy and matter are two sides of a coin, we may one day convert solar energy into matter just as surely as we can now fuse atoms to produce the energy of the sun? Does the law of entropy require that we conceive of the ultimate destiny of man as being to inhabit space or at least, to overcome the Earth's entropy increase, to harvest the resources of space? Or is the primary message of the law of entropy not one of cosmic destiny and extraterrestrial being, but one of humility—that we humans are limited as a species by the law of entropy and our relatively closed terrestrial system . . . limited as to capacity, and ultimately as to our time on the cosmic stage?

In such a state of humility, reflection on the law of entropy could enable us to see that we are now living off our valuable and largely irreplaceable low entropy natural capital, when prudence requires us to live off of our income. Our income is the energy we receive from the sun. If we were to live off of our relatively high entropy solar income, however, like a recalcitrant debtor we would have to change how we live. We would have to change everything. Not to change would bankrupt us and nature.

What is it in us that supports such a spendthrift existence, makes us so careless of present and future generations of all forms of life and of Earth's natural systems, and blinds us to what is obvious?

Entropy, the second law of thermodynamics, . . . something to think about.