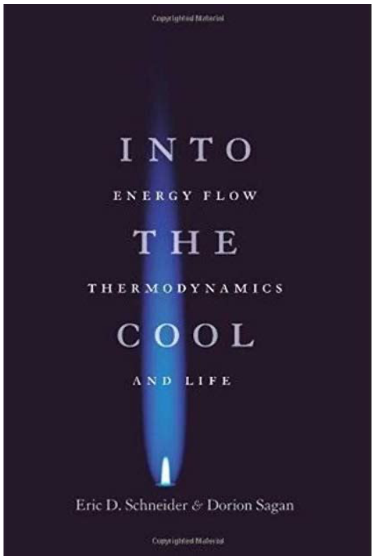
Matter Cycles, Energy Flows, Entropy Ensures Complexity Grows

A Review of *Into the Cool: Energy Flow, Thermodynamics, and Life,* by Eric Schneider and Dorion Sagan

Blaine A. Snow, 2021



This outstanding book on thermodynamics, evolution, and life is the authors' interpretation of already-existing science that explains the development of complex life on earth as nature's creative response to the requirements of thermodynamics, namely heat dissipation and entropy. Although not technical, *Into the Cool* is not easy reading. It requires significant knowledge of general science as the authors bounce between astronomy, physics, chemistry, biology, and ecology. The book earned a spot on my all-time favorites shelf because of how well it fit into and how much it added to my knowledge of the sadly still-marginalized paradigm of natural evolution, emergence, and complexity.

The authors' basic idea is as follows: throw enough energy for a long enough time (the sun, a star) at a standard cosmic mix of basic elements and chemicals (the earth, a planet), add a few other geophysical conditions such as the right temperatures, protective magnetic fields, and such, and – *Voila!* life forms necessarily arise as nature seeks every possible route to fulfilling the requirements of the second law of thermodynamics. In this view, life forms are literally nature's endlessly creative strategies for dissipating heat and bringing the system "into the cool." "Very cool," I'd say – an idea which from a scientific physics/chemistry standpoint, provides a unique view of the evolution of complexity and why it arises at all. In this view, organisms and their ecosystems become complex vehicles whose primary physical job is to cool down the planet and help dissipate heat, ultimately back into space. Entropy and nature's "need" to fulfill its requirements drives the whole shebang; life forms are simply a system byproduct that increase the efficiency of energy dissipation. "Heat moves, without recompense, into the cool" (36).

The basic principle behind this view is summed up in the phrase: **"Nature abhors a gradient"**. The authors use this basic principle to describe why life arose within this sun/earth system. A gradient is nothing other than a difference – in temperature, pressure, density, concentration, number, distribution, probability and so forth. Because of entropy, the laws of large numbers, and the laws of probability, nature always tends or "wants" to level or equal out differences and this also means drifting towards the most probable states. It's just another way of thinking about direction or telos – natural change from difference to sameness, higher to lower energy, or from lower probability to higher probability, from far-from-equilibrium (less likely) to equilibrium (more likely). In this view, "God" is "energy flowing downhill."

…life's complexity is a natural outgrowth of the thermodynamic gradient reduction implicit in the second law; where and when possible, organizations [life forms] come cycling into being to dissipate entropy as heat. Gradients, such as that between the sun and space, may be huge, and draining them may take literally eons. Nonetheless, the complex systems that come swirling into being near gradients are natural. Although they may sometimes seem to be organized by an outside force, no 'agent deliberating' as Aristotle put it over twenty centuries ago, is needed (xvii).

Self-organization? Well, sort of. Evolution? Yes, but with a twist. This is self-organization as an outcome of, or necessary response to, energy dissipation. Evolution as an outcome of nature continually finding better ways (in this case, through novel life forms) to dissipate energy. And of course, it can happen anywhere you have stars and planets with the right features and properties. So, with billions of confirmed exoplanets out there, in our galaxy alone, there must be plenty of other times/places/localities where some kind of complexity has arisen/will arise/is arising. One thing "goes downhill" (energy) while another thing "goes uphill" (complexity). Nobel Prize-winning chemist Ilya Prigogine who did important foundational research on self-organizing systems far from equilibrium summarized it this way, "Entropy is the price of structure."

Perhaps it all sounds too simple or too wacky or too irreverent or too purposeless or too something (add your own favorite reason to discount something). It may not fulfill your pet wish for the "purpose of life on earth" (which might also be no purpose) but it does help to identify ways of thinking about purpose as three kinds of telos or direction, given here in a hierarchy of complexity:

1. *Teleomatic Purpose or* ***Physical*** *Directedness*: gravity and entropy, end-producing behavior; movement as mutual attraction (gravity) or movement towards equilibrium or state of highest probability (entropy)
2. *Teleonomic Purpose or* ***Living*** *Directedness*: end-directed behavior of organisms, goal-directedness based on survival and natural selection, reproduction, replication
3. *Teleological Purpose or* ***Mental*** *Directedness*: conscious purpose goal-oriented behavior in self-reflective organisms; human purpose

Since taking shape in the 1800s, physical science remains divided into two fundamentally different camps, one centered around gravity, simple-closed Newtonian systems, and time symmetry, the other around heat, thermodynamics, complex-open systems, and time-asymmetry. The former is the reductionist God-view of the world, in Nagel's words "the view from nowhere," while the latter is the human-centered view which, over time, has come to take into account living systems, embodied consciousness, and human experience. The former is the worldview of physics and mathematical certainty, determinism, time-symmetry. The latter is the worldview of statistics, the laws of averages, large numbers, thermodynamics, energy flows, and far-from-equilibrium organization. The authors explain:

Thermodynamics had released the arrow of time. It went quivering into Newton's shiny smooth *apple, generating heat as friction. By and by, perpetual-motion machines were realized to be an unworkable fantasy. The past and future were different, and science could no longer ignore it. Thermodynamics gave science a wake-up call, forced it to grapple with the reality of linear time. The wake-up call is still reverberating in the collective scientific mind, still groggy from Newton's dreams. Plato had described a timeless realm of pure Ideas, of which our changing world was only an imperfect copy… Newton was a kind of English scientific Jesus – able to access the eternal mind of God and show how he did his divine handiwork. But thermodynamics messed all that up. It measured loss, and implied that – despite the magnificent motions of the planets – time moves in only one direction. The direction of burning* (37).

These are the foundational ideas of the book outlined in the first seven chapters of Part 1: "The Energetic." The three chapters of Part 2: "The Complex," describe the physics of complexity and how systems far from equilibrium can sustain organization, structure, and function through the emergence of novel ways a system responds to the requirements of energy dissipation. There's been a ton of careful research done on how complexity emerges and evolves. Some of the newest thinking in this area is the new philosophy of science that is called "the new mechanism" or also "the new mechanical philosophy" which has no resemblance with the old-school idea of machine-based mechanisms: see Stewart Glennan's The New Mechanical Philosophy and also the article in the *Stanford Encyclopedia of Philosophy* by Carl Craver entitled "Mechanisms in Science". A more technical book on complexity emergence is Prigogine and Nicolis' Exploring Complexity. And another fascinating volume that deals with dynamical complexity as it relates to embodied mind is Di Paolo, Buhrmann, and Barandiaran's Sensorimotor Life: An Enactive Proposal.

Chapters 11-17 of Part 3: "The Living" explore the ways in which nature abhors a gradient in the biological world, discussing the science and various views on the origin of life and biological and ecological evolution. The book was written when the exoplanet revolution was in its infancy so much of the current science of exoplanets doesn't factor into their narrative. Chapter 15, "The Secret of Trees," gives one of the best examples of the gradient reduction principle in the book: "The tree-sun relationship is perhaps the strongest, simplest, and most pertinent example of our thermodynamic paradigm. Trees 'reaching' for the sun and optimally capturing and degrading the gradient between the sun and frigid outer space seems to graphically incarnate our vision of the thermodynamic part of the biological world. Go out and observe trees, and you will see living dissipative systems stretching skyward to capture available solar energy" (219-220). "Trees are thus giant dissipating systems converting high-quality solar energy into low-grade latent heat" (223). Chapter 16, "Into the Cool," gives numerous examples of how natural ecosystems cool the earth, how the more complex and diverse an ecosystem is, the better it cools or absorbs solar radiation. In Chapter 17, "Trends in Evolution," the authors survey the various views of evolution and argue a thermodynamic gradient perspective adds an important new dimension to our current understanding of evolutionary mechanisms such as gene-bound natural selection.

Chapters 18-20 of Part 4: "The Human" explore various aspects of how entropy and heat dissipation play out in human contexts, for example energy flows with regard to aging and exercise in chapter 20. Chapter 21 looks at human economic systems, supply-demand gradients, money and material flows, and the need to take into consideration unidirectional flows. The authors cite Romanian polymath Nicholas Georgescu-Roegen who developed a new biological-evolutionary approach to economic theory, *The Entropy Law and the Economic Process* (1971). In it he debunked the standard view of the time of the economy as a cyclical process of production and consumption: *No other conception could be further from the facts. Even if only the physical facet of the economic process is taken into consideration, this process is not circular, but *unidirectional*… the economic process consists of a continuous transformation of low entropy into high entropy, that is, into *irrevocable waste*, or with a topical term, into pollution* (ibid, 281).

The last chapter, number 20, "Purpose in Life," may be the most interesting. They examine the idea that "life's purposeful nature, broadly understood, has thermodynamic origins." Purpose is understood in this context as "end-directed behavior" and does not require consciousness to invoke an ultimate purpose for all of existence (which doesn't explain away consciousness but rather says it's not necessary to explain purposefulness). Nor does it require a divine plan. Life is purposeful because "living beings seek out gradients, and they show direction in their individual growth, ecological developments, and overall evolution. [It] does not mean that there is a knowable end point, or that humans are that end point. It means rather that we are part of a cosmically creative process that builds up structure, complexity, and intelligence as it destroys gradients" (300). The remainder of the chapter is a fascinating tour through the ideas of purpose, direction, and telos in science and religion. The book ends with a helpful appendix describing eleven "Principles of Open Thermodynamic Systems."

I've been reading books on systems theory, self-organization, and complexity for almost four decades and in 1990 published a small systems theory guidebook (*Education in the Systems Sciences: An Annotated Guide to Education and Research Opportunities in the Sciences of Complexity,* available on Academia.edu). Schneider and Sagan's book is an outstanding contribution to the literature supporting a human-centered view of science which sees life and its evolution as natural processes that can arise anywhere conditions permit. Now that we know there are literally billions of planets revolving around their own suns, and millions similar to earth right here in our own galaxy, many scientists believe that it's only a matter of years before some form of complex life is discovered and confirmed. And the soon-to-launch James Webb Space Telescope (Nov-2021) may be the instrument that does just that.

Post Script: the first part of my title "Matter Cycles, Energy Flows...," was taken from a book by biologist Harold Morowitz, possibly this one: Energy Flow in Biology. Others of his books fit well with the ideas behind *Into the Cool.*