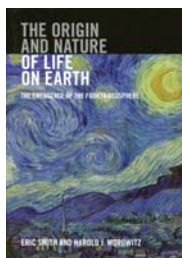


The Origin and Nature of Life on Earth

The Emergence of the Fourth Geosphere

Eric Smith and Harold J. Morowitz

Cambridge U. Press, 2016. \$49.99 (691 pp.). ISBN 978-1-107-12188-1



Physicists have long been interested in our cosmic origins, especially in the origin of life. Typically, however, scientists see the origin of life as a problem for biochemistry: If we can synthesize the “right stuff,” including biomolecules such as ATP, peptides, and nucleic acids, from abiotic starting materials, the problem of the origins of life should readily be solved. Or so the story usually goes.

When Stanley Miller performed his famous spark-discharge experiment in the early 1950s, simulating what many thought were the conditions present at the chemical origin of life, there was optimism that life would soon be crawling out of the lab. Now, more than 60 years later, we still have not resolved how to make life in the lab, nor do we understand how it first appeared on Earth. The past few years have witnessed a sort of phase transition, however, as interested researchers pursue entirely novel approaches to the problem.

Eric Smith and Harold Morowitz, authors of *The Origin and Nature of Life on Earth: The Emergence of the Fourth Geosphere*, are among the leaders in reshaping how we think about origins. Both were trained in physics: Smith is a theoretical physicist and Morowitz (who passed away in 2016) was a biophysicist. It is tempting to describe their book as a summary of the series of papers the two have coauthored over the years, but the book is so rich in detail that “summary” hardly seems the right word. *The Origin and Nature of Life on Earth* reads more like a well-executed textbook, one that covers much of what you need to know to jump in and start researching the origins of life. Smith and Morowitz cover topics ranging from the relevant geochemistry to the organization of metabolic pathways to the theory of nonequilibrium phase transitions. For physicists wishing to dive headfirst into the origin-of-life field, this book is a great place to start.

Unlike a textbook, however, the book is not merely a compendium of existing knowledge; it offers genuinely new per-

spectives. Smith and Morowitz turn scientists’ conventional origin stories on their heads. Rather than focus strictly on the chemical origin of life, they regard life as a planetary process. That is, the authors envision the origins of life not as local events but instead as a series of planetary phase transitions corresponding to a transition in the Earth system at all scales. Hence, they introduce the idea of life as a “fourth geosphere” that complements the other three: the atmosphere, hydrosphere, and lithosphere. In so doing, they make the problem of the origin of life one that may be tractable for physicists, and they lay out a possible framework for how to do it.

One of the most important insights in the book is a rethinking of what the “living state” is. Most of us think about the individual cell as the fundamental unit of life. Indeed, when Erwin Schrödinger wrote his famous book *What Is Life?* in 1944, he had individual cells in mind.

The search for individual molecular species capable of self-replication has figured prominently in the development of almost all scientific theories of the origin of life. But Smith and Morowitz argue that individuality is not a primitive organizational motif in the biosphere but appears only after a series of phase transitions have already yielded a significant amount of structure. That view resonates with earlier work by Carl Woese, who describes a long period of horizontal gene transfer between organisms before a transition to the more familiar vertical descent from parent to offspring seen in Darwinian evolution. In other words, Woese and Smith and Morowitz agree that Darwinian evolution emerged late. It is not the starting point for the emergence of life but instead is a byproduct of it.

Much of the book focuses on detailing organizational motifs besides individuality that may have emerged before Darwinian evolution commenced. The emergence of life, the authors say, can be viewed as a cascade of successive phase transitions away from a lifeless Earth. Phases that

conferred stability endured, which led to the highly embedded and hierarchical organization of life observed today.

Smith and Morowitz describe the collaboration of many kinds of nonequilibrium structures in the biosphere as a “confederacy of subsystems.” They suggest that the emergence of life is a series of successive transitions between independent subsystems, which gain autonomy from the environment by becoming more dependent on one another. For example, the authors argue that the three core functions of cellularization—unifying bioenergetics, catalytic rate enhancement, and homeostatic regulation of the cytosol—could each have emerged at different times, but it is their integration and collaboration that enable cells to create a new membrane when the nucleus splits.

One question is left open: If it is not a property of individuals, then *what is life?* Smith and Morowitz offer a compelling new vision to address that question: They argue that one must consider the biosphere as a whole. They support their claim by continually returning to the concept of the ecosystem as the fundamental unit of living organization. Their conception of life highlights an interesting contrast between the approach of biologists, who focus on diversity, and that of physicists, who seek to understand regularity.

Smith and Morowitz contend that by shifting the focus from individuals to ecosystems, they make explanations simpler, not harder. Universal properties of core metabolism exist at the level of ecosystems, whereas most individuals do not in general express those universalities. This means that the emergence of ecosystems may be more amenable to study via the tools of physics, many of which are structured to study statistical regularities, than is the emergence of individuals, who are highly contingent.

The main takeaway from *The Origin and Nature of Life on Earth* is that we need to start thinking of life not as something that happens *on* a planet, but instead as something that happens *to* a planet. In so doing, we may find new pathways to solving the puzzle of life’s origins—ones that suggest those origins may indeed be a problem ripe for contributions from physics.

Sara I. Walker
Arizona State University
Tempe