Physics makes rules, evolution rolls the dice

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Chico Q. Camargo
University of Exeter
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Constrained by the same laws of physics, alien life forms should look familiar to us, argues Cockell.

PHYSICS

Physics makes rules, evolution rolls the dice

An astrobiologist argues that alien life will likely look a lot like life on Earth

By **Chico Camargo**

Picture a ladybug in motion. The image that came into your head is probably one of a small, round red-and-black insect crawling up a leaf. After reading Charles Cockell's *The Equations of Life*, however, you may be more likely to think of this innocuous organism as a complex biomechanical engine, every detail honed and operating near thermodynamic perfection.

In a fascinating journey across physics and biology, Cockell builds a compelling argument for how physical principles constrain the course of evolution. Chapter by chapter, he aims his lens at all levels of biological organization, from the molecular machinery of electron transport to the social organisms formed by ant colonies. In each instance, Cockell shows that although these structures might be endless in their detail, they are bounded in their form. If organisms were pawns in a game of chess, physics would be the board and its rules, limiting how the game unfolds.

Much of the beauty of this book is in the diversity of principles it presents. In the chapter dedicated to the physics of the ladybug, for example, Cockell first describes an unassuming assignment in which students are asked to study the properties of the insect. Physical principles emerge naturally: from the surface tension and viscous forces between the ladybug's feet and vertical surfaces, to the diffusion-driven pattern formation on its back, to the thermodynamics of surviving as a small insect at water-freezing temperatures. These discussions are accompanied by a series of equations that one would probably not expect to see in a single textbook, as various branches of physics—from physical chemistry to optics—are discussed side by side.

Physics itself is different at different scales. A drop of water, for example, is inconsequential to a human being. If you are a ladybug, however, water surface tension is a potential problem: Having a drop of water on your back might become as burdensome as a heavy backpack that can't be discarded. For a tiny ant, a droplet large enough can turn into a watery prison because the molecular forces in play are too strong for the insect to escape.

Cockell also describes how physical constraints make evolution possible by causing different DNA sequences to be translated into the same amino acids, leading amino acids to form proteins with the same shapes. If one were to consider, for example, that every position in a chain of 300 amino acids—not far from the length of an average protein—could be one of 20 possible amino acids, a simple calculation would reveal that there are approximately 2×10^{390} potential combinations. If each of those chains were to adopt a different shape, evolution would never lead to the same protein shape twice. But because of the laws of physics, most proteins assume a very limited set of shapes, combining patterns of α-helices and β-sheets.

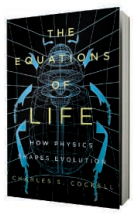
At the end of every chapter, the reader is reminded of how the laws of physics nudge, narrow, mold, shape, and restrict the "endless forms most beautiful" that Charles Darwin once described. Cockell's persistence pays off as he gears up for his main argument: If life exists on other planets, it has to abide by the same laws as on Earth.

Because the atoms in the Milky Way behave the same as in any other galaxy, Cockell argues that water in other galaxies will still be an abundant solvent, carbon should still be the preferred choice for self-replicating complex molecules, and the thermodynamics of life should still be the same. Sure, a cow on a hypothetical planet 10 times the diameter of Earth would need wider, stronger legs, but there is no reason to believe that replaying evolution on another planet would lead to unimaginable life forms. Rather, one should expect to see variations on the same theme.

Cockell ends the book by celebrating the elegant equations that represent the relations between form and function. Rather than being a lifeless form of reductionism, equations, he argues, are our window into what physics renders possible (or impossible) for life to achieve. In equations, we express how our biosphere is full of symmetry, pattern, and law. Within them, we express the boldest claim of them all: that these limitations should be no less than universal. ■

The reviewer is at the Oxford Internet Institute, University of Oxford, Oxford OX1 3JS, UK. Email: chico.camargo@oii.ox.ac.uk

The Equations of Life
How Physics Shapes Evolution
Charles S. Cockell
Basic Books, 2018, 348 pp.



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