

THIS IS BIOLOGY

The Science of the Living World

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Designed by Gwen Frankfeldt

Preface

Some years ago the then-President of France, Valéry Giscard d'Estaing, declared the twentieth century "the century of biology." If this is perhaps not entirely accurate for the century as a whole, it has certainly been true for the second half. Today, biology is a thriving field of inquiry. We have witnessed unprecedented breakthroughs in genetics, cellular biology, and neuroscience, as well as spectacular advances in evolutionary biology, physical anthropology, and ecology. A whole industry has grown out of research in molecular biology; the results are readily apparent in fields as diverse as medicine, agriculture, animal breeding, and human nutrition, to name only a few.

The prospects for biology have not always been so bright. From the Scientific Revolution in the seventeenth century until well after World War II, science for most people meant the "exact" sciences—physics, chemistry, mechanics, astronomy—all of which relied heavily on mathematics and emphasized the role of universal laws. During this time physics was considered the exemplar of science. By comparison, the study of the living world was considered an inferior endeavor. Even today most people continue to hold profound misconceptions about the life sciences. For example, a failure to understand biology is frequently displayed in the media, whether the topic is the teaching of evolution, the measurement of intelligence, the possibility of detecting extraterrestrial life, the extinction of species, or the risks of smoking.

More regrettable, many biologists themselves have an obsolete notion of the life sciences. Modern biologists tend to be extreme specialists. They may know all about particular bird species, sex hormones, parental behavior, neuroanatomy, or the molecular structure of genes, yet they often are uninformed about developments outside their field of expertise. Rarely do biologists have the time to stand back from the advances in their own specialty and look at the life sciences as a whole. Geneticists, embryologists, taxonomists, and ecologists all consider themselves to be biologists, but most of them have little appreciation of what these various specialties have in common and how they differ fundamentally from the physical sciences. To shed some light on these issues is a major purpose of this book.

I have been a naturalist almost since I learned to walk, and my love of plants and animals led me to approach the living world holistically. Fortunately, the teaching of biology at the German high school I attended around 1920 centered on the whole organism and its interactions with the animate and inanimate environment. We would now say that the focus was on life history, behavior, and ecology. Physics and chemistry, both of which I also studied in high school, were something entirely different, and had little to do with living plants and animals.

During the years when I was a medical student, I was far too excited about medicine, and far too busy, to pay any attention to such basic questions as "What is biology?" and "What makes biology a science?" Indeed, there was not any subject taught at that time—at least not in the German universities—which was designated "biology." What we would now call biology was taught in departments of zoology and botany, both of which strongly emphasized the study of structural types and their phylogeny. To be sure, courses were also given in physiology, genetics, and other more or less experimental disciplines, but there was little integration of the subjects, and the conceptual framework of the experimentalists was largely incompatible with that of the zoologists and botanists, whose work was based in natural history.

After switching my studies from medicine to zoology (particularly birds) following the completion of my preclinical examinations, I took

courses in philosophy at the University of Berlin. But to my disappointment, they built no bridges between the subject matter of the biological sciences and that of philosophy. Yet in the 1920s and 30s a discipline was developing that would eventually be designated "philosophy of science." In the 1950s, when I became acquainted with the teachings of this field, I was again bitterly disappointed. This was no philosophy of science; this was a philosophy of logic, mathematics, and the physical sciences. It had almost nothing to do with the concerns of biologists. Around this time I sat down and made a list of the major generalizations of evolutionary biology stated in books and published papers—a few of which, by this time, I had contributed myself—and found that not a single one of them was adequately covered in the philosophical literature; most of them were not even mentioned.

Still, at this point I had no plans to make a contribution to the history and philosophy of science. My various essays on these topics were the result of invitations to conferences and symposia, which forced me to lay aside temporarily my researches in evolutionary theory and systematics. My only intention was to point out how very different biology was in certain respects from physics. For example, in 1960 I was invited by Daniel Lerner of the Massachusetts Institute of Technology to participate in a lecture series dealing with cause and effect. I had been interested in the problem of biological causation since my Serin finch paper in 1926 and another paper on the origin of bird migration in 1930. Therefore I welcomed this opportunity to sort through my thoughts on this subject. I had long been aware of a categorical difference between the inanimate and the living world. Both worlds obey the universal laws discovered and analyzed by the physical sciences, but living organisms obey also a second set of causes, the instructions from the genetic program. This second type of causation is nonexistent in the inanimate world. Of course, I was not the first biologist to discover the duality of causation in organisms, but my 1961 published paper from the lecture series was the first to provide a detailed analysis of the subject.

In truth, my various essays about the differences between the life sciences and the physical sciences were directed not so much at Preface

philosophers and physicists as at my fellow biologists, who had unwittingly adopted many physicalist concepts in their writings. For example, the claim that every attribute of complex living systems can be explained through a study of the lowest components (molecules, genes, or whatever) struck me as absurd. Living organisms form a hierarchy of ever more complex systems, from molecules, cells, and tissues, through whole organisms, populations, and species. In each higher system, characteristics emerge that could not have been predicted from a knowledge of the components.

At first I thought that this phenomenon of emergence, as it is now called, was restricted to the living world; and indeed, in a lecture I gave in the early 1950s in Copenhagen, I made the claim that emergence was one of the diagnostic features of the organic world. The whole concept of emergence was at that time considered to be rather metaphysical. When the physicist Niels Bohr, who was in the audience, stood up to speak during the discussion period, I was fully prepared for an annihilating refutation. However, much to my surprise, he did not at all object to the concept of emergence but only to my notion that it provided a demarcation between the physical and the biological sciences. Citing the case of water, whose "aquosity" could not be predicted from the characteristics of its two components, hydrogen and oxygen, Bohr stated that emergence is rampant in the inanimate world.

In addition to reductionism, another particularly objectionable bête noire for me was typological thinking, later baptized "essentialism" by the philosopher Karl Popper. It consisted of classifying the variation of nature into fixed types (classes), invariant and sharply demarcated against other such types. This concept, going back to Plato and Pythagorean geometry, was singularly unsuited to evolutionary and population biology, where one finds not classes but aggregates of unique individuals, that is, populations. Explaining variable phenomena in living nature in terms of populations—so-called population thinking—seems to be difficult for those accustomed to physicalist thinking. I repeatedly argued this problem with the physicist Wolfgang Pauli, who was most anxious to understand what we biologists had in mind. He finally came close to understanding it when I suggested

to him to think of a gas consisting of only 100 molecules, each differing from the others in direction and speed of movement. He called it an "individual gas."

Biology has also been misunderstood by many of those attempting to construct a history of science. When Thomas Kuhn's Structure of Scientific Revolutions was published in 1962, I was puzzled as to why it should have caused such a commotion. To be sure, Kuhn had refuted some of the most unrealistic theses of the traditional philosophy of science and had called attention to the importance of historical factors. But what he offered as a replacement seemed to me just as unrealistic. Where in the history of biology were the cataclysmic revolutions and where were the long periods of normal science postulated by Kuhn's theory? From what I knew of the history of biology, they did not exist. No doubt Darwin's On the Origin of Species, published in 1859, was revolutionary, but ideas about evolution had been in the air for a century. Moreover, Darwin's theory of natural selection—the key mechanism in evolutionary adaptation—was not fully accepted until almost a century after its publication. Throughout this time there were minor revolutions but never any period of "normal" science. Whether or not Kuhn's thesis was valid for the physical sciences, it did not fit biology. Historians coming from a background in physics seemed not to grasp what had happened in the study of living organisms over three centuries.

More and more clearly I began to see that biology was a quite different kind of science from the physical sciences; it differed fundamentally in its subject matter, its history, its methods, and its philosophy. While all biological processes are compatible with the laws of physics and chemistry, living organisms could not be reduced to these physicochemical laws, and the physical sciences could not address many aspects of nature that were unique to the living world. The classical physical sciences, on which the classical philosophy of science was based, were dominated by a set of ideas inappropriate to the study of organisms: these included essentialism, determinism, universalism, and reductionism. Biology, properly understood, comprises population thinking, probability, chance, pluralism, emergence, and historical narratives. What was needed was a new philosophy of science that could

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incorporate the approaches of all sciences, including physics and biology.

When planning this volume, I had in mind a more modest task, however. I wanted to write a "life history" of biology that would introduce the reader to the importance and richness of biology as a whole, while helping the individual biologist approach a problem that is steadily becoming more formidable: the information explosion. New workers annually join those already in the field and add to the avalanche of new publications. Practically all biologists I have ever talked with have complained to me that they no longer have time to keep up with the literature in their own specialty, much less adjacent disciplines. And yet often it is feedback from outside one's narrow domain that is decisive for a conceptual advance. New directions for research frequently come into view when one steps back from one's own field and sees it as part of a larger endeavor to explain the living world, in all its wonderful diversity. I hope that this book will provide a conceptual framework from which working biologists can attain this broader perspective on their specific research agenda.

Nowhere is the information explosion more apparent than in molecular biology. A detailed discussion of this field is absent from this volume not because I think molecular biology is less important than other parts of biology but for exactly the opposite reason. Whether we deal with physiology, development, genetics, neurobiology, or behavior, molecular processes are ultimately responsible for whatever happens, and every day researchers are making fresh discoveries in all these domains. In Chapters 8 and 9 I have highlighted some of the major generalizations ("laws") discovered by molecular biologists. Still, it strikes me that while we have identified many trees, we have not yet seen the forest. Others may disagree; in any case, a comprehensive overview of molecular biology requires a competence I do not have.

The same can be said for another exceedingly important discipline, the biology of mental processes. We are still in a stage of local exploration, and I simply do not command the required knowledge of neurobiology and psychology to attempt a broad analysis. A final area not covered in great detail in this volume is genetics. The genetic program plays a decisive role in every aspect of an organism's life: its

structure, development, functions, and activities. Since the rise of molecular biology, the emphasis in genetics has shifted to developmental genetics, which has become virtually a branch of molecular biology, and for this reason I have not attempted to survey this field. However, I hope that my treatment of biology as a whole will be helpful in an eventual "life history" of these and other critical branches of biology that were not the direct focus of this volume.

If biologists, physical scientists, philosophers, historians, and others with a professional interest in the life sciences discover useful insights in the chapters that follow, this book will have accomplished one of its primary goals. But every educated person should have an understanding of basic biological concepts—evolution, biodiversity, competition, extinction, adaptation, natural selection, reproduction, development, and a host of others that are discussed in this book. Overpopulation, the destruction of the environment, and the malaise of the inner cities cannot be solved by technological advances, nor by literature or history, but ultimately only by measures that are based on an understanding of the biological roots of these problems. To "know thyself," as the ancient Greeks commanded us, entails first and foremost knowing our biological origins. To help readers gain a better understanding of our place in the living world, and of our responsibility to the rest of nature, is the major objective of this book.

Cambridge, Massachusetts September 1996

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CHAPTER ONE

What Is the Meaning of "Life"?

Primitive humans lived close to nature. Every day they were occupied with animals and plants, as gatherers, hunters, or herdsmen. And death—of infants and elders, women in childbirth, men in strife—was forever present. Surely our earliest ancestors must have wrestled with the eternal question, "What is life?"

Perhaps, at first, no clear distinction was made between life in a living organism and a spirit in a nonliving natural object. Most primitive people believed that a spirit might reside in a mountain or a spring as well as in a tree, an animal, or a person. This animistic view of nature eventually waned, but the belief that "something" in a living creature distinguished it from inanimate matter and departed from the body at the moment of death held strong. In ancient Greece this something in humans was referred to as "breath." Later, particularly in the Christian religion, it was called the soul.

By the time of Descartes and the Scientific Revolution, animals (along with mountains, rivers, and trees) had lost their claim to a soul. But a dualistic split between body and soul in human beings continued to be almost universally accepted and is even today still believed by many people. Death was a particularly puzzling problem for a dualist. Why should this soul suddenly either die or leave the body? If the soul left the body, did it go somewhere, such as to some nirvana or heaven? Not until Charles Darwin developed his theory of evolution through natural selection was a scientific, rational explanation for

death possible. August Weismann, a follower of Darwin at the end of the nineteenth century, was the first author to explain that a rapid sequence of generations provides the number of new genotypes required to cope permanently with a changing environment. His essay on death and dying was the beginning of a new era in our understanding of the meaning of death.

When biologists and philosophers speak of "life," however, they usually are not referring to life (that is, living) as contrasted with death but rather to life as contrasted with the lifelessness of an inanimate object. To elucidate the nature of this entity called "life" has been one of the major objectives of biology. The problem here is that "life" suggests some "thing"—a substance or force—and for centuries philosophers and biologists have tried to identify this life substance or vital force, to no avail. In reality, the noun "life" is merely a reification of the process of living. It does not exist as an independent entity.¹ One can deal with the process of living scientifically, something one cannot do with the abstraction "life." One can describe, even attempt to define, what living is; one can define what a living organism is; and one can attempt to make a demarcation between living and nonliving. Indeed, one can even attempt to explain how living, as a process, can be the product of molecules that themselves are not living.²

What life is, and how one should explain living processes, has been a subject of heated controversy since the sixteenth century. In brief, the situation was this: There was always a camp claiming that living organisms were not really different at all from inanimate matter; sometimes these people were called mechanists, later physicalists. And there was always an opposing camp—called vitalists—claiming instead that living organisms had properties that could not be found in inert matter and that therefore biological theories and concepts could not be reduced to the laws of physics and chemistry. In some periods and at certain intellectual centers the physicalists seemed to be victorious, and in other times and places the vitalists seemed to have achieved the upper hand. In this century it has become clear that both camps were partly right and partly wrong.

The physicalists had been right in insisting that there is no metaphysical life component and that at the molecular level life can be