PREFACE

This book is not about biology, biochemistry or any other finished and finite discipline, but about life. Life seems to me the supreme marvel of the universe—familiar, thoroughly material, probably ubiquitous yet elusive and ultimately mysterious. My purpose is to assess how far we have come toward a scientific understanding of the phenomenon of life.

With so broad, not to say nebulous a subject, it seems best to spell out the premises on which this inquiry rests. First, I am a scientist by profession, not a philosopher; we shall be concerned here with what natural science has to say about the nature of life, not how it appears to a psychologist, theologian, poet or epistemologist. Second, I take it that the term "life" designates a real phenomenon, recognizable by a set of properties characteristic of some natural objects and lacking in others; one of our goals must be to identify the essential features that distinguish living organisms from other things. Although we have been able to study but one kind of life, the terrestrial variety, it is likely that life exists elsewhere in the universe, and it is arguable that life everywhere will be based on this common set of general principles. Third, during the past century we have come a very long way by scrutinizing the workings, architecture and chemistry of cells and organisms; what we have learned makes a solid foundation for reflection on the nature of life in general. Finally, I hold that the quest for an answer to the riddle, "What is Life?" is one of the grand themes that resonate through the scientific conversation of this century—a period whose science is also its singular glory. That riddle embraces and transcends the subject matter of all the biological sciences, and much of physical science as well. A physics that has no place for life is as impoverished as would be a biology not informed by chemistry. The study of life as a natural phenomenon, a fundamental feature of the universe, must not be allowed to slip into the black hole of departmental tribalism.

Let me enlarge for a moment on the latter point, for herein lies much of the motivation for writing this book. What science knows of the nature of life, it owes to the labors of countless specialists—physicists and chemists, mathematicians and geologists, geneticists and biochemists and physiologists, biologists evolutionary and biologists molecular. The fruits of our labors are first inscribed in shelf upon shelf of professional journals, and subsequently reincarnated in textbooks that have grown too heavy to carry, let alone read. But the nature of life is not a practical topic for research. General insights, if there be any, must be distilled from numberless particular discoveries, and here time may no longer be on our side. The relentless accumulation of information on all subjects, however desirable in itself, frustrates understanding by pressing everyone into ever narrower borders. A second hindrance is the spirit of the times, the clamor that knowledge has value only insofar as it lends itself to practical ends. Scientists themselves increasingly subscribe to the thesis that science must serve the uses of power, not of philosophy: it is, after all, on our usefulness that we base our claim to scarce public resources. The most productive era of fundamental inquiry may thus be approaching an end, and that makes it timely to gather the threads of knowledge spun out by research and see what pattern they make.

That conversational word "understanding" has already cropped up several times, and since it stands for the object of this entire exercise some attempt at definition is in order. Scientists use the word in a somewhat special sense, that was nicely set forth by Mary Midgley in her critical study, *Science as Salvation*. "Understanding anything is finding order in it. . . . It is simply putting [the pattern] into the class of things meaningful—noting how its parts relate to it as a whole, and how it itself relates to the larger scene around it" (1). And "explanation?" To strive for a plausible, self-consistent view of the world, and to communicate it to others, is a less exalted quest. But I cannot agree with those who dismiss it as unworthy, as long as we remember the difference.

One response to the question, What is Life? is simply, Look Around! Note the birds and the butterflies, zebras and ammonites, the intricate web of life present and past, and join the unending struggle to ensure its continuance in the face of human arrogance and mindlessness. This has been eloquently said by others, far better than I could, and it is not what I have in mind here. For the past forty years, I have been immersed in research on the biochemistry and physiology of microorganisms, with emphasis on the fundamental aspects such as bioenergetics and mor-

phogenesis. In consequence, the central problems of life present themselves to me at the interface of chemistry and biology. How do lifeless chemicals come together to produce those exquisitely ordered structures that we call organisms? How can molecular interactions account for their behavior, growth, reproduction? How did organisms and their constituents arise on an earth that had neither, and then diversify into the cornucopia of creatures that enliven each drop of pond water? My purpose is not to "reduce" biology to chemistry and physics, but to gain some insight into the nature of biological order. In an earlier book, I wrote that "Living things differ from non-living ones most pointedly in their capacity to maintain, reproduce and multiply states of matter characterized by an extreme degree of organization" (2). This still rings true; biological organization is the key to the nature of life, and the central theme of this book.

Most branches of science bear on the problem of life, but some are more pertinent than others. This book celebrates microorganisms, and that requires explanation because with most folks the word "life" does not conjure up the image of bacteria or protozoa. Microorganisms do not receive much attention in books about biology, and the public at large knows them chiefly as agents of disease. We who love microbes are apt to justify our peculiar passion by extolling their diversity, far greater than that of all higher forms of life. We point to their manifold interactions with humans, more commonly beneficial than harmful; and we insist that the operation of the biosphere is wholly dependent on microbial ministration. But the reason they star in this book is that reflection on the smallest and simplest forms of life has been singularly fruitful: whether it is molecules we seek to understand or organisms, communities or evolution, the proper study of mankind is often not man but microbes. Geological history reinforces the point. Microorganisms, the bacteria and protists, can make a biosphere all by themselves, and did so for billions of years when the earth was young. Higher organisms hold mysteries that are of special concern to us humans: the genetic basis of disease, the immune response, embryonic development and the nature of mind are now at the forefront of the research effort. But for the purposes of an inquiry into the nature of life, these are peripheral issues. They represent potentialities inherent in living matter, but are not required for its existence.

A company of potential readers looked over my shoulder throughout this writing. First my colleagues from academe, quick to find fault, demanding factual accuracy at all costs and restraining my penchant for generalization; I have heeded their admonitions as best I could. But

there was also a party of students, surfeited with facts but curious still, wanting to be reminded of what it was that drew them into science in the first place. A couple of teachers came from a local college or high school, charged with making science intelligible to students whose interests all lie elsewhere; at the end of the day, such teachers may hold in their hands the future of science. I spotted a few members of that endangered species, the educated laity, pleading for simplicity and clarity in the face of unavoidable complexity. And every so often Lyndon Johnson's ghost would whisper in my ear the late president's favorite question: And therefore, what? The latter all persuaded me to step back from technicalities and detail, and to paint with a broad brush. In the end I tried to write the kind of synoptic and non-technical volume that I myself seek out when my reading draws me into strange waters.

Inevitably, then, this is a personal book—one scientist's attempt to wring understanding from the tide of knowledge. It grew out of the experience of a lifetime devoted to research, scholarship and instruction; but since my purpose is to make sense of the facts of life rather than to expound the facts themselves, this inquiry walks the edge of science proper. The arguments and conclusions presented here seem to me sound, but they are certainly not the last word on the subject. The most valuable lessons that the discipline of science teaches are to play the game of conjecture and refutation, to appreciate the provisional nature of our knowledge, and to prize the doubt! If what I have written here encourages a few readers to look up from their gels and genes to peer at the far horizon, I shall be well content. Of my shortcomings as an investigator, scholar, philosopher, and expositor I am keenly aware. But I can claim to share one merit with Erwin Schrödinger, who gave us our marching orders fifty years ago: I, also, am willing to make a fool of myself in a good cause.