

PROLOGUE

'I spent the afternoon musing on Life. If you come to think of it, what a queer thing Life is! So unlike anything else, don't you know, if you see what I mean.'

PG Wodehouse

The subject of this book addresses basic questions that have transfixed and tormented humankind for millennia, ever since we sought to better understand our place in the universe—the nature of living things and their relationship to the non-living. The importance of finding a definitive answer to these questions cannot be overstated—it would reveal to us not just who and what we are, but would impact on our understanding of the universe as a whole. Has the universe been fine-tuned to support life, as implied by proponents of the so-called anthropic principle? Or, to take a more Copernican view of man's place in the universe, 'is the human race just a chemical scum on a moderate-sized planet', as argued by Stephen Hawking, the noted physicist? A wider conceptual gulf would be hard to conceive.

Some 65 years ago another renowned physicist, Erwin Schrödinger, wrote a book whose catchy title *What is Life?* directly addressed the issue. In the opening lines of that book Schrödinger wrote:

How can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry? The preliminary answer...can be summarized as follows: The obvious inability of present-day physics and chemistry

to account for such events is no reason at all for doubting that they can be accounted for by those sciences.

Sixty-five years have passed but despite the enormous advances in molecular biology in those years, illuminated by a long list of Nobel prizes, we continue to struggle with Schrödinger's simple and direct question. And a struggle it is. Carl Woese, one of the leading biologists of the twentieth century, has recently gone as far as to claim that the state of present-day biology is reminiscent of that of physics at the turn of the twentieth century, before Albert Einstein, Niels Bohr, Erwin Schrödinger, and the other great twentieth-century physicists totally revolutionized the subject; that the time for biology's revolution has finally come. Strong sentiments indeed! What is no less remarkable is that modern biology appears to be happily meandering along its current mechanistic path with most of its practitioners indifferent, if not oblivious, to the shrill cry for reassessment.

Yes, it is true that in this modern era we know unequivocally that there is no *élan vital*, that living things are made up of the same 'dead' molecules as non-living ones, but somehow the manner in which those molecules interact in a holistic ensemble results in something very special—us, and every other living thing on this planet. So, paradoxically, despite the profound advances in molecular biology over the past half-century, we still do not understand what life is, how it relates to the inanimate world, and how it emerged. True, over the past half-century considerable effort has been directed into attempts to resolve these fundamental issues, but the gates to the Promised Land seem as distant as ever. Like a mirage in the desert, just as the palm trees signalling the oasis seemingly materialize,

shimmering on the horizon, they fade away yet again, leaving our thirst to understand unquenched, our drive to comprehend unsatisfied.

So what is the basis of this deeply troubling and persistent dilemma? To clarify in simplest terms where the problem lies, consider the following hypothetical tale: you are walking through a field and you suddenly come across a refrigerator—a fully functional refrigerator in a field with some bottles of beer inside, all nicely chilled. But how could a refrigerator be working in the middle of a field, apparently unconnected to any external energy source, yet maintaining a cold interior? And just what is it doing there, and how did it get there? You take a closer look and you see a solar panel on its top, which is connected to a battery, which in turn operates the compressor that all fridges have in order to function. So the mystery of *how* the refrigerator works is resolved. The refrigerator captures solar energy through the photovoltaic panel, so it is the sun that is the source of energy that operates the refrigerator and enables it to pump heat from cold to hot—in the opposite direction to the one that normally governs heat flow. Thus, despite Nature's drive to equalize the temperature inside and outside the cabinet, in this physical entity that we call a 'refrigerator', there exists a functional design that enables us to keep our food and drinks at a suitably low temperature.

But the mystery of *how* it got there in the middle of the field remains. Who put it there? And why? Now if I told you that no one put the refrigerator there—that it came about spontaneously through natural forces, you would react in total disbelief. How absurd! Impossible! Nature just doesn't operate like that! Nature doesn't spontaneously make highly organized far-from-equilibrium,

purposeful entities—fridges, cars, computers, etc. Such objects are the products of human design—purposeful and deliberate. Nature, if anything, pushes systems *toward* equilibrium, toward disorder and chaos, *not* toward order and function. Or does it?

The simple truth is that the most basic living system, a bacterial cell, is a highly organized far-from-equilibrium functional system, which in a thermodynamic sense mimics the operation of a refrigerator, but is orders of magnitude more complex! The refrigerator involves the cooperative interaction of, at most, several dozen components, whereas a bacterial cell involves the interaction of thousands of different molecules and molecular aggregates, some of enormous complexity in themselves, all within a network of thousands of synchronized chemical reactions. In the case of the fridge, the function is obvious—to keep the beer or whatever else is in the cabinet cold by pumping heat from the cold interior to the hotter exterior. But what is the function of the bacterial cell with its organized complexity? Its function can be readily recognized simply by observing its action. Just as the function and workings of the refrigerator can be uncovered by inspecting its operation, so the cell's function—its purpose if you like—can be revealed by seeing what it does. And what do we see? Every living cell is effectively a highly organized factory, which, like any man-made factory, is connected to an energy source and power generator that facilitates its operation. If the energy source is cut off the factory ceases to operate. This miniature factory takes in raw material, and through the utilization of power from the factory's power generator, converts those raw materials into the many functional components, which will then be assembled to produce the factory's output. And what is that output? What does this highly elaborate

nano-factory produce? More cells! Every cell is ultimately a highly organized and efficient factory for making more cells! The Nobel biologist Francois Jacob expressed it rather poetically: 'the dream of every cell, to become two cells'.

And here precisely lies the life problem. Just as the likelihood of a functional fridge—cabinet, energy collector, battery, compressor, gas—spontaneously coming together naturally seems inconceivable, even if its parts were all readily available, the likelihood for the spontaneous formation of a highly organized far-from-equilibrium miniature chemical factory—a nano-factory—also seems inconceivable. It is not just common sense that tells us that highly organized entities don't just spontaneously come about. Certain basic laws of physics preach the same sermon—systems tend toward chaos and disorder, not toward order and function. No wonder several of the great physicists of the twentieth century, amongst them Eugene Wigner, Niels Bohr, and Erwin Schrödinger, found the issue highly troublesome. Biology and physics seem contradictory, quite incompatible. No wonder the proponents of Intelligent Design manage to peddle their wares with such success!

The paradox inherent in the very existence of a living cell has profound consequences. It means that the issue of life's emergence is not just some esoteric activity of historical interest, analogous to an individual seeking to uncover his family tree. Until the paradox associated with life's emergence is resolved, we will not understand what life is. And, as final confirmation that understanding has been achieved, we will be able to translate that understanding into a coherent proposal for the synthesis of a chemical system that we would categorize as 'living'.

The purpose of this book is to reassess this enthralling subject and demonstrate that a general law that underlies the emergence, existence, and nature of all living things can now be outlined. I will argue that thanks to a newly defined area of chemistry, termed by Günter von Kiedrowski 'Systems Chemistry', the existing chasm separating chemistry and biology can now be bridged, and that *the central biological paradigm, Darwinism, is just the biological manifestation of a broader physicochemical description of natural forces*. This admittedly ambitious attempt to merge biology into chemistry rests on the idea that there is a kind of stability in nature that has been previously overlooked, one I have termed *dynamic kinetic stability*. Amalgamating that form of stability into a Darwinian view of evolution leads to a *general (or extended) theory of evolution*, encompassing both biological and pre-biological systems. Interestingly, Darwin himself already understood that a general principle of life is likely to exist. In a letter to George Wallich in 1882 he wrote:

I believe that I have somewhere said (but cannot find the passage) that the principle of continuity renders it probable that the principle of life will hereafter be shown to be part, or consequence, of some general law...

This book is an attempt to demonstrate that Charles Darwin in his genius and far-sightedness was right, and that such a theory can now be formulated. I will attempt to show that chemistry, the science that bridges physics and biology, can provide answers, still in part incomplete, to these fascinating questions. Achieving a better understanding of what life is may not only tell us who and what we are, but will hopefully provide greater insight into the very nature of the cosmos and its most basic laws.

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