CHAPTER FOUR

Life on Earth

Of Microbes and Man

THE ADVANCES OF SCIENCE in the modern age have come at the cost of certain traditional reasons for belief in God. When we had no idea how the universe came into existence, it was easier to ascribe it all to an act of God, or many separate acts of God. Similarly, until Kepler, Copernicus, and Galileo upset the applecart in the sixteenth century, the placement of Earth at the center of the majestic starry heavens seemed to represent a powerful argument for the existence of God. If He put us on center stage, He must have built it all for us. When heliocentric science forced a revision of this perception, many believers were shaken up.

But a third pillar of belief continued to carry considerable weight: the complexity of earthly life, implying to any reasonable observer the handiwork of an intelligent designer. As we

shall see, science has now turned this upside down. But here, as with the other two arguments, I would like to suggest that science should not be denied by the believer, it should be embraced. The elegance behind life's complexity is indeed reason for awe, and for belief in God—but not in the simple, straightforward way that many found so compelling before Darwin came along.

THE "ARGUMENT FROM DESIGN" dates back at least to Cicero. It was put forward with particular effectiveness by William Paley in 1802 in a highly influential book, *Natural Theology, or Evidences of the Existence and Attributes of the Deity Collectedfiom the Appearance of Nature.* Paley, a moral philosopher and Anglican priest, posed the famous watchmaker analogy:

> In crossing a heath, suppose I pitched my foot against a stone, and were asked how the stone came to be there; I might possibly answer that, for anything I knew to the contrary, it had lain there forever. Nor would it perhaps be very easy to show the absurdity of this answer. But suppose I had found a watch upon the ground, and it should be inquired how the watch happened to be in that place; I should hardly think of the answer, which I had before given, that for anything I knew, the watch might have always been there . . . the watch must have had a maker: that there must have ex-

> isted, at some time, and at some place or other, an artificer or artificers, who formed it for the purpose which we find it actually to answer; who comprehended its construction, and designed its use. . . . Every indication of contrivance, every manifestation of design, which existed in the watch, exists in the works of nature; with the difference, on the side of nature, of being greater or more, and that in a degree which exceeds all computation.[1]

The evidence of design in nature has been compelling to humanity throughout much of our existence. Darwin himself, before his voyage on the HMS *Beagle,* was an admirer of Paley's writings, and professed to be convinced by this view. However, even simply as a matter of logic, there is a flaw in Paley's argument. The point he is making can be summarized as follows:

1. A watch is complex.
2. A watch has an intelligent designer.
3. Life is complex.
4. Therefore, life also has an intelligent designer.

But the fact that two objects share one characteristic (complexity) does not imply they will share all characteristics. Consider, for example, the following parallel argument:

1. Electric current in my house consists of a flow of electrons.
2. Electric current comes from the power company.

3. Lightning consists of a flow of electrons.
4. Therefore, lightning comes from the power company.

As appealing as it seems, Paley's argument cannot be the whole story. To examine the complexity of life and our own origins on this planet, we must dig deep into the fascinating revelations about the nature of living things wrought by the current revolution in paleontology, molecular biology, and genomics. A believer need not fear that this investigation will dethrone the divine; if God is truly Almighty, He will hardly be threatened by our puny efforts to understand the workings of His natural world. And as seekers, we may well discover from science many interesting answers to the question "How does life work?" What we cannot discover, through science alone, are the answers to the questions "Why is there life anyway?" and "Why am I here?"

ORIGINS OF LIFE ON PLANET EARTH

Science begins to answer the question of life's complexity with a timeline. We now know that the universe is approximately 14 billion years old. A century ago, we didn't even know how long our own planet had been around. But the subsequent discovery of radioactivity and the natural decay of certain chemical isotopes provided an elegant and rather precise means of determining the age of various rocks on Earth. The scientific basis of this method is described in detail in Brent Dalrymple's book *The Age of the Earth,* and depends upon the known and very long

half-lives by which three radioactive chemical elements steadily decay and transform into different, stable elements: uranium slowly becomes lead, potassium slowly becomes argon, and the more exotic strontium becomes the rare element called rubidium. By measuring the amounts of any of these pairs of elements, we can estimate the age of any particular rock. All of these independent methods give results that are strikingly concordant, pointing to an age of Earth of 4.55 billion years, with an estimated error of only about 1 percent. The oldest rocks that have been dated on the current earth surface are approximately 4 billion years old, but nearly seventy meteorites and a number of moon rocks have been dated at 4.5 billion years old.

All evidence currently available suggests that the earth was a very inhospitable place for its first 500 million years. The planet was under constant and devastating attack from giant asteroids and meteorites, one of which actually tore the moon loose from Earth. Not surprisingly, therefore, rocks dating back 4 billion years or more show absolutely no evidence of any life forms. Just 150 million years later, however, multiple different types of microbial life are found. Presumably, these single-celled organisms were capable of information storage, probably using DNA, and were self-replicating and capable of evolving into multiple different types.

Recently, Carl Woese has put forward the plausible hypothesis that at this particular time on earth, exchange of DNA between organisms was readily accomplished.[2] Essentially, the biosphere consisted of a large number of miniscule independent cells, but they interacted extensively with one another. If a

particular organism developed a protein or series of proteins that provided a certain advantage, those new features could quickly be acquired by its neighbors. Perhaps in that sense, early evolution was more a communal than an individual activity. This kind of "horizontal gene transfer" is well documented in the most ancient forms of bacteria that now exist on the planet (archaebacteria), and may have provided an opportunity for new properties to be rapidly spread.

But how did self-replicating organisms arise in the first place? It is fair to say that at the present time we simply do not know. No current hypothesis comes close to explaining how in the space of a mere 150 million years, the prebiotic environment that existed on planet Earth gave rise to life. That is not to say that reasonable hypotheses have not been put forward, but their statistical probability of accounting for the development of life still seems remote.

Fifty years ago, famous experiments by Stanley Miller and Harold Urey reconstructed a mixture of water and organic compounds that might have represented primeval circumstances on Earth. By applying an electrical discharge, these researchers were able to form small quantities of important biological building blocks, such as amino acids. The finding of small amounts of similar compounds within meteorites arriving from outer space has also been put forward as an argument that such complex organic molecules can arise from natural processes in the universe.

Beyond this point, however, the details become quite sketchy. How could a self-replicating information-carrying molecule assemble spontaneously from these compounds? DNA,

with its phosphate-sugar backbone and intricately arranged organic bases, stacked neatly on top of one another and paired together at each rung of the twisted double helix, seems an utterly improbable molecule to have "just happened"—especially since DNA seems to possess no intrinsic means of copying itself. More recently, many investigators have pointed instead to RNA as the potential first life form, since RNA can carry information and in some instances it can also catalyze chemical reactions in ways that DNA cannot. DNA is something like the hard drive on your computer: it is supposed to be a stable medium in which to store information (though, as with your computer, bugs and snafus are always possible). RNA, by contrast, is more like a Zip disk or a flash drive—it travels around with its programming, and is capable of making things happen on its own. Despite substantial effort by multiple investigators, however, formation of the basic building blocks of RNA has not been achievable in a Miller-Urey type of experiment, nor has a fully self-replicating RNA been possible to design.

The profound difficulties in defining a convincing pathway for life's origin have led some scientists, most notably Francis Crick (who with James Watson discovered the DNA double helix), to propose that life forms must have arrived on Earth from outer space, either carried by small particles floating through interstellar space and captured by Earth's gravity or even brought here intentionally (or accidentally) by some ancient space traveler. While this might solve the dilemma of life's appearance on Earth, it does nothing to resolve the ultimate question of life's origin, since it simply forces that astounding event to another time and place even further back.

A word is in order here about an objection often raised by some critics to any possibility of the spontaneous origin of life on Earth, based on the Second Law of Thermodynamics. The Second Law states that in a closed system, where neither energy nor matter can enter or leave, the amount of disorder (more formally known as "entropy") will tend to increase over time. Since life forms are highly ordered, some have argued that it would therefore be impossible for life to have come into being without a supernatural creator. But this betrays a misunderstanding of the full meaning of the Second Law: order can certainly increase in some part of the system (as happens every day when you make the bed or put away the dishes), but that will require an input of energy, and the total amount of disorder in the entire system cannot decrease. In the case of the origin of life, the closed system is essentially the whole universe, energy is available from the sun, and so the local increase in order that would be represented by the first random assembly of macromolecules would in no way violate this law.

Given the inability of science thus far to explain the profound question of life's origins, some theists have identified the appearance of RNA and DNA as a possible opportunity for divine creative action. If God's intention in creating the universe was to lead to creatures with whom He might have fellowship, namely human beings, and if the complexity required to start the process of life was beyond the ability of the universe's chemicals to self-assemble, couldn't God have stepped in to initiate the process?

This could be an appealing hypothesis, given that no serious scientist would currently claim that a naturalistic explana-

tion for the origin of life is at hand. But that is true today, and it may not be true tomorrow. A word of caution is needed when inserting specific divine action by God in this or any other area where scientific understanding is currently lacking. From solar eclipses in olden times to the movement of the planets in the Middle Ages, to the origins of life today, this "God of the gaps" approach has all too often done a disservice to religion (and by implication, to God, if that's possible). Faith that places God in the gaps of current understanding about the natural world may be headed for crisis if advances in science subsequently fill those gaps. Faced with incomplete understanding of the natural world, believers should be cautious about invoking the divine in areas of current mystery, lest they build an unnecessary theological argument that is doomed to later destruction. There are good reasons to believe in God, including the existence of mathematical principles and order in creation. They are positive reasons, based on knowledge, rather than default assumptions based on (a temporary) lack of knowledge.

In summary, while the question of the origin of life is a fascinating one, and the inability of modern science to develop a statistically probable mechanism is intriguing, this is not the place for a thoughtful person to wager his faith.

THE FOSSIL RECORD

While amateur and professional scientists have been turning up fossils for centuries, these discoveries have reached a particularly intense phase over the last twenty years. Many of the pre-

vious gaps in understanding of the history of life on Earth are now being filled by the discovery of extinct species. Furthermore, their age can often be accurately estimated, based on the same process of radioactive decay that helped determine the age of the earth.

The vast majority of organisms that have ever lived on Earth have left absolutely no trace of their existence, since fossils arise only in highly unusual circumstances. (For example, a creature has to be caught in a certain type of mud or rock, without being picked apart by predators. Most bones rot and crumble. Most creatures decay.) Given that reality, it is actually rather amazing that we have such a wealth of information about organisms that have lived on this planet.

The timeline revealed by the fossil record is woefully incomplete, but still very useful. For example, only single-celled organisms appear in sediments that are older than about 550 million years, although it is possible that more complicated organisms existed prior to this time. Suddenly, approximately 550 million years ago, a great number of diverse invertebrate body plans appear in the fossil record. This is often referred to as the "Cambrian explosion," and is chronicled in highly readable form by the late Stephen Jay Gould, the most passionate and lyrical writer on evolution of his generation, in his book *Wonderful Life*. Gould himself questioned how evolution could account for the remarkable diversity of body plans that appeared in such a short span of time. (Other experts have been much less impressed with the claim that the Cambrian represents a discontinuity in life's complexity, though their writings have been less widely distributed to the general public. The so-called Cambrian

explosion might, for example, reflect a change in conditions that allowed fossilization of a large number of species that had actually been in existence for millions of years.)

While attempts have been made by certain theists to argue that the Cambrian explosion is evidence of the intervention of some supernatural force, a careful examination of the facts does not seem to warrant this. This is another "God of the gaps" argument, and once again believers would be unwise to hang their faith upon such a hypothesis.

Current evidence suggests that the land remained barren until about 400 million years ago, at which point plants appeared on dry land, derived from aquatic life forms. A scarce 30 million years later, animals had also moved onto land. At one time, this step pointed to another gap: there appeared to be few transitional forms between sea creatures and land-dwelling tetrapods in the fossil record. Recent discoveries, however, have documented compelling examples of just this kind of transition.[3]

Beginning about 230 million years ago, dinosaurs dominated the earth. There is now general acceptance that their reign came to a sudden and catastrophic end approximately 65 million years ago, at the time of the collision of planet Earth with a large asteroid that fell in the general vicinity of what is now the Yucatan peninsula. Fine ash kicked up by this horrendous collision has been identified around the world, and the catastrophic climate changes that occurred from this vast amount of dust in the atmosphere apparently were too much for the dominant dinosaur species, leading to their demise and the subsequent rise of mammals.

That ancient asteroid collision is a tantalizing event. It may

have been the only possible means by which the dinosaurs could have become extinct and mammals could have flourished. We probably wouldn't be here if that asteroid had not hit Mexico.

Most of us have a particular interest in the fossil record of humans, and here too the discoveries of the last few decades have been profoundly revealing. Bones of more than a dozen different hominid species have been discovered in Africa, with steadily increasing cranial capacity. The first specimens we recognize as modern *Homo sapiens* date from about 195,000 years ago. Other branches of hominid development appear to have encountered dead ends: the Neanderthals that existed in Europe until 30,000 years ago, and the recently discovered "hobbits," tiny people with small brains who lived on the island of Flores in Indonesia until extinction as recently as 13,000 years ago.

While there are many imperfections of the fossil record, and many puzzles remain to be solved, virtually all of the findings are consistent with the concept of a tree of life of related organisms. Good evidence exists for transitional forms from reptiles to birds, and from reptiles to mammals. Arguments that this model cannot explain certain species, such as whales, have generally fallen by the wayside as further investigation has revealed the existence of transitional species, often at precisely the date and place that evolutionary theory would predict.

DARWIN'S REVOLUTIONARY IDEA

Born in 1809, Charles Darwin initially studied to become a cleric of the Church of England, but developed a deep interest

in naturalism. Though the young Darwin was initially compelled by Paley's watchmaker argument, and saw design in nature as proof of a divine source, his views began to change when he traveled on the HMS *Beagle from* 1831 to 1836. He visited South America and the Galapagos Islands, where he examined the fossilized remains of ancient organisms and observed the diversity of life forms in isolated environments.

Building on these observations, and based on additional work over more than twenty years, Darwin developed the theory of evolution by natural selection. In 1859, faced with the possibility of being scooped by Alfred Russel Wallace, he finally wrote and published his ideas in the profoundly influential book *The Origin of Species.* Recognizing that the arguments in this book were likely to have broad reverberations, Darwin modestly commented near the end of the book, "When the views advanced by me in this volume, and by Mr. Wallace, or when analogous views on the origin of species are generally admitted, we can dimly foresee that there will be a considerable revolution in natural history."[4]

Darwin proposed that all living species are descended from a small set of common ancestors—perhaps just one. He held that variation within a species occurs randomly, and that the survival or extinction of each organism depends upon its ability to adapt to the environment. This he termed natural selection. Recognizing the potentially explosive nature of the argument, he hinted that this same process might apply to humankind, and developed this more fully in a subsequent book, *The Descent of Man.*

The Origin of Species engendered immediate and intense

controversy, though the reaction from religious authorities was not as universally negative as is often portrayed today. In fact, the notable conservative Protestant theologian Benjamin Warfield of Princeton accepted evolution as "a theory of the method of the divine providence,"[5] while arguing that evolution itself must have had a supernatural author.

There are many myths about public reaction to Darwin. For example, though there was a famous debate between Thomas H. Huxley (an ardent promoter of evolution) and Bishop Samuel Wilberforce, Huxley probably did not say (as legend has it) that he was unashamed to have a monkey for an ancestor, and would only be ashamed to be related to anyone who obscured the truth. Furthermore, far from his being ostracized by the religious community, Darwin was buried in Westminster Abbey.

Darwin himself was deeply concerned about the effect of his theory on religious belief, though in *The Origin of Species* he took pains to point out a possible harmonious interpretation: "I see no good reason why the views given in this volume should shock the religious feelings of anyone. . . . A celebrated author and divine has written to me that he 'has gradually learned to see that it is just as noble a conception of the deity to believe that he created a few original forms capable of self-development into other and needful forms, as to believe that he required a fresh act of creation to supply the voids caused by the action of his laws.' "[6]

Darwin even concludes *The Origin of Species* with the following sentence: "There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator

into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning, endless forms most beautiful and most wonderful have been, and are being evolved."[7]

Darwin's own personal beliefs remain ambiguous and seemed to vary throughout the last years of his life. At one time he said, "Agnostic would be the most correct description of my state of mind." At another time he wrote that he was greatly challenged by "the extreme difficulty, or rather the impossibility, of conceiving this immense and wonderful universe, including man with his capacity for looking far backwards and far into futurity, as the result of blind chance or necessity. When thus reflecting I feel compelled to look to a First Cause having an intelligent mind in some degree analogous to that of man; and I deserve to be called a Theist."[8]

No serious biologist today doubts the theory of evolution to explain the marvelous complexity and diversity of life. In fact, the relatedness of all species through the mechanism of evolution is such a profound foundation for the understanding of all biology that it is difficult to imagine how one would study life without it. Yet what area of scientific inquiry has generated more friction with religious perspectives than Darwin's revolutionary insight? From the circuslike Scopes "monkey trial" in 1925 right through to today's debates in the United States about the teaching of evolution in the schools, this battle shows no signs of ending.

DNA, THE HEREDITARY MATERIAL

Darwin's insight was all the more remarkable at the time because it lacked a physical basis. It took a century of work to discover just *how* there could be modifications in life's instruction book, in order to accommodate Darwin's "descent with modifications" idea.

Gregor Mendel, a relatively obscure Augustinian monk in what is now the Czech Republic, was a contemporary of Darwin and had read *The Origin of Species,* but they probably never met. Mendel was the first to demonstrate that inheritance could come in discrete packets of information. Through painstaking experiments with pea plants in the garden of his monastery, he concluded that hereditary factors involved in such attributes as the wrinkled or smooth appearance of peas were controlled by mathematical rules. He didn't know what a gene was, but his observations suggested that something like genes must exist.

Mendel's work was largely ignored for thirty-five years. Then, in one of the remarkable coincidences that occasionally arise in the history of science, it was rediscovered simultaneously by three other scientists within a few months of the turn of the twentieth century. In his famous studies on "inborn errors of metabolism," rare diseases that occurred in certain families in his medical practice, Archibald Garrod was able to show conclusively that Mendel's rules applied to humans, and that these disorders came about as a consequence of the same kind of inheritance that Mendel had appreciated in plants.

Mendel and Garrod added mathematical specificity to the notion of heritability in humans, though of course the reality of inherited characteristics such as skin and eye color was already familiar to anyone who was a close observer of our species. The mechanism behind these patterns remained obscure, however, as no one had successfully deduced the chemical basis of inheritance. Most researchers in the first half of the twentieth century assumed that inherited traits must be conveyed by proteins, since they appeared to be the most diverse molecules of living things.

It was not until 1944 that the microbiological experiments of Oswald T. Avery, Colin M. MacLeod, and Maclyn McCarty showed that it was DNA, not protein, that was capable of transferring inherited characteristics. Though the existence of DNA had been known for almost a hundred years, it was previously considered to be little more than nuclear packing material, of no particular interest.

Less than a decade later, a truly beautiful and elegant answer to the chemical nature of inheritance emerged. The furious race to determine the structure of DNA was won in 1953 by James Watson and Francis Crick, as is chronicled in Watson's entertaining book *The Double Helix.* Watson, Crick, and Maurice Wilkins, utilizing data produced by Rosalind Franklin, were able to deduce that the DNA molecule has the form of a double helix, a twisted ladder, and that its information-carrying capacity is determined by the series of chemical compounds that comprise the rungs of the ladder.

As a chemist, knowing how extraordinary the qualities of DNA really are, and how brilliant its solution is to the problem

of coding life's design, I am in awe of this molecule. Let me try to explain just how elegant DNA really is.

As shown in Figure 4.1, the DNA molecule has a number of remarkable features. The outside backbone is made up of a monotonous ribbon of phosphates and sugars, but the interesting stuff lies on the inside. The rungs of the ladder are made up of combinations of four chemical components, called "bases." Let's call them (from the actual chemical names of these DNA bases) A, C, G, and T. Each of these chemical bases has a particular shape.

Now imagine that out of these four shapes, the A shape can fit neatly only on a ladder rung next to the T shape, and the G shape can fit only next to the C shape. These are "base pairs." Then you can picture the DNA molecule as a twisting ladder, with each rung made up of one base pair. There are four possible rungs: A-T, T-A, C-G, and G-C. If any single base is damaged on any one strand, it can be easily repaired by reference to the other strand: the only possible replacement for a T (for example) is another T. Perhaps most elegantly, the double helix immediately suggests a means of its self-copying, since each strand can be used as a template for the production of a new one. If you split all the pairs in half, cutting your ladder down the center of each rung, each half-ladder contains all the information needed to rebuild a complete copy of the original.

As a first approximation, one can therefore think of DNA as an instructional script, a software program, sitting in the nucleus of the cell. Its coding language has only four letters (or two bits, in computer terms) in its alphabet. A particular instruction, known as a gene, is made up of hundreds or thou-

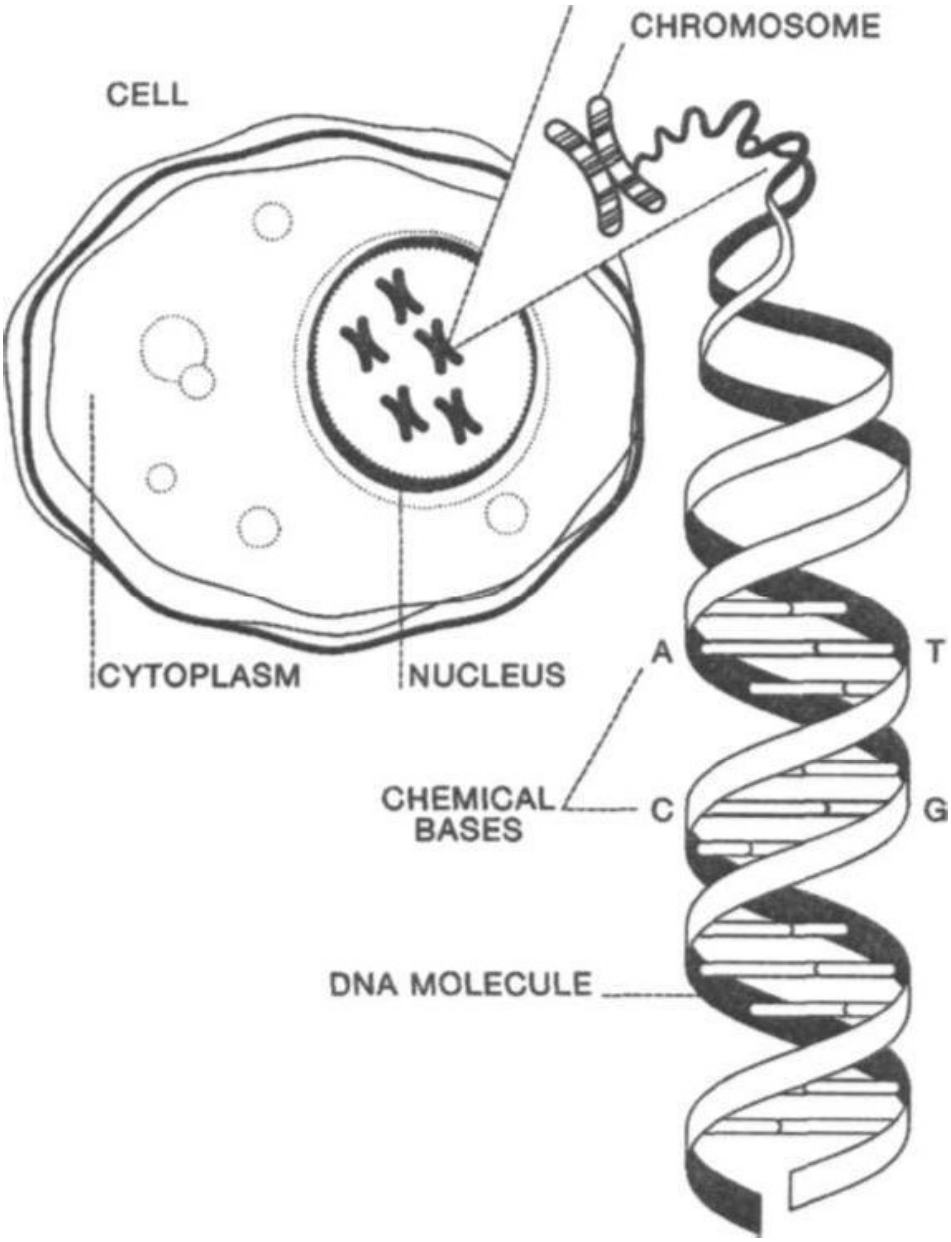

Figure 4.1. The double helix of DNA. Information is carried by the order of the chemical bases (A, C, G, and T). DNA is packaged into chromosomes, which reside in the nucleus of every cell.

sands of letters of code. All of the elaborate functions of the cell, even in as complex an organism as ourselves, have to be directed by the order of letters in this script.

At first, scientists had no idea how the program was actually "run." This puzzle was neatly solved by the identification of "messenger RNA." The DNA information that makes up a specific gene is copied into a single-stranded messenger RNA molecule, something like a half ladder with its rungs dangling from a single side. That half ladder moves from the nucleus of the cell (the information storehouse) to the cytoplasm (a highly complex gel mixture of proteins, lipids, and carbohydrates), where it enters an elegant protein factory called the ribosome. A team of sophisticated translators in the factory then read the bases protruding from the floating half-ladder messenger RNA to convert the information in this molecule into a specific protein, made up of amino acids. Three "rungs" of RNA information make one amino acid. It is proteins that do the work of the cell and provide its structural integrity (Figure 4.2).

This brief description only scratches the surface of the elegance of DNA, RNA, and protein, which continues to be a source of awe and wonder. There are sixty-four possible three-letter combinations of A, C, T, and G, but only twenty amino acids. That means that there has to be built-in redundancy: for instance, GAA in DNA and RNA codes for the amino acid called glutamic acid, but so does GAG.

Investigations of many organisms, from bacteria to humans, revealed that this "genetic code," by which information in DNA and RNA is translated into protein, is universal in all known organisms. No tower of Babel was to be allowed in the language of life. GAG means glutamic acid in the language of soil bacteria, the mustard weed, the alligator, and your aunt Gertrude.

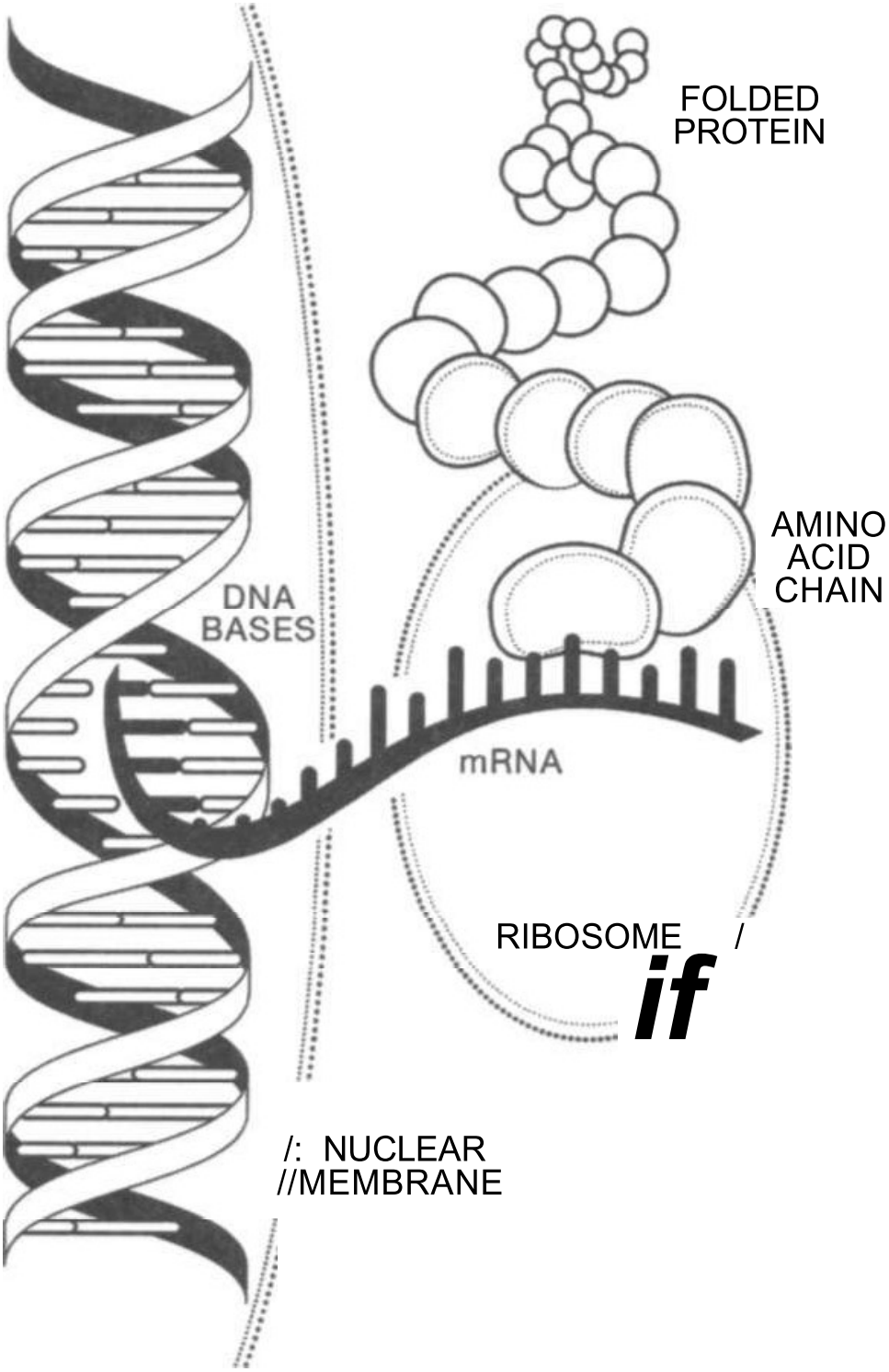

Figure 4.2. The flow of information in molecular biology: DNA -^RNA protein.

These advances gave birth to the field of molecular biology. The discovery of various other miniature chemical wonders, including proteins that act like scissors or glue, has enabled scientists to manipulate DNA and RNA by stitching together bits and pieces of these instructional molecules from different sources. This collection of molecular biological laboratory tricks, collectively referred to as recombinant DNA, has inspired a whole new field of biotechnology, and together with other advances promises to revolutionize the treatment of many diseases.

BIOLOGICAL TRUTH AND ITS CONSEQUENCES

For the believer who has previously taken the argument from design as a compelling demonstration of God's role in creating life, the conclusions put forward in this chapter can be unsettling. No doubt many readers have reasoned for themselves, or been taught in various religious settings, that the glorious beauty of a flower or the flight of an eagle could come about only as the consequence of a supernatural intelligence that appreciated complexity, diversity, and beauty. But now that molecular mechanisms, genetic pathways, and natural selection are being put forward to explain all this, you might be tempted to cry out, "Enough! Your naturalistic explanations are taking all the divine mystery out of the world!"

Do not fear, there is plenty of divine mystery left. Many people who have considered all the scientific and spiritual evidence still see God's creative and guiding hand at work. For me, there

is not a shred of disappointment or disillusionment in these discoveries about the nature of life—quite the contrary! How marvelous and intricate life turns out to be! How deeply satisfying is the digital elegance of DNA! How aesthetically appealing and artistically sublime are the components of living things, from the ribosome that translates RNA into protein, to the metamorphosis of the caterpillar into the butterfly, to the fabulous plumage of the peacock attracting his mate! Evolution, as a mechanism, can be and must be true. But that says nothing about the nature of its author. For those who believe in God, there are reasons now to be more in awe, not less.