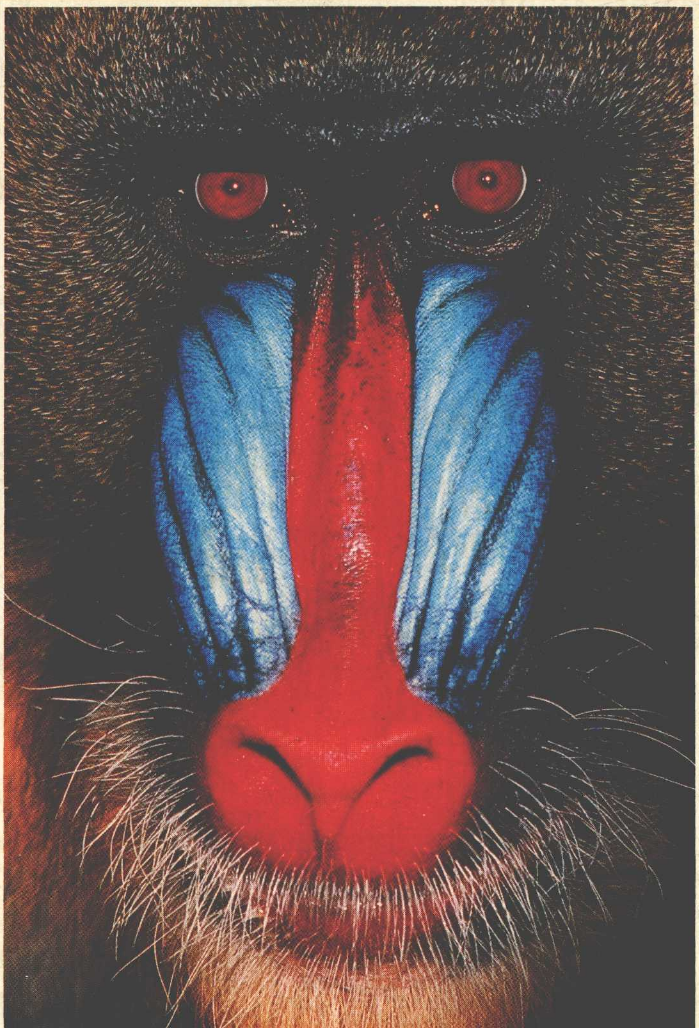
BIOLOGY

AN INTRODUCTION



Johnson · Rayle · Wedberg

Biology
An Introduction

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About the cover: The mandrill, a type of baboon, is an inhabitant of the jungles of West Central Africa. Mandrills are social animals, living in groups of up to 50. The bright colors of the animals aid in communication within the group. For instance, when an animal becomes excited, the colors increase in brilliance on the face and the similarly colored buttocks. To show submission to a dominant male, a subordinate male presents his back side to the dominant male. In these and other ways the social hierarchy of the group is maintained. (See Essay 30–1, "Social Life of Baboons," pp. 546–547.)

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Preface

We have written *Biology: An Introduction* for students taking college-level biology for the first and perhaps the only time. With this audience in mind, we have emphasized the most important principles and processes of biology. Many of the concepts are presented from the perspective of their historical development, which we believe gives students a *feel* for biology. As a science, biology is more than a body of knowledge. It is also a means for obtaining knowledge, and understanding how scientists unravel life's mysteries is an important part of understanding biology. We believe that a major strength of this book lies in walking that fine line between providing enough background information to make the concepts understandable and overwhelming our audience with unnecessary detail.

To us, biology is a fascinating subject. It is our goal, both through teaching and writing, to convey some of its fascination to others. We hope this book instills in its reader some of the excitement of biology that made its writing a labor of love.

CONTENT AND ORGANIZATION

Our ideas concerning an introductory biology text have been shaped over many years by our experiences in the classroom. Our teaching experiences, and most importantly, the feedback we have received from thousands of introductory biology students, have made it clear that no single approach, no specific order of topics, is vastly superior to others. However, we have chosen a "levels-of-organization" approach because it works well for us and because it is easily adapted to most other teaching syllabi. We have made every effort to keep each chapter as independent as possible in order to provide some flexibility for instructors who prefer alternative topic orders.

We begin *Biology: An Introduction* with a short Introduction that provides an overview of the physical beginnings of our planet, particularly as they relate to earth as a life-supporting system. This leads naturally into a consideration of what life is, including an introduction to some of the key concepts of biology. We then go on to discuss the scientific method and, finally, the relationship between science and society. The main text follows and is divided into five units.

Unit One, **Molecules and Cells,** begins with two chapters that provide the chemical background necessary to understand modern biology. The chemistry is woven into a discussion of the origin of life. Dovetailing these topics has worked well in our classrooms, for it gives students a biological framework on which to hang the otherwise "dry" principles of chemistry. Besides, the matter of how life began on earth is intriguing for biologists and lay persons alike, and it provides an excellent model to approach what science is and how it works. The remaining chapters in this unit focus on the structure, function, and bioenergetics of cells. The two chapters which cover cellular respiration and photosynthesis contain overviews of these topics, which can stand alone if more complete coverage of the topics is not desired.

Unit Two, **Cell Division, Genetics, and Molecular Biology,** deals with subjects that lend themselves particularly well to an historical approach. We have taken advantage of this in several instances by providing not only the historical background, but also some of the experimental evidence underlying our current state of knowledge. We personally prefer to discuss classical genetics before embarking on the more difficult topic of molecular genetics, but this sequence could certainly be reversed.

Unit Three, **Microorganisms and Plants,** and Unit Four, **Animal Diversity and Physiology,** are the organismal sections of our text. They begin with the principles of classification, then diverge into specific coverage of the main groups of organisms and their physiology. This is probably the part of a biology course where instructors differ the most in terms of their coverage. Therefore, we took special care to make the chapters within these units as self-contained as possible. Instructors not wishing to follow our sequence, or opting for a more limited coverage of diversity or physiology, can design their own paths without much difficulty.

Our text closes with Unit Five, **Evolution, Behavior, and Ecology.** Our review of many course outlines for introductory biology indicates that this is the way most instructors wind up their courses. However, we have designed the chapters so that they can be covered earlier.

SPECIAL FEATURES

• Balanced Coverage

Special efforts have been made to provide balanced coverage of all areas of biology. We have included material on plant diversity and physiology, animal diversity, and the physiology of nonhuman animals—topics often underemphasized in other introductory biology textbooks.

• Special Topic Essays

Topics of special and current interest are explored in these optional essays. Subjects include Agent Orange, the artificial heart, herpes, oncogenes, and many others. These essays highlight important concepts through fascinating examples, and explore material of particular interest to students.

• Clear, Concise Writing Style

In an effort to make the book as readable as possible, we have tried to keep the technical terminology to a minimum. Clear, step-by-step explanations with appropriate examples help students understand even the most difficult topics.

• Artwork

Over 600 figures and photos, many in full color, blend with the text to make this book inviting to study from or just browse through. We have tried to keep the artwork large for ease of reference. Special attention has been given to diagrams illustrating important concepts.

• Integration of Text and Art

Every figure has been worked and reworked with the text so that the two complement each other. In addition, every effort has been made to ensure that each figure appears near its corresponding text. We feel that this careful integration of text and art makes this book a superior teaching and learning tool.

• Pedagogy

To aid the student in mastering the material in *Biology: An Introduction,* each of the 33 chapters ends with a summary, study questions, and suggested readings. A comprehensive glossary and index are included at the back of the book. A **Student Study Guide** written by Dr. Bernice Stewart of Prince Georges Community College in Largo, Maryland, is available through campus bookstores. For each chapter in the text, the Study Guide provides an overview, learning objectives, a detailed chapter outline, a list of new terms, a programmed self-test, a sample exam, and answers to the sample exam.

Dr. H. L. Wedberg has written an **Instructor's Guide** which is available to adopters of the text. For each text chapter, the Instructor's Guide includes a chapter outline, an overview, teaching suggestions, answers to the study questions in the text, and two chapter tests. A 3-ring binder containing the Instructor's Guide and 65 two-color **overhead transparencies** is available to qualified adopters. **Computerized Testing Service** is also available to qualified adopters.

ACKNOWLEDGMENTS

Writing a textbook today requires the dedicated efforts of many behind-the-scenes individuals. We are deeply indebted to the people at Benjamin/Cummings who made this venture a reality. For their unwavering enthusiasm, support, and professional attitude throughout the project, special recognition must go to Jim Behnke, Editor-in-Chief, and Jane Gillen and Andy Crowley, Sponsoring Editors; to Carol Verburg, who contributed significantly as a developmental editor during the early stages; to Amy Satran and Deborah Gale for their developmental assistance on several chapters; to Barbara Haynes, Kathy Monahan, Wayne Clark, and Carla Simmons for their beautiful drawings and diagrams; to Julie Kranhold and the staff at Ex Libris for their careful attention at the final production stage; to Carl May for providing many excellent photographs; to Bonnie Garmus, who did much of the final photo research; and especially to Pat Burner, production coordinator, developmental editor, copyeditor, and general ramrod. Pat's critical eye to every aspect of the manuscript and her unswerving dedication to detail have been major factors contributing to the clarity of both the text and art.

We are also very grateful to Dr. LeRoy McClenaghan and James Funston for developing and revising several sections in the text, and to Dr. Andrew Smith of Arizona State University, who conceived of the animal behavior chapter and wrote the first draft.

Many reviewers (listed to the right) provided helpful criticisms and suggestions for revision at various stages of manuscript development. We are very thankful for their guidance. In addition, many of our colleagues at San Diego State University read chapters, offered suggestions, and answered incessant questions. For your unselfishness and patience, fellow faculty, we thank you.

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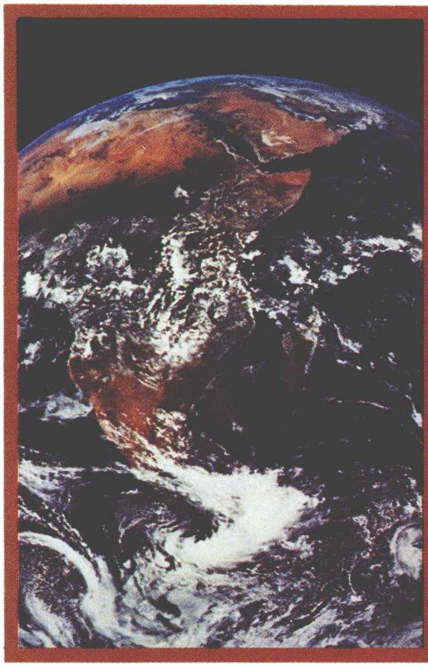


Introduction

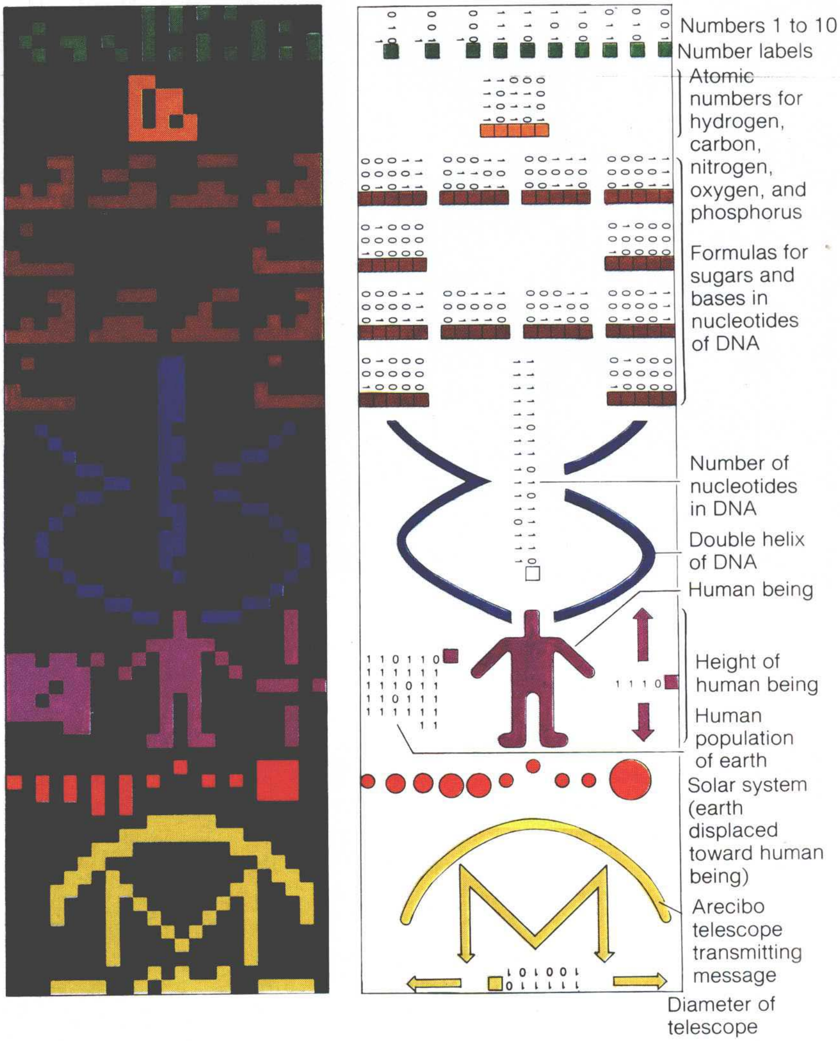
We humans are an intelligent and curious lot. We study our world with a fervent zeal, unraveling mysteries that other creatures can't even conceptualize. No wonder we think of ourselves as special. Ironically, though, the more we learn about ourselves and our surroundings, the less special we seem to become. For example, biologists tell us that we are animals, albeit intelligent ones, linked by threads of common ancestry to all other creatures, past and present—that in the giant tree of life we are no more than a tiny branch of new growth. And astronomers have been chipping away at our egocentric views for centuries, giving us an even more humble perspective.

Recent findings in astronomy indicate that the earth is probably not the only life-bearing planet in the universe. Although the possibility of living creatures inhabiting Mars or other planets within our solar system now seems remote, the probability of life existing on planets in other solar systems within the Milky Way galaxy appears to be quite high. And the Milky Way with its hundreds of billions of stars (each potentially a solar system) is but one galaxy in a sea of over 10 billion known galaxies! Thus, there could be untold trillions of earth-like planets in the cosmos, any of which could be inhabited by creatures with a comparable or even higher intelligence and technology than ours.

If there is intelligent life out there, then why not try to communicate with our distant neighbors? This thought has occurred to many scientists, and several attempts have been made to communicate our existence to other parts of the universe. For example, in November, 1974, a coded radio message was transmitted from the Arecibo Observatory in Puerto Rico toward a distant star cluster. This radio pulse took a mere five hours to reach the outer limits of our own solar system. The message is simple enough to be deciphered by any beings who possess an intelligence and technology at least equivalent to ours (Figure I–1). If communication with an extraterrestrial civilization was successful, the cultural shock would leave no human institution untouched. Imagine what might go through the "minds" of any unearthly beings receiving our radio message!

Perhaps other stars formed in much the same way as our sun (Figure I–2). If so, then these stars may also have orbiting planetary systems. Most of these planets would not have the proper physical environments to support life as we know it, just as earth is the only planet among the nine in our solar system that appears to bear life. If you were to embark on a "star trek" mission in search of extraterrestrial life, what type of planet would you seek? Knowing that earth supports life, you would probably look for a planet that is similar

FIGURE I–1
To Whom It May Concern! Graphic representation of a 3-minute radio message beamed to the stars from the Arecibo Observatory in November, 1974. If intelligent, extraterrestrial life intercepted this message, they would presumably plot the series of sound characters in a form like that shown on the left. For the rest of us, the explanation of the plotted message appears on the right. The message has already traveled more than twice the distance to the nearest star.



to our own. It might be useful, then, to look at the special physical characteristics that the earth acquired during its origin, and how this planet changed through time to become the "living Earth" (Figure I–3).

THE ORIGIN OF EARTH

According to one currently popular idea, the forerunner of our solar system was a large, swirling cloud of dust and gases. Gravitational attraction within the cloud pulled the particles inward, forming a flattened disc that became smaller and denser with time. In accordance with a law of physics, our swirling cosmic cloud must have turned faster and faster as it became smaller, just as a tether ball's angular speed (revolutions per minute) increases as it gets closer to the pole. Eventually, the cloud was spinning so fast that small patches of it were cast into nearby space by centrifugal force, just as you would be thrown to one side of a speeding automobile making a sharp turn. These cast-off dust patches also became smaller and denser as a result of their own gravities, ultimately becoming the nine planets. The central mass of debris condensed into a medium-sized star, our sun.

When the earth first became a solid ball of matter, it had an atmosphere consisting of the lightest, most abundant elements in the universe: hydrogen and helium (Figure I–4a). However, because the primor-

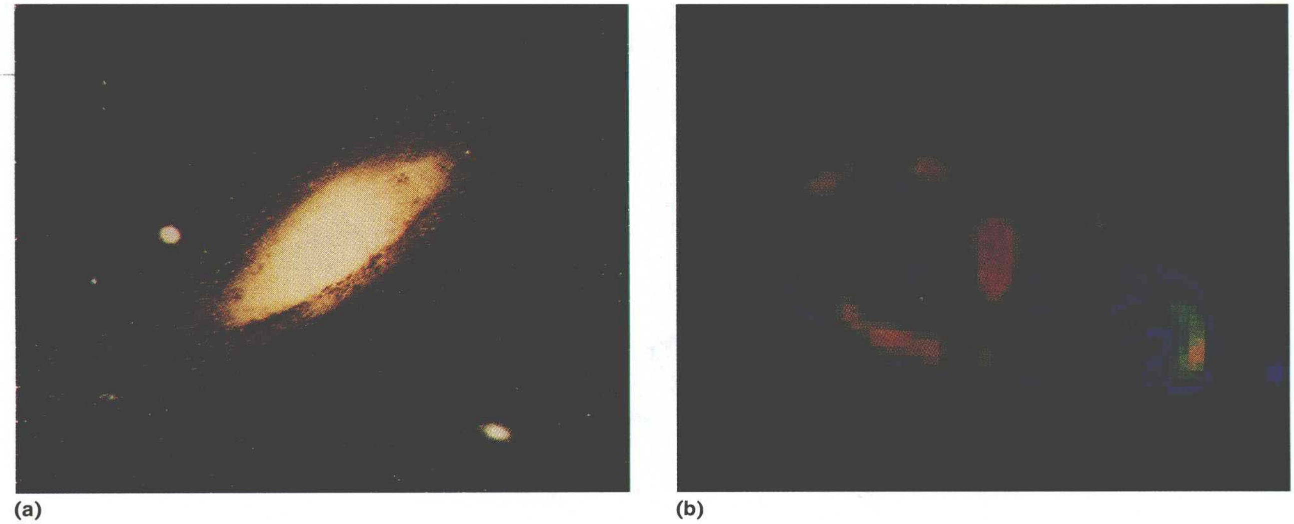


FIGURE I–2
Star Formation. (a) The Andromeda Galaxy as seen with a conventional optical telescope. (b) A computer-processed image of the Andromeda Galaxy recently obtained by the Infrared Astronomical Satellite. The red, orange, and yellow areas indicate regions where young stars are probably forming, each potentially a solar system.

FIGURE I–3
Earth. This photograph was taken by the Apollo 17 astronauts from a distance of 80,000 kilometers (about 60,000 miles).

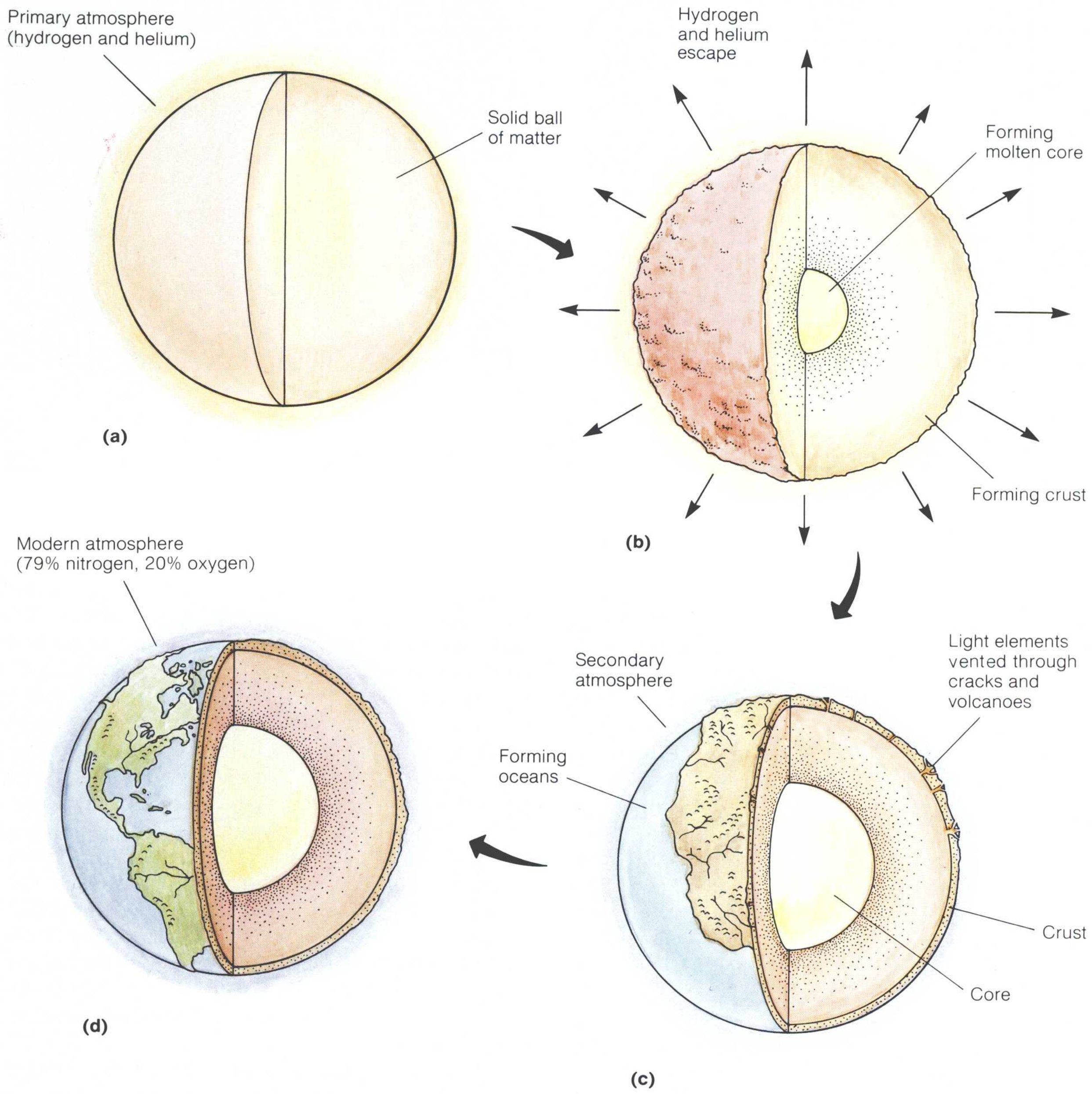


FIGURE I–4

The Shaping of Earth. (a) According to one theory, the dust patch forerunner of earth condensed into a solid ball with a primary atmosphere of hydrogen and helium. (b) Too light to be retained by earth's gravitational pull, the primary atmosphere gases gradually escaped into space. Meanwhile, rocks were liquefied by heat produced by radioactive decay processes occurring deep inside the ball. This permitted the heavier molten elements to flow toward the earth's core and the lighter elements to float toward the surface. (c) The internal heat also created pressure, which was periodically vented through cracks, fissures, and volcanoes in the crust. These vents spewed forth gases that became the secondary atmosphere, the chemical cauldron of life's beginnings. (d) The earth today has an atmosphere composed largely of nitrogen and oxygen gases.

FIGURE I–5
The Mount Saint Helens Volcano. Volcanic eruptions are a major source of atmospheric gases today, and they undoubtedly contributed to the formation of the secondary atmosphere some 4.5 billion years ago.

dial earth was relatively small and close to the sun, its gravity was too slight and its temperature too high to retain this primary atmosphere. Thus, most of the hydrogen and helium escaped earth's gravity and floated off into space.

In the meantime, events were occurring in the earth's interior that would eventually lead to the formation of a new, secondary atmosphere. Deep below the surface, radioactive decay processes (similar in principle to those occurring in a nuclear reactor) were generating tremendous amounts of heat. Since this heat was unable to escape through the solid ball of matter, it accumulated and melted much of the subsurface rock. In the molten state, the heavier, denser elements (mainly nickel and iron) sank toward the center, forming a molten core. The lighter elements (such as carbon, oxygen, and nitrogen) "floated" toward the surface to become the earth's outer crust (Figure I–4b). The buildup of heat also produced pressure below the crust. This pressure was vented periodically through cracks and volcanoes, which spewed out lava and gases composed largely of the light crust elements (Figure I–5). These elements reacted with each other and with the hydrogen still present in the atmosphere, forming various gases and, significantly, vast amounts of water. The gases—methane, ammonia, hydrogen sulfide, carbon monoxide, carbon dioxide, and nitrogen—became the earth's secondary atmosphere (Figure I–4c).

The formation of the earth's secondary atmosphere set the chemical stage for events that would transform the earth into a life-bearing planet. The generous amount of water formed was too much to remain suspended as vapor in the atmosphere, and it condensed into liquid form to become the oceans. It rained a lot back then, and the lightning generated by the frequent storms provided part of the "spark" that encouraged chemical reactions to occur among the atmospheric gases. According to the chemical origin of life theory, these simple gases reacted with one another to form larger, more complex substances, which in turn reacted to produce even larger substances. After millions of years of increasing chemical complexity, the surface waters of earth became dotted with the first tiny life forms, probably something resembling the simple bacteria of today. From that moment forward, the earth has had an uninterrupted biological history.

As the early organisms grew in numbers and increased in complexity, they gradually changed the very atmosphere from which they were "born." In using up some of the atmospheric gases to support their growth, and with the emergence of plantlike creatures that produced oxygen gas, the secondary atmosphere ultimately gave way to our present atmosphere. The air we breathe contains about 79% nitrogen gas, 20% oxygen gas, and trace amounts of other gases.

If during your imaginary search for other life-supporting planets you found one with an atmosphere similar to earth's secondary or present one, that would indeed be very encouraging. To be a good candidate for life support, however, your planet should also have plenty of water and a moderate temperature. All three of these conditions hinge primarily on the planet's size and its distance from its sun.

Let us further imagine that your spaceship does happen upon a planet that meets these physical criteria, and you decide to have a closer look. Your mission, you recall, is to find life. If life does exist there, it may not take the forms familiar to us on earth. For example, the adage, "If it quivers, it's alive," may not help you discover life on a planet with no animals. What, then, are the most basic characteristics of all living things?

WHAT IS LIFE?

Asking a biologist to define "life" is like asking a geologist to define "rock." Since both terms refer to natural states of matter, they really defy definition. The best we can do is to *characterize* a living organism in terms of its physical attributes, such as size, form, chemical composition, activities, and other observable features. And by identifying the characteristics that are shared by all organisms, perhaps we can put into words what we all intuitively know to be life.

One of the characteristics of living things is their highly **complex organization** (Figure I–6a). Even very simple organisms, such as microscopic bacteria, are much more complex than the most sophisticated computers. This complexity is built from special types of chemical substances that are found only in biological structures. And from these structures arise the activities that are uniquely life. Included among these activities are the other major characteristics of life: metabolism, growth, sensitivity, and reproduction.

The most fundamental of all biological activities is cellular metabolism. Every organism is a chemical "factory," carrying out thousands of different chemical reactions collectively known as **metabolism.** A major part of metabolism involves the formation of complex molecules from simpler ones obtained from the environment. For example, animals obtain sugars and other small molecules from the food they eat (Figure I–6b). They then transform these building blocks into the more complex substances that make up their bodies. But this process, like most biological activities, requires energy. The energy is provided by another part of metabolism, which breaks down food molecules like sugars, converting their inherent energy to other forms of useful energy. So, organisms use food both as chemical building blocks and as energy sources; but where does the food come from? The green plants of the earth are the ultimate source of energy-laden food—they capture light energy from the sun and use it to build food molecules from simpler substances, namely carbon dioxide and water.

Another characteristic common to all living things is growth. **Growth** is an increase in size or mass, and it results from the various metabolic processes that build complex molecules within organisms. Growth is generally accompanied by **development,** an orderly, progressive series of events that gives form to the body and results in specialization of activities within the organism. For example, your life began as a microscopic fertilized egg, a single cell. This cell divided to produce two cells, these divided to produce four cells, and so on. But this growth process did not culminate in a giant blob of cells, but rather a form that is distinctly human (Figure I–6c–e). During this development, the billions of cells in your growing body took on a variety of highly specialized functions—skin cells protect, eye cells see, blood cells transport, and so forth. Each different type of organism has its own specific pattern of growth and development, and this fact enables us to distinguish an ant from a goat, a tiger from a tulip, and so on.

All organisms display **sensitivity**—the ability to detect and respond to changes in the environment (Figure I–6f). A sunflower bends toward the sun, Canadian geese fly south for the winter, and a frog snatches a fly with its tongue—these are all examples of sensitivity. Sensitivity does not always imply the existence of sophisticated sense organs and a well-developed nervous system. Even single-celled bacteria can sense food nearby and move toward it.

Finally, the capacity for **reproduction**—the act of producing new individuals that are like the parent—is undoubtedly the most distinctive characteristic of living things. You can find examples of chemical processes occurring outside of living systems (such as the reaction between iron and oxygen to form rust), or inanimate objects growing in size (such as a snowball rolling down a snowy bank), or even machines that exhibit sensitivity (such as a signal-triggered garage door opener), but you will never see any nonliving thing produce copies of itself. Reproduction provides for the continuity of life through the generations (Figure I–6g). Indeed, reproduction is the thread that links all present life forms to their ultimate ancestors—the simple creatures that started the experiment of life on earth some 3.6 billion years ago.

FIGURE I–6

The Characteristics of Life. (a) The internal structure of a plant stem illustrates the complex organization of organisms. (b) This grasshopper is munching on a tasty morsel of metabolic fuel. (c–e) Growth and development in humans begins with a fertilized egg, then passes through (c) an embryonic stage (9 weeks) and (d) a fetal stage (4 months) to become (e) a baby. (f) A river otter and crayfish detect each other's presence—a clear example of sensitivity. (g) Different generations of cedar waxwings illustrate that reproduction provides continuity to life on earth.

TWO THEMES IN BIOLOGY

Two major themes in biology weave throughout this book, both so fundamental to the study of modern biology that we will introduce them here: (1) organisms have evolved, and (2) life and its processes conform to the laws of chemistry and physics.

Evolution

Living things have changed, are changing, and will continue to change. This is the basic tenet of biological evolution, and it is so ingrained in the minds of biologists that few of them argue the basic idea anymore, at least not with each other. No one can ignore the fossils, relics of past flora and fauna that represent distinctly different life forms than presently exist. Yet, there are obvious resemblances between modern organisms and fossils of the recent past, and between recent fossils and those slightly older, that makes evolutionary descent an inescapable conclusion (Figure I–7). Evolution is a unifying principle in biology, and it will undoubtedly continue to be a major framework that binds diverse specializations within the life sciences.

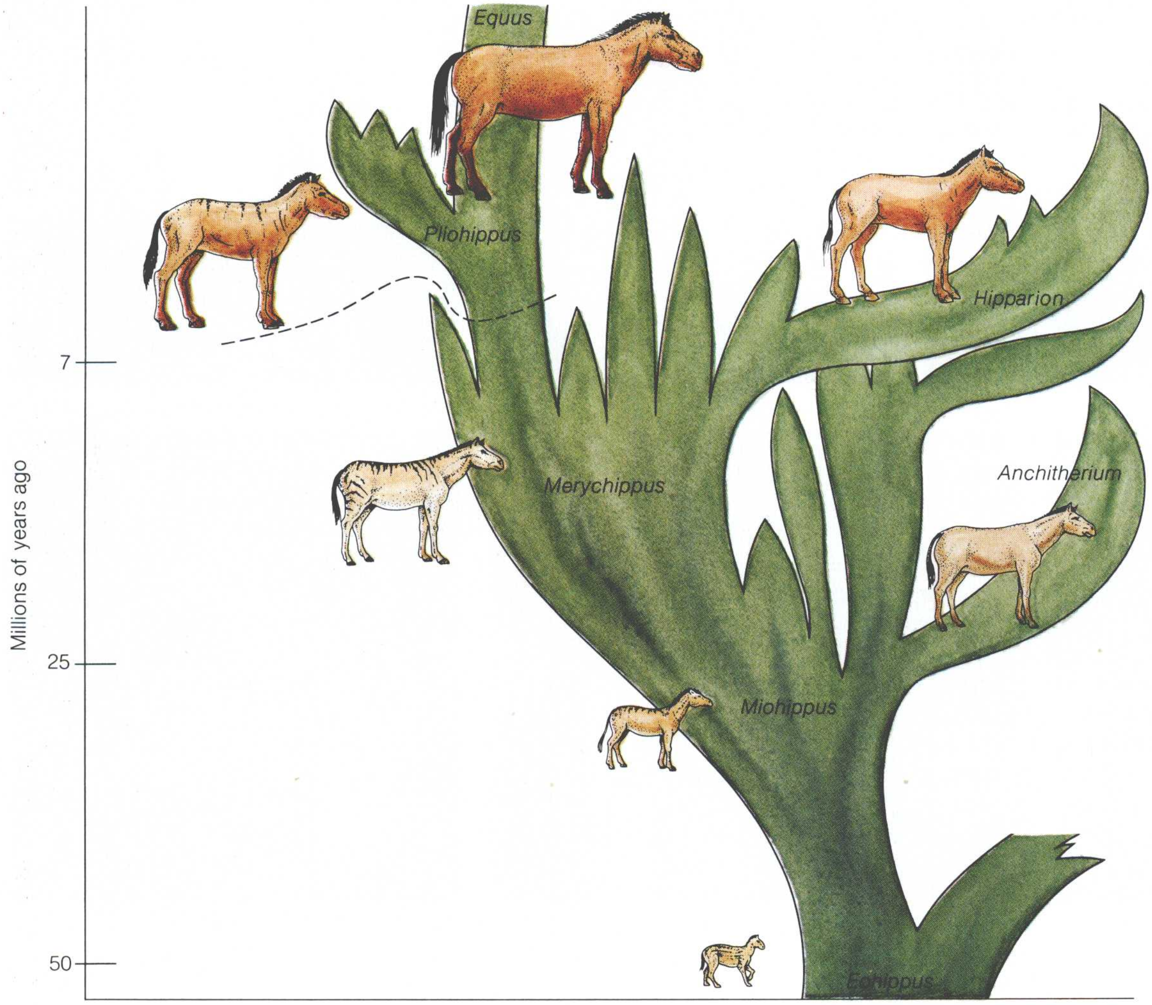


FIGURE I–7
The Evolutionary Tree of Horses. Based on a rather good fossil record, scientists have been able to construct this evolutionary history of horses. Note that only one kind of horse (*Equus*) has survived to modern times.

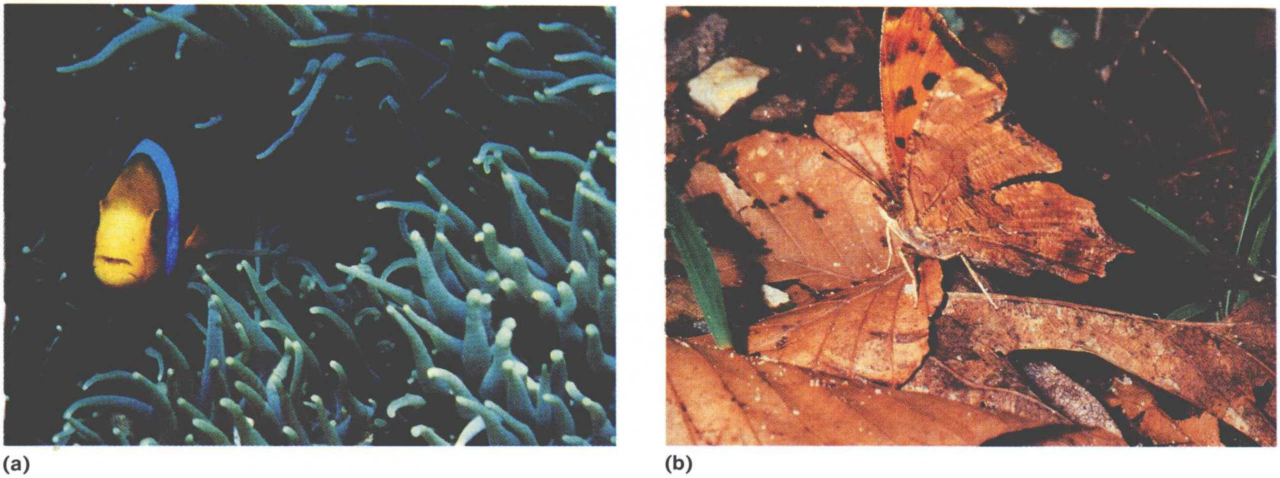


FIGURE I–8

Adaptation. (a) Lurking among the sea anemones is a clown fish, which is unaffected by the paralyzing stings of the anemones' tentacles. Other fish, including predators of the clown fish, are susceptible, however. Thus, the clown fish finds protection among the anemones' tentacles. (b) The "Question Mark" butterfly cannot be seen easily because the undersides of its wings match the surrounding dead leaves.

The theory of evolution says more than the fact that living things have changed with time. As Charles Darwin (1809–1882) realized, the idea of evolution is of little value without a reasonable mechanism to explain how it works. To fill this gap, Darwin offered the powerful principle of **natural selection.** He realized that all creatures wage a constant struggle against environmental constraints to survive and reproduce more of their kind. In this struggle, those individuals better suited to the environment survive and reproduce in greater proportion than those less fit, leaving more offspring with their specific characteristics.

Darwin's concept of natural selection, so simple and yet so elegant, has two important implications. The first is **adaptation,** the process of evolutionary change in which organisms become increasingly suited to their specific environmental circumstances (Figure I–8). A fish with gills and fins is adapted to living in water; birds have light bones and feathered wings adapted for flight. But changing circumstances can render a previously well-adapted organism less fit to survive and reproduce, jeopardizing its continued existence as a species. It is estimated that over 95% of all species that have ever lived are now extinct.

The second implication of natural selection is that physical characteristics, such as fins, wings, and hollow bones, are passed from one generation to the next via reproduction; that is, **traits are inheritable.** We know today that traits are passed along in the form of DNA, the genetic material (Figure I–9). Occasionally,

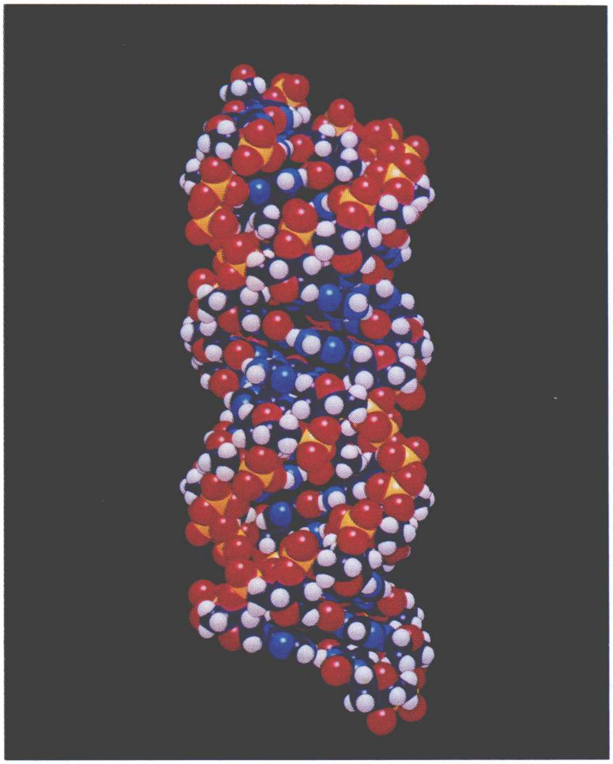


FIGURE I–9

DNA. Computer-generated model of a short segment of DNA. DNA houses the genetic instructions that determine the specific characteristics of organisms.

changes occur in DNA that can alter specific traits (such as fin length in a fish). If the change has adaptive value (if it renders the organism more fit), then the altered trait will probably appear more frequently in subsequent generations because the individuals having it may be more successful than others in the struggle to survive and reproduce. And because the earth offers such a wide assortment of environments, natural selection operating over billions of years has produced an enormous diversity of living things, each type adapted to its own particular environment.

Organisms Conform to the Laws of Chemistry and Physics

Prior to the twentieth century, the distinction between living and nonliving things appeared to be obvious. Organisms were said to have a "vital force," an indescribable "spark of life" found only among the living. The adherents of this theory, the so-called **vitalists,** argued that living things were not only composed of unique types of substances, but they carried out processes that were unmatched in the inanimate world—indeed, even the chemist could not duplicate them. Louis Pasteur (1822–1895), a renowned vitalist, contended that only *living* yeasts could carry out the fermentation of sugar to alcohol; that is, he considered fermentation to be a vital process. In 1897, Eduard Buchner proved Pasteur wrong by demonstrating that a "nonliving" extract prepared from broken yeast cells could change grape juice into wine. With this demonstration of a biological process occurring in the absence of any possible vital force, vitalism as an acceptable scientific idea was dead.

Vitalism has been supplanted by **reductionism,** the theory (or philosophy) that life has a purely chemical basis and its operation can be explained entirely in terms of the physical laws that pertain to all natural phenomena. Reductionism opened up a new era in biology. It meant that life and its processes could be studied using the powerful analytical tools of the chemist and physicist.

Over the past 50 years or so, inquiries into the "anatomy of life" have dispensed with the scalpel in favor of the biochemist's mortar and pestle. All of the basic types of molecules that make up living things have now been identified and synthesized in laboratories. And with the appropriate molecules present, all of the chemical processes that take place in cells can be duplicated in test tubes. Given the natural properties of the molecules found in cells, there is nothing mystical or "vital" about the chemical processes in which they participate.

The phenomenal advances in biochemical research have brought us to the point where we can manipulate the genetic constitution of certain types of cells almost at will. For example, some "genetically-engineered" bacteria produce *human* hormones. With new advances in molecular biology coming every week, we can look forward to solving some very old problems, such as cancer, in the not-too-distant future.

THE SCIENTIFIC METHOD

Biology is a natural science, and that has certain implications with regard to how biologists study life. In the broadest sense, science refers to a body of systemized knowledge. But "science" also implies a means for obtaining that knowledge. There are three generally recognized ways to obtain new knowledge. One is *intuition,* a "mental flash" of insight. Intuition is an important process in our everyday lives, as it is in science. It can provide instant insights into problems that otherwise might take years to solve. However, intuition is not always reliable and often leads us down the wrong track. Moreover, even if an intuitive insight seems perfectly clear to you, you are still left with the task of convincing others that it is correct. The second avenue to knowledge is by way of an authority, such as a guru in spiritual matters or a book for factual information. Depending on their sources of facts, however, authorities differ and often contradict one another. In order to decide among differing authoritative views, you may want to know how the authorities obtained their knowledge. You will probably find that the authoritative knowledge you accept, or the intuitive notions that prove correct, will have observed or experiment-based facts to support them. Observation and experimentation are the tools of the third means for gaining knowledge—the **scientific method.**

The scientific method entails a series of logical steps that, in actual practice, are not always taken in sequence. In fact, scientific discoveries are often made by mistakes in the application of the method, but that does not make them any less scientific, as long as they are still subject to observed or experimental justification. In most instances, however, scientific knowledge starts with some casual observation about something. This may generate an idea that spurs further, more

FIGURE I–10
The Unscientific Method.

directed observations. Eventually, some sort of tentative conclusion is reached, which generally takes the form of a **hypothesis**—a testable statement of what appears to be true. For example, suppose you come home to a darkened house and flip on a light switch only to find that the light doesn't work. Your mind instantly forms several hypotheses, the most readily testable of which is, "The power is out." To test this idea, you quickly try another light switch. Presto, that light works, so you dismiss the first hypothesis and shift to a second one: "The light bulb must be burned out." This is easily tested by replacing the bulb, and when this is done, you flip on the switch and the light comes on. You therefore conclude that the second hypothesis is correct. However, the fussy scientist deep inside your mind reminds you that the hypothesis is only *probably* correct. No hypothesis, no scientific theory or law, can be proven beyond any shadow of doubt. No matter how firm the scientific concept is, one exception can invalidate it. In the case of the light bulb hypothesis, it is quite possible (albeit unlikely) that in the time it took you to go from the first light switch (inoperative) to the second (operative), the power outage was corrected.

As we have seen in the light bulb example, hypotheses are testable. A statement such as "God exists" is not a hypothesis because we cannot test it through direct observation or appropriate experimentation. The truth of such statements must be supported by other means that lie outside the realm of science.

Testing a hypothesis involves the collection of data, or facts, that either substantiate it or make it necessary to modify or discard it. When the scientist is reasonably sure that the hypothesis is supported by the data, the next step is to tell the world by publishing the results. This is generally done by submitting a research paper to an appropriate scientific journal, which has editors and often peer reviewers. Their function is to ensure that the work is significant, of high quality, and that the author's conclusions are indeed supported by the data. If the paper fails in any of these regards, it will be rejected for publication.

An important inclusion in any scientific paper is a section on methodology. The scientist must include an accurate and detailed description of how the observations and/or experiments were conducted. Other scientists may then apply the published methods to verify, extend, or possibly reject, the published results. Thus, publishing the results of a scientific investigation is the formal solution to the type of problem illustrated in Figure I–10.

SCIENCE AND SOCIETY

In its purest form, science is amoral. It is shackled neither by value judgments nor moral restraints, for the fruit of scientific endeavor—knowledge—is neither good nor bad. **Technology,** on the other hand, deals with the application of ideas, often scientific ones,