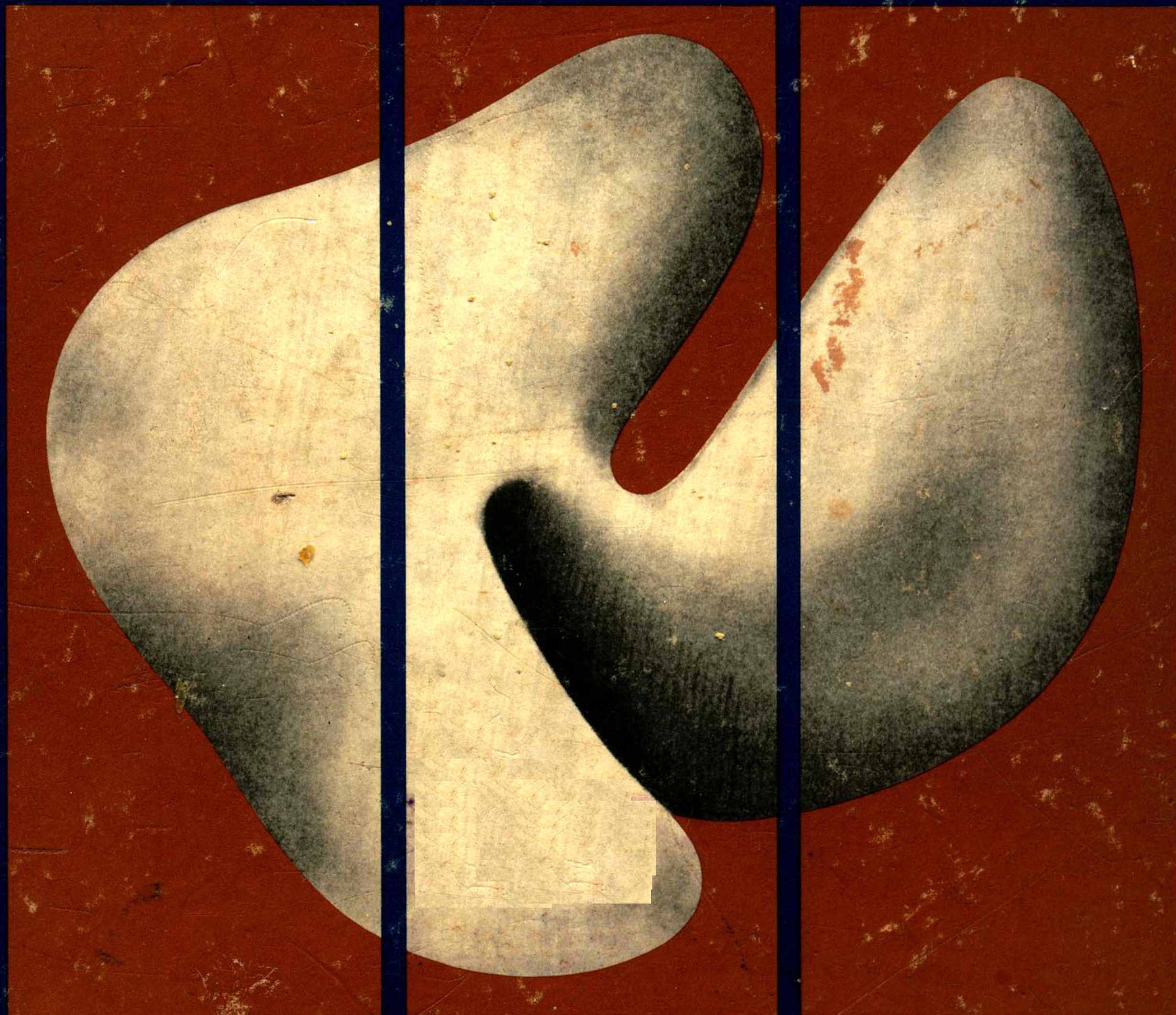
BIOLOGY

A HUMAN APPROACH 2nd Edition



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SECOND EDITION

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PREFACE TO THE SECOND EDITION

The wide acceptance of the first edition of *Biology: A Human Approach* has provided us with a great sense of satisfaction. We are pleased to know that the book is being used by so many students and that instructors have found our view of teaching biology in harmony with their own. Yet over the last few years, as readers have told us of their views, we knew portions of the text could be revised and improved upon. This second edition is our attempt to respond to these challenges.

The major changes in this edition have involved a condensation and simplification of the chemistry found in Part I (The Cell), the addition of a totally new chapter, Animal and Human Behavior, to Part II (The Human Organism), and the rewriting and amplification of topics that have changed markedly in the past few years (for example, genetic engineering, environmentally induced cancers, and immunology). At the end of each chapter there is a summary, a list of key words that are boldfaced and ordered as they are defined in the text, and topics for review and discussion. No chapter, figure, or figure legend in need of improvement was left untouched. At the same time, we felt that change for its own sake was not constructive; thus material that we felt was satisfactory remains unchanged.

As in the first edition, the index may also be used as a glossary. Key terms are boldfaced where they are defined in the text; the page number where their definition may be found is likewise boldfaced in the index, providing a quick and easy reference. We hope that students will find this method of indexing and the lists of key words added to the end of each chapter to be useful study aids. For example, after they read a given chapter, students may wish to run down the list of key words. If they can successfully define all key words for themselves, they are on the way to achieving a good grasp of the chapter's content. Definitions of unknown terms can be checked quickly by looking back through the chapter, since the key words are listed in order as they appear in the chapter; or definitions may be easily found by turning to the index.

We would like to thank Clay Sassaman and Charles Taylor for their assistance in updating the genetics and ecology chapters.

As before, any errors remain our own.

I.W.S.
V.G.S.

February, 1978
Riverside, California

PREFACE TO THE FIRST EDITION

This book is intended for use by undergraduate students who are likely to pursue careers in fields other than the biological sciences. Because this will perhaps be both their introductory and final course in the subject, we want to present to those students not only biological concepts but related information that will better enable them to understand themselves and the world in which they live. We have tried to write a book that is clear, enjoyable, and relevant to the personal life of students majoring in the arts, humanities, and social sciences, but not a watered-down major's text.

As implied by the book's title, we have selected the human organism as its central theme. Here we treat biology—the study of life—in its modern and often controversial aspects. Hopefully, biology framed in this way has both meaning and excitement rather than being an abstract stumbling block serving merely to satisfy the breadth requirements of the liberal arts major. The human approach to biology has immediate personal relevance for most students because humans have an inherent interest in themselves. By design, we have omitted detailed considerations of the life histories of plants or animals, and plant and animal anatomy. On the other hand, the text goes more deeply into areas relevant to the student's present and future. Basic biological concepts are illustrated by reference to areas of immediate human concern, such as cancer, abortion, human genetics, human ecology, transplantation immunity, and genetic engineering. When a topic is mentioned, it is given sufficient depth to make exposure meaningful. It is our hope that a human approach to biology will generate sufficient interest in biological phenomena and how these are investigated that, although formal coursework may end here, in depth studies will continue thereafter in an informal way.

The chapters are arranged in a sequential order, the study of advanced areas depending on an understanding of more elementary concepts. Thus, the book progresses from The Cell (Part One) to The Human Organism (Part Two) and ends with a view of man from an ecological perspective, The Human Population (Part Three). Within each section there is also a progression from simple to complex levels so that what goes before is used as a basis for later discussions. However, the text treatment is flexible enough to permit diverse sequences of chapters, so an array of readings can be accommodated to courses of varying length.

To demonstrate the human implications of biological processes, most chapters begin with a photograph, a news article, or a short excerpt from the popular literature. These are designed to pique reader interest and to point up the timeliness of the subject matter. The chapter proper, the academic core of the text, attempts to stress the importance of biological facts to the human condition—where we are and how we might possibly change. At intervals in each chapter, relevant asides are presented in boxes. For example: why cyanide kills; curling of hair and the shape of protein molecules; transplanting a gene; human mammary tumors; smog, smoking, and emphysema. Boxed material serves as motivational cement, holding firm the reader's attention to the text's core material.

Since the book is written for undergraduate college students regardless of their previous scientific background, it seemed important that all students have some of the basic tools of biology at hand. The role of chemistry in biology cannot be minimized. The simple chemistry essential to an understanding of today's biology is presented in an appendix to the text proper so that chapter continuity and student interest are not sidetracked by a "chemistry hurdle" at the book's beginning. Reading the chemistry appendix at appropriate points in the text rather than all at once will serve to reduce the activation-energy barrier of this subject.

This book spans its subject from the level of molecules to populations, and no single person can claim excellence in all of these diverse specialties. In the preparation of the text we have been most fortunate in having the able assistance of colleagues who read and gave criticism of these pages so that the text was as error-free as possible. No doubt errors still remain; the fault for these is ours. We particularly want to thank: William L. Belser, Roger D. Farley, Robert W. Gill, Robert L. Heath, Richard L. Moretti, Donald I. Patt, E. Crellin Pauling, Timothy Prout, Rodolfo Ruibal, Vaughan H. Shoemaker, William W. Thomson, Irwin P. Ting, and Linda Tanigoshi.

We hope the fruits of our labors are enjoyed with the same delight that we derived by writing about and teaching biology in this way.

CONTENTS

PROLOGUE

Man is a threatened species. The twin specters facing him are overpopulation and unbridled technology—both self-induced.

The double threat is aimed most directly at man's environment. As the United States strives to accommodate more human beings than it has ever had to serve before, increased demands are placed on our natural resource bank. Our surroundings become increasingly crowded, noisy, and soiled.

. . . Buffeted by the elements and beset by other life forms, man has always stubbornly insisted on exercising every option open to him. Does he still run his own show today: Or has he finally stumbled upon two forces—population and technology—that he considers too sacred to tamper with: Is he still convinced that the roaring crescendo from babies and bulldozers is the sweet music of progress?

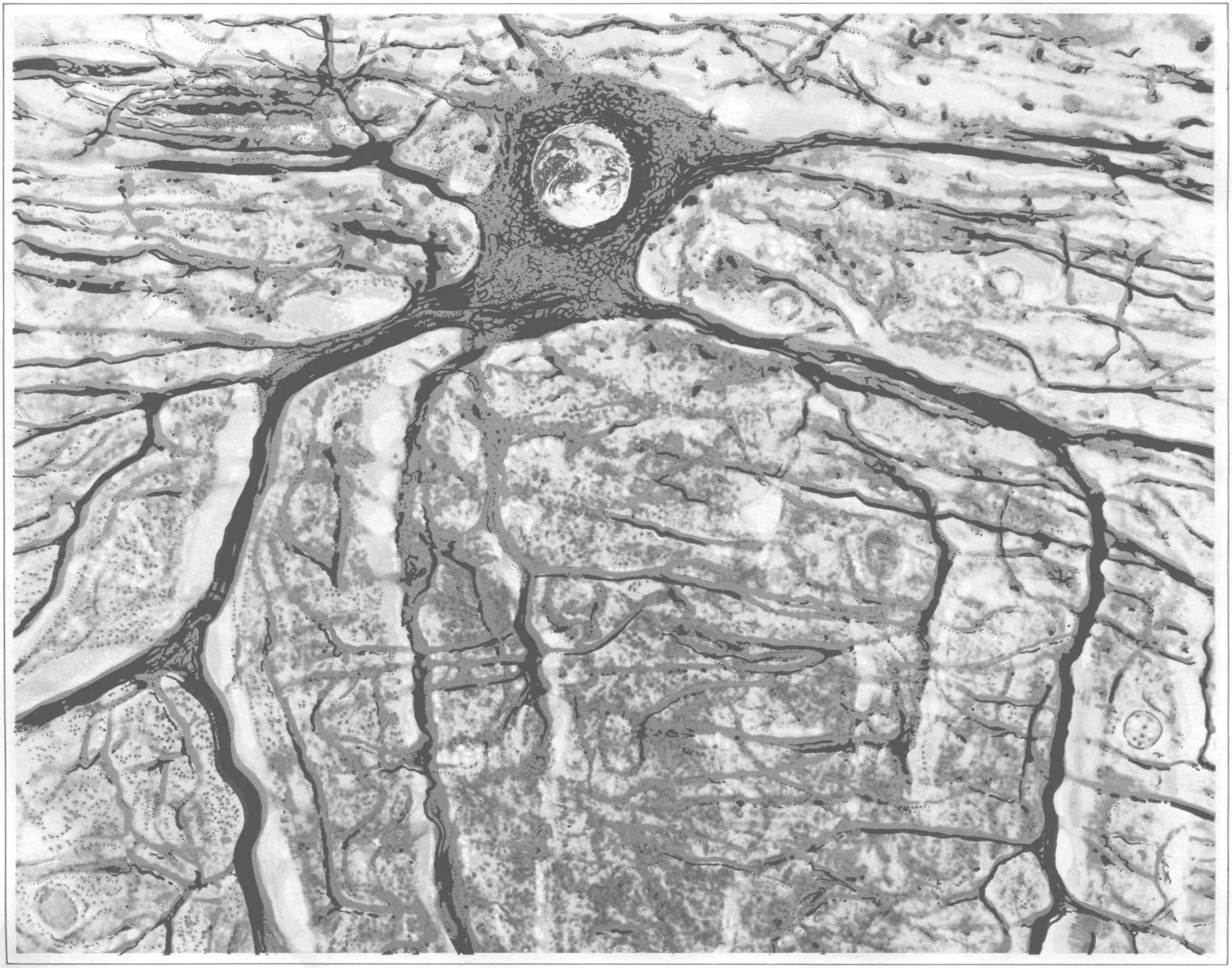
Does he confuse technology with science? Will he continue to accord to the jackhammer the same revered status as the test tube? Or will he recognize in time that the tools he uses to rip up mountains and destroy estuaries must be extensions of his mind as well as his muscle? Will he see that science must remain free, since it is the *search* for truth, but that technology is only a means of *applying* truth—and that these applications need the control and balance of wisdom and a concern for posterity?

Man stands at a fork in his environmental road to the future.

The two arms of the signpost do not state categorically, "Man—Master of Himself" and "Man—An Extinct Species," but it is increasingly apparent that the direction he takes now will move him rapidly along the path toward one or the other destination.

Let us look closely for a moment at this creature who pauses at the crossroads and clamors for attention with our own voice. Who is he? Where has he come from and how has he made the journey this far?

From "Man . . . An Endangered Species?" U.S. Department of the Interior Conservation Yearbook No. 4 (Washington, D.C.: U.S. Government Printing Office, 1968).



THE CELL

Some say the spaceship earth is doomed. There is only a short time before there will be little oxygen to breathe or food to eat; the effluents of the inhabitants will soon overcome them. Time has run out, and no matter what we do, nothing can save us. This pessimistic view of our future may become a reality in a very short time, but let us imagine for the moment that there is still time to recover the ship and its inhabitants. How can the earth be saved from self-destruction?

Recovery tactics must depend upon a clear understanding of the nature of the earth and its occupants—the substances which compose this self-contained system and how they interact with each other. It would be helpful, indeed desirable, to understand the most fundamental elements that make up this system. In the physical and chemical world the fundamental unit is the atom, and it is impossible to understand physical and chemical events without recognizing what atoms are like and what they do. In the biological world, our world, the cell is the fundamental unit, and similarly we cannot comprehend biological phenomena without an appreciation of the cell, its structure and operation. It is elemental that many of the problems confronting earthly inhabitants depend upon the nature of the cells which make up earthlings. An understanding of the cell is basic to understanding ourselves and all life.

Is there life on Mars?

On July 20, 1976, as the sun broke over the Martian horizon, a spindly three-legged spacecraft sat silently on a dry, barren landscape. Suddenly, a silvery arm stretched out from the Viking Lander and scooped up a heap of reddish soil. The Viking, after an 11-month journey in space, successfully responded to commands from controllers on the Earth 200 million miles away. The robot arm retracted, twisted its wrist, and dropped the soil into an opening on the top of the spacecraft. The search for extraterrestrial life had begun.

How does one look for life that may be very different from our own? How can one be sure that observations reveal living processes rather than nonbiological activity? More than 10 years ago, a Space Study Board agreed that anything organized to draw nourishment from the environment and reproduce itself should be considered "life."

The most obvious way to seek life on Mars is to look for it, and the Lander's cameras are being used to see if anything moves or looks suspiciously biological. Another way is to test for the presence of organic molecules. On board Viking, a tiny laboratory is housed in a one-foot cube weighing only 30 lbs. It is crammed with 140,000 electronic components—including 122,000 transistors, 40 thermostats, 3 tiny ovens, bottled radioactive gases, a small xenon lamp to simulate sunshine, and a pocket-sized chromatograph to analyze the chemical components of the soil. Three separate experiments have been performed.

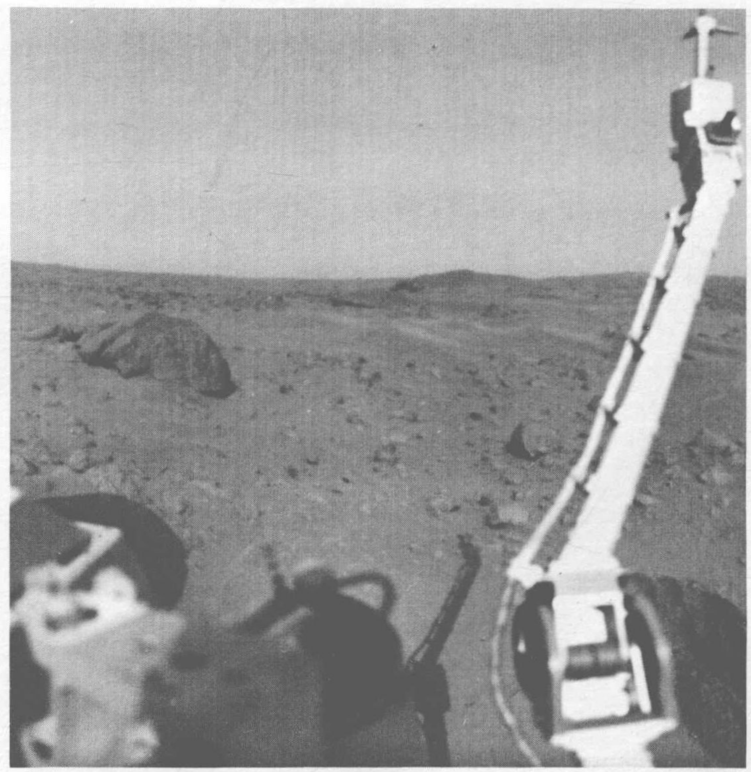
One of the experiments sought to learn if anything in the soil assimilates Martian air (mainly carbon dioxide) to form carbon-containing material. The soil sample was exposed to carbon dioxide whose carbon was radioactive, and incubated for up to 5 days under simulated Martian sunlight. The soil was then tested to see if it became radioactive by incorporating that carbon. This would provide evidence that organisms are growing on Mars. The tests did not find organic molecules; however, small amounts of such carbon-based compounds could go unnoticed.

Living things on Earth use nutrients and release waste products and gases, a process called metabolism. To test for this, a Martian soil sample was moistened with a substance scientists have named "chicken soup," a nutrient broth rich in vitamins and amino acids and containing radioactive carbon. The sample was incubated to see if anything consumed the "soup" and released radioactively labelled products. A rapid release of carbon dioxide occurred. This could have been the result of microbes metabolizing the "soup," or simply the chemical activity of soil compounds called peroxides.

The third test submerged a soil sample in a liquid nutrient for 12 days in an atmosphere of helium, krypton, and carbon dioxide. At intervals, the miniaturized lab sampled the atmosphere in the chamber for hydrogen, nitrogen, oxygen, methane, and carbon dioxide—gases generally produced by living organisms. The sample released oxygen far more rapidly than plants usually do; such a reaction could be biological or the result of decomposition of soil peroxides.

The results of these three experiments were equivocal. The official NASA position stated that it was impossible to say that there was or was not life on Mars; however, physicist Robert Jastrow said unofficially, "Although the Viking experiments have contradictory elements, they seem to indicate that life, or some process closely imitating life, exists on Mars today." Further experiments with Martian soil are planned.

Should the billion-dollar Viking project find even the most primitive organisms, it will help confirm what many scientists suspect: Life is not unique to Earth, and it is probably commonplace throughout the universe.



1

GENESIS: THE ORIGIN OF LIFE

1–1 WHAT IS LIFE?

The business of biology is life. But what is life? What do we really mean when we say that an object is living or nonliving? How do we distinguish between the inanimate and the dead? How shall we recognize living matter on other planets (see facing page), and when can we say that a man is dead and can serve as a donor for organ transplants? It is necessary for us to develop some notion of what life is. We shall find in the process that this is no easy task and no definition of life is completely satisfactory; we can nevertheless make an attempt.

For most of us it is easier to recognize life than to define it. We are aware that we are alive and that someday we shall be dead. Animals and plants are alive; earth, fire, water, and air are not alive. Living things have certain characteristics, none of which by itself is sufficient to define them as being alive, but which, when taken together, enable us to distinguish them from the nonliving. The capacities for growth, maintenance and repair, reproduction, movement, responsiveness, change—these are the properties of the living. But how are these characteristics of life different from the growth of crystals, the division of raindrops, the swift movement of a mountain stream, the response and change in a piece of wood as it is consumed by fire? Let us examine the characteristics of living things one by one in greater detail.

Growth, maintenance, and repair

It is easy for us to recognize living things; however, it is important to recognize that life is not a thing or a substance. **Life** is a property possessed by individuals characterized by the capacity to perform a series of highly organized interacting processes that occur within a definite structural framework. In order to continue these processes, living systems must obtain materials from the environment, utilizing and altering these substances for the synthesis, maintenance, and repair of their own structures and eliminating those materials that are no longer useful. The flow of materials through the living system is called **metabolism.** The tests for life performed on Martian soil by the Viking Lander attempted to detect metabolism in various ways (see facing page).

The metabolic processes of life require an energy supply for their continuance which involves the performance of work, and living systems are capable of converting, transporting, and storing energy. They perform these energy transformations with the aid of organic catalysts called **enzymes.**

One of the end results of all these transformations is an increase in size, or **growth**—from the inside out. Thus, the growth of living systems differs from that of nonliving ones such as crystals, which grow by the addition of material from the outside and do not transform the added material during the process. Moreover, a crystal is unable to repair or maintain itself except under special conditions.

Reproduction

Living systems do not only grow, convert, transport, and store energy—they are also capable of self-duplication, or **reproduction.** Many nonliving systems are capable of reproduction, however. Crystals divide, as do streaming raindrops, and fire can be reproduced by incandescent sparks. How does reproduction in living systems differ from this kind of reproduction? The method of reproduction in living systems is far more complex, exact, and specific than in nonliving ones. Living systems can make identical copies of themselves. Moreover, the process of self-duplication is especially important in living systems because it includes a capacity for **mutation,** or change, and these changes are perpetuated exactly in subsequent generations of the organism involved. The changes in form which may occur during the division of a raindrop or a crystal or the reproduction of fire are not subsequently perpetuated.

A system that cannot change to meet the needs imposed by changes in its environment is at a severe disadvantage, which may eventually prove fatal; in other words, a system incapable of mutation is unable to **evolve** (change with time). Living things exist in endless variety and complexity, and they are able to cope with the demands of the environment because of their ability to mutate, adapt, and evolve.

Responsiveness and movement

Living systems are not static; they are capable of responding to changes in both the external and internal environment, not only from generation to generation but within generations. If somebody pricks your finger with a pin, your initial response is probably to withdraw your finger. The capacity to respond to stimuli is related to the fact that living systems are self-regulating. A particular stimulus induces an appropriate response, but the response may not always be the same. After withdrawing your finger, you might take the pin from the offending party, you might hit him with your fist, or you might simply walk away. Responses are mediated by the living system. A crystal, when it is placed in the right conditions, will always grow; likewise fire and rain are at the mercy of outside controls. Living systems to a greater or lesser extent can control the end results of stimuli themselves.

The dynamic changes characteristic of the living world are often evidenced as motion. Sometimes the motion is on a slow time scale so that the change is not immediately apparent (as in plants), and at other times it takes place quite rapidly and is easily recognizable (as in animals). In many living systems the motion takes place over such short distances that it is not perceived by the human eye, but there are conditions where motion covers great distances and is easily observable. Like the capacity for responsiveness, the capacity for movement that living systems have is self-regulating; in nonliving systems it generally is not. A raindrop must fall, and a fire must rage or die.

Thus, **life** as we have defined it (and the definition is to a large extent arbitrary) involves a series of highly organized interacting processes that form a system that is potentially capable of perpetual change.

What is the advantage of defining and describing living systems in these mechanistic terms (Box 1A)? First, it avoids mystery, and second, it rules out the concept of the existence of a vitalistic force such as entelechy or the "soul of life." The reason for avoiding such ideas is that they preclude a scientific examination of the living system; simply stated, such a characterization of life defies testing by scientific methods (Box 1B) and is of little value in biological inquiry.

1–2 SPONTANEOUS GENERATION

If we agree that life can be defined in mechanistic terms, then we can further ask the question: How did life originate? Somewhere in our educational experience, most of us have come across the doctrine of **spontaneous generation,** that is, the sudden appearance of living things from something nonliving. This view held dominion over much of man's thinking up until the seventeenth century, and it was supported by some of the greatest and clearest scientific minds of the time. The supporters of this view cited examples and gave recipes for

BOX 1A Vitalism versus mechanism

Throughout the history of biological thought, there has raged the controversy whether or not living phenomena can be described in terms of chemistry and physics. The **vitalists** (adherents to the philosophy of vitalism) take the view that living phenomena cannot be included under the heading of chemistry and/or physics but rather that there is a kind of directing force or spirit resident within the living organism. Vitalists believe that this life force is beyond human comprehension and that a distinct and inviolable barrier exists between the living and the nonliving world. According to the vitalists, the origin of life could be explained only as a result of divine creation.

In contrast, the **mechanistic** view of life states that living phenomena can be described by chemistry and physics; the line of demarcation between the living and the nonliving is not sharply defined, and no vitalistic spirit or soul directs the living organism. The mechanists suggest that living phenomena can be examined and tested by the methods of science (see Box 1B).

Vitalism is an ancient view of living phenomena, but it reappears even in modern times. A distinguished physicist, W. Elasser, in 1958 wrote of "biotonic phenomena," that is, "phenomena in the organism that cannot be explained in terms of mechanistic function." And in 1963 P. Mora suggested: "Living entities, at all levels in almost all their manifestations, have something of a directed, relentless, acquiring and selfish nature, a perseverance to maintain their own being and a continuous *urge* to dominate their surroundings, to take advantage of all possible circumstances, and to adjust to new conditions." Perhaps the clearest refutation of vitalism would be the creation of a living organism by completely synthetic means out of simple chemical elements. Disturbing and convincing as such an experiment might be, no doubt a resourceful vitalist would claim that even this system was taken over by a life force. Vitalistic views, old as well as new, replete with misconceptions and defying examination by objective criteria, are of little value in helping us to understand biology.

As you read this book, you will see that most of the processes having to do with life that we do understand can be explained in terms of chemistry and physics. Those we do not yet understand are potentially explicable in these terms. Superstition and vitalism were early attempts to explain away things that could not be understood at the time because physics and chemistry had not yet advanced far enough.

the production of living material from the nonliving: sweaty shirts stored with wheat in a dark place were supposed to give rise to mice, the hairs of a horse's tail when placed in water produced worms, and decaying meat gave rise to maggots (fly larvae). The strangest part about these recipes was that they really appeared to work!

In 1668 an Italian physician and poet named Francesco Redi (Figure 1–1) performed a simple but classic test that shook the foundations of the doctrine of spontaneous generation. Where others were content to observe nature and suggest imaginative explanations for various phenomena, Redi was not content merely to observe natural phenomena as they occurred, but he set out to test ideas and to arrange some of the components of nature so that analysis of phenomena could be made; in short, he did an **experiment.** Redi arranged three jars of decaying meat; one of the jars he covered with gauze, another was covered with parchment, and the third was left uncovered. Flies were attracted to the meat samples in the gauze- and parchment-covered jars, but could land only on the meat in the open jar; in this jar maggots developed, but not in either of the others. Decaying meat in itself did not give rise to maggots, he concluded. It was necessary for flies to land on the meat and deposit their eggs, which subsequently hatched and gave rise to maggots.

This simple refutation of the generation of life from substances such as rotting meat held sway for only a short time. In 1675 a Dutch linen merchant with a penchant for grinding magnifying lenses, Anton van Leeuwenhoek (Figure 1–2), found that his lenses showed living microscopic creatures in rainwater. Broth too would give rise to all sorts of living creatures if one waited for a while. The resourceful defenders of spontaneous generation argued that although one could not get worms, flies,