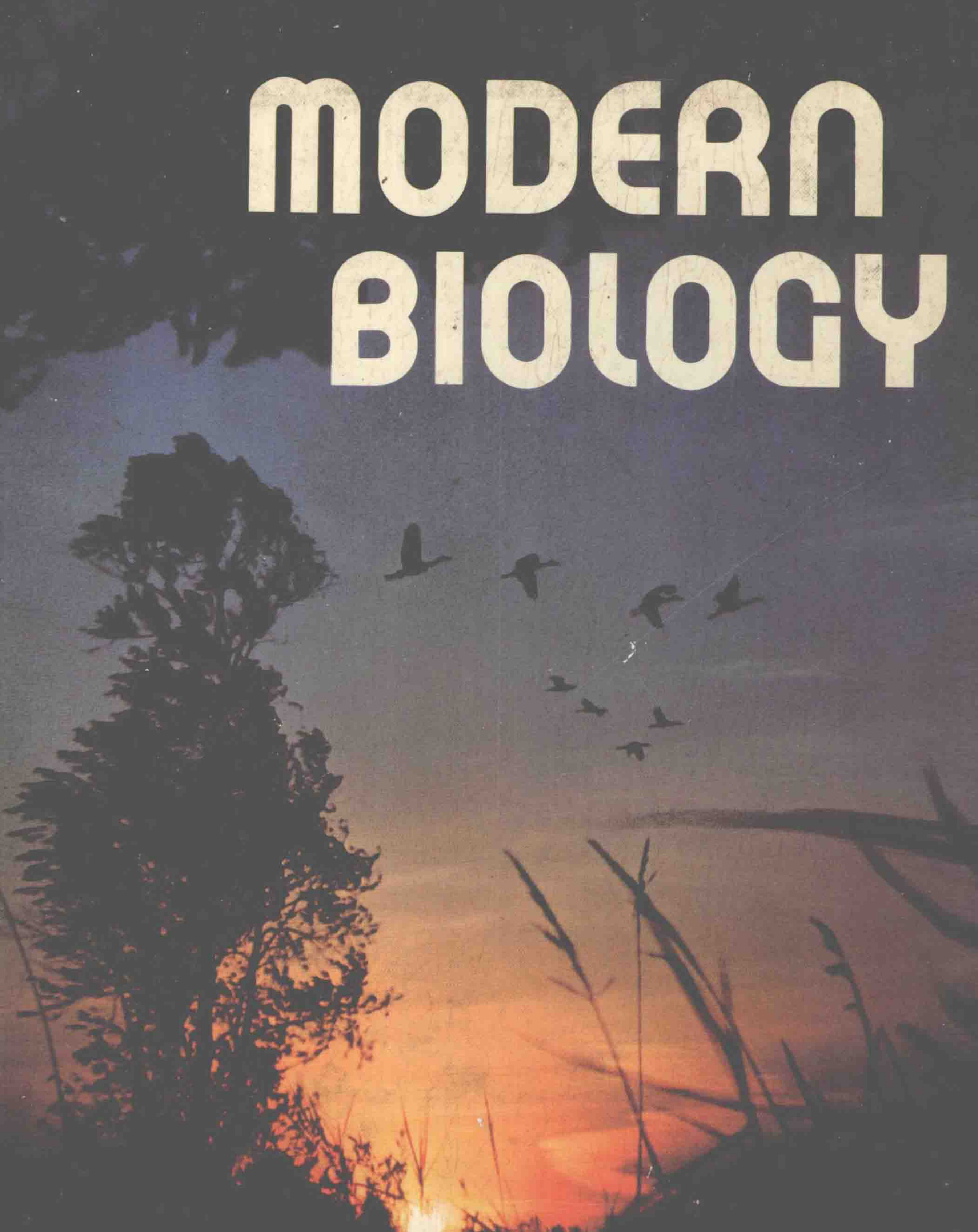
MODERN BIOLOGY



JAMES H. OTTO
ALBERT TOWLE

MODERN BIOLOGY

HOLT, RINEHART and WINSTON, INC.
NEW YORK • LONDON • TORONTO • SYDNEY

James H. Otto
is a biology teacher and head of the Science Department at George Washington High School, Indianapolis, Indiana.

Albert Towle
is a professor of biology and supervisor of biology student teachers at California State University, San Francisco, California.

Cover photograph *Dan Morrill*

Unit opening photographs

1 *Alvin E. Staffan, National Audubon Society*
2 *Photo courtesy of The American Museum of Natural History*
3 *Eric Gravé, Photo Researchers, Inc.*
4 *E. Ellingsen*
6 *N. Smythe, National Audubon Society*
7 *Russ Kinne, Photo Researchers, Inc.*
8 *Douglas Faulkner*

All other photographs are acknowledged on the page on which they appear.

Printed in the United States of America

ISBN: 0–03–091337–3

56 032 98765

PREFACE

With the flood of new knowledge produced by greatly accelerated biological inquiry in recent years, our picture of life has vastly greater clarity and detail than that of only one or two decades ago. Through the development of new research tools such as the electron microscope and high-speed centrifuge, and techniques for using these tools, biologists have made great advances in cellular biology. Increased knowledge of the cell and its processes has revolutionized many other areas of biology. Improved techniques in biochemistry, including the use of radioisotopes as tracer elements in biochemical reactions, have led to substantial discoveries and new concepts of life at the molecular level. Extensive research in the areas of genetics and microbiology are having far-reaching effects on the lives of all of us. Advances in these areas are bringing us ever closer to the conquest of cancer and other cellular disorders, genetic diseases and disorders and, perhaps, control of the aging process. While much of this knowledge is still at the level of research, many of the latest discoveries have had such an impact on our understanding of life that they need to be included in the high school course in biology. Ecology has taken on new meaning today. It is far more than a branch of biology. It has become a cause and a program for action. Pollution threatens our very survival in the years ahead. Young people are very much aware of this global threat.

The authors of MODERN BIOLOGY have always believed that the learning process should involve a mastery of certain fundamental concepts at the beginning of the course in biology. From these initial understandings, the progression from the cell to protists, to plants and animals, and, finally, to man will come naturally. In following this systematic approach to the study of biology, the student discovers unity in the organisms he studies. Culminating the course, the student explores the ecological relationships of living things and their environmental problems and adaptations. In the study of ecology, it is important that the student realize his place and his responsibility in the living world.

The authors have preserved the approach and methodology that have evolved successfully in thousands of secondary school classrooms and laboratories These features have been tested, tried, and proved effective by thousands of our nation's science teachers. The many professional biologists making significant discoveries in the research laboratories who have learned from earlier editions of this text are evidence of the value of such teaching methods.

MODERN BIOLOGY begins with a consideration of the living condition and discusses the unique properties of living organisms that set life apart from the nonliving. It continues with molecular and cellular biology, from which it moves logically into reproduction and genetics. An understanding of genetics gives meaning to organic variation and methods of scientific classification. Units dealing with microbiology, multicellular plants, invertebrate animal life, the vertebrate animals, and the biology of man follow in logical sequence. The final unit, dealing with ecological relationships, offers a fitting climax and overview of the entire biology course.

In the preparation of this, the eighth revision of MODERN BIOLOGY, the authors have up-dated all areas in which new knowledge is significant to the high school student. The chemistry chapter was re-written for simplification and clarity. Photosynthesis and respiration are discussed in a single chapter in order to compare the matter and energy relations of the two processes. The composition of nucleic acids and the role of DNA, messenger RNA and transfer RNA in protein synthesis are topics included in another revised chapter. A discussion of interferon, a recently discovered body defense against viruses, is included in the chapter on infectious disease. The final unit, dealing with ecology, contains new materials on soil, water, and air pollution and an expanded discussion of forest conservation measures and methods of protecting wildlife and saving endangered species.

As in previous editions of this book, the language of science has been an important consideration. Key scientific terms are included as needed. However, the general style of writing has been kept as informal as possible. The authors have tried to keep the readability in proportion with the age of the average student. Difficult words are pronounced phonetically, and all new words or terms are displayed in boldface italic type and are defined the first time they are used. Italic type is used for emphasis.

The present authors are indebted to the late Truman J. Moon, whose successful texts BIOLOGY FOR BEGINNERS and BIOLOGY were the predecessors of this book. Mr. W. David Otto, a biology teacher at the John Marshall High School in Indianapolis, revised the bibliographies at the end of chapters. The authors are indebted, also, to Dr. J. Paul Burnett of the Lilly Research Laboratories in Indianapolis for his many helpful suggestions.

In regard to the sections in MODERN BIOLOGY dealing with evolution, we feel that we have used scientific data to present this material as theory rather than fact. The information presented allows for the widest possible interpretation that can be applied to any set of values either religious or scientific. We have made every attempt to present this material in a nondogmatic fashion.

CONTENTS

CHAPTER ONE

THE SCIENCE OF LIFE

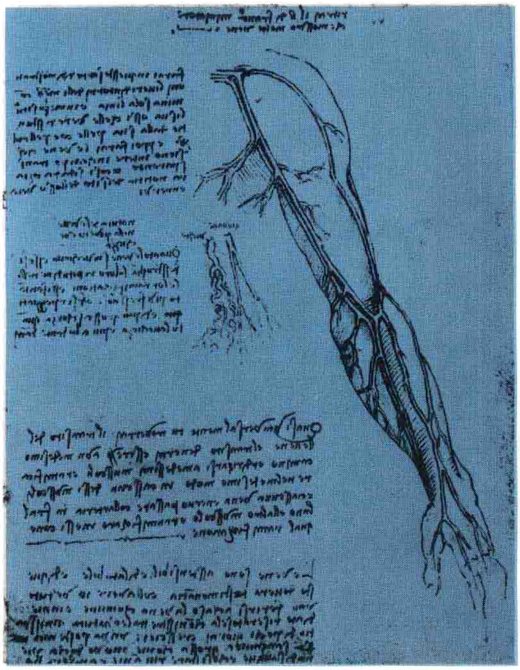
Biology in a golden age

What is biology? The word comes from the Greek *bios,* meaning "life," and *logos,* meaning "study of" or "science of." Biology is the knowledge about living things that has come to us from previous generations and to which the biologists of our time are contributing. Like the other sciences, biology is a method of investigating events and problems we need to understand and to solve. Biology arose out of man's curiosity about himself and other living things and out of his need to survive and to improve his condition on the planet Earth.

Biology, again like the other sciences, is pushing forward with unbelievable speed. It is no exaggeration to say that we have gained more biological knowledge in the past twenty years than in the previous twenty centuries! Biology is truly in a golden age. Why this sudden explosion of knowledge in our time? Let us examine the position of biology today and see if we can discover what lies behind its many achievements in recent years.

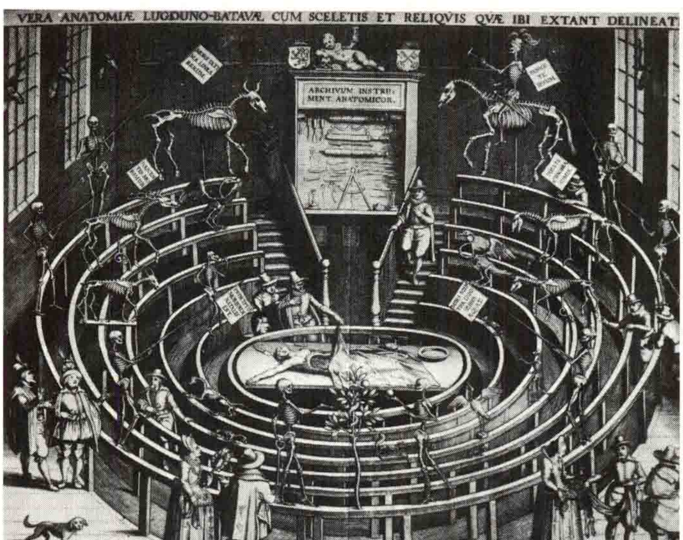
■ *Science has an international heritage.* With the coming of the Renaissance, science began to develop on a worldwide scale. Slowly at first, but with increasing pace, scientists pushed back the barriers of ignorance, superstition, and prejudiced thinking that during the Middle Ages had stifled man's search for understanding. In the sixteenth century, a Belgian medical student, Andreas Vesalius, rebelled against the methods that characterized medieval medicine and established a scientific study of anatomy (Figure 1-1).

In the seventeenth century, William Harvey, an English physician, questioned the ancient belief that blood ebbed and flowed in the veins of the body like the tides of the sea. He proposed instead that it circulated through both the arteries and the veins. Later in that same century, Marcello Malpighi (mahl-PEEG-ee), an Italian scientist, used a microscope and saw in the lung of a frog the capillaries that completed the path between the arteries and veins. This observation provided vital support for Harvey's

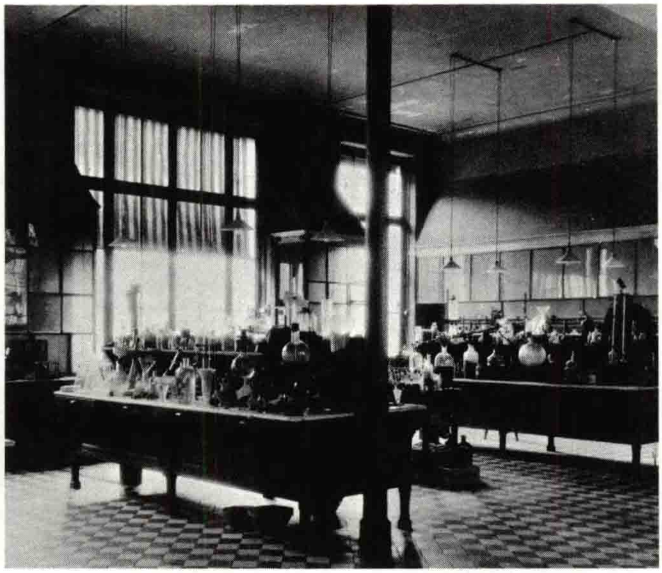


1-1 Anatomical research and drawings by Leonardo da Vinci (such as the drawing at the left) earned such admiration and respect that they laid the groundwork for the anatomical research of Vesalius (right). (courtesy IBM Corporation; The Granger Collection)

theory of circulation. Harvey's contribution is today regarded as the first major achievement of modern physiology—an important branch of biology.



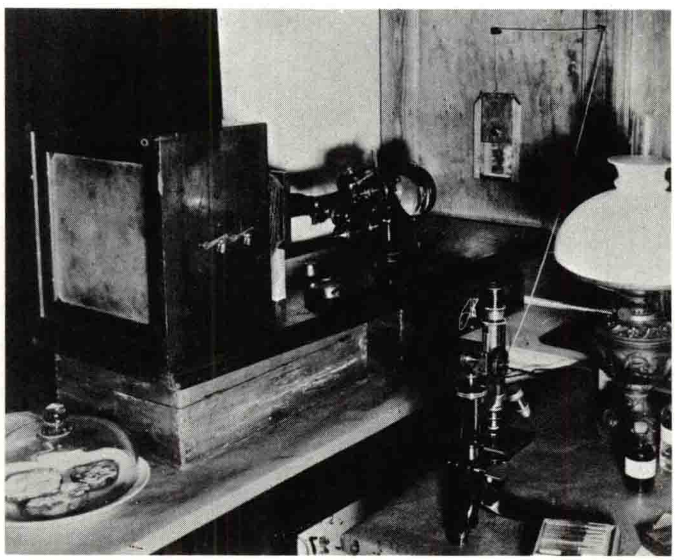
1-2 By the early 1600's, in certain cities of Europe, such as Leyden, it had become fashionable to go to the anatomy theatre to chat. (courtesy WHO)

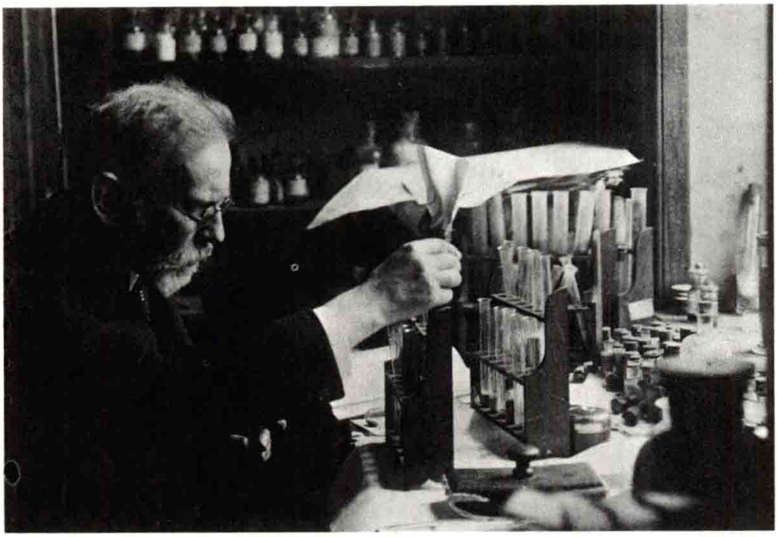


1-3 By the nineteenth century, Louis Pasteur (above left) had founded the science of bacteriology. The photograph of the laboratory for biological chemistry at the Pasteur Institute in Paris (above, right) was taken only a few years after Pasteur's death. (The Granger Collection; The Bettmann Archive)

In the eighteenth century, Edward Jenner, an English doctor, performed the first vaccination when he immunized a small boy against smallpox. In France, in the nineteenth century, Louis Pasteur established the science of bacteriology. A few years later, Robert Koch (KOK) of Germany gave the world the means to investigate infectious diseases by developing techniques for culturing disease-causing bacteria in the laboratory. A century ago, Gregor Mendel (MEND'l), an Austrian monk, conducted

1-4 Robert Koch discovered how to culture disease-causing bacteria in the laboratory. Identify as many materials and pieces of equipment as you can. (Culver Pictures; The Bettmann Archive)





1-5 In the early 1900's, Paul Ehrlich made the first major contribution in the field of chemotherapy. (Culver Pictures)

1-6 Some twenty years later, Sir Alexander Fleming (shown in his laboratory) discovered penicillin, the first modern-day antibiotic.

his famous breeding experiments with peas. Out of his work came several ideas that still serve as the basis for much of the modern science of heredity. In 1909, the German doctor Paul Ehrlich discovered "606," an arsenic compound that would kill the syphilis-causing organism in the human bloodstream. This triumph ushered in the age of chemotherapy in medicine. In 1929, a Scottish physician and bacteriologist, Sir Alexander Fleming, discovered penicillin, the first of a long line of life-saving antibiotics.

■ *Science gradually supplanted superstition and prejudice.* Man is curious by nature. He has always sought explanations for

1-7 Part of a recipe for cough medicine. This page is taken from a thirteenth-century Arabic translation of De Materia Medica, a systematic, 5 volume pharmacopoeia compiled by Dioscorides, a Greek physician and surgeon of the first century. This source, among others, served as an inspiration for later botanical research. (Metropolitan Museum of Art, Rogers Fund, 1913) the events and phenomena he could not understand. In early times, he was satisfied with answers unsupported by logic or fact, generally arrived at by guesswork or superstitious beliefs. For example, people's lives were supposedly influenced by the position of heavenly bodies at the hour of birth. Did anyone ever find any evidence for this belief? Did anyone even try? As another example, the mud in ponds was supposedly transformed into eels, fish, and frogs. The air from a marsh was thought to cause malaria, which means, literally, "bad air."

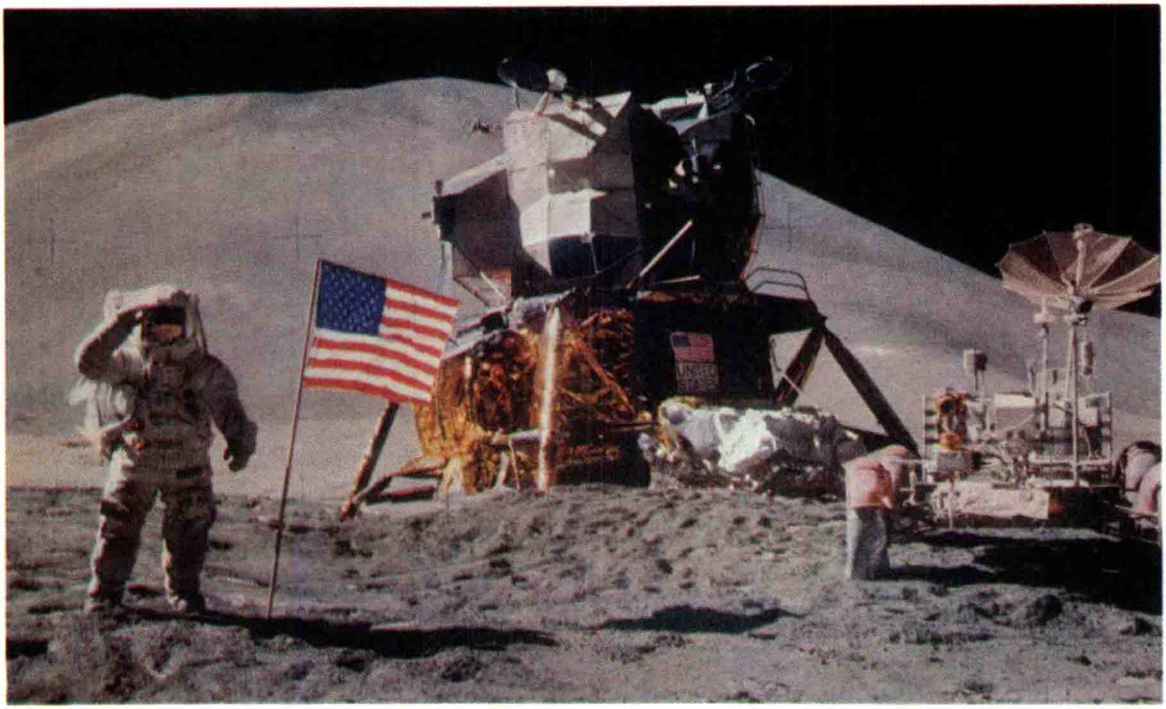
It took several centuries to throw off the yoke of superstition and prejudice and establish a new system of objective thinking and investigation. With the new system came scientific freedom: freedom to investigate; freedom to prove and disprove; freedom to base conclusions on observed facts.

■ *Science is a vast body of knowledge.* The fruits of scientific research and investigation are knowledge and understanding. Each generation of scientists receives a heritage of information from preceding generations. This provides the basis for new investigation that will add to the body of knowledge for following generations.

There is no end to scientific exploration. The solving of one problem points to the need for further investigation. You might think of scientific knowledge as a circle of light in a sea of darkness. Through the centuries, the scientists of many nations have expanded this circle enormously. But as the circle has expanded, the size of its perimeter, or the fringe of knowledge, has also increased. In other words, in our circle of biological understanding, the more we learn about life, the more we find remains to be discovered.

■ *Science has progressed at a remarkable rate in areas related to biology.* At one time, definite lines could be drawn between the major areas of science. Today no such separations exist; all scientific knowledge is interrelated. Can we separate chemistry from biology? As you study the organization of the many substances involved in the living condition, you may be surprised to find that everything about life as the biologist has come to understand it can be considered in terms of a vastly complex biochemical system. Growth, response, and heredity all result from chemical activity. In the last analysis, life is chemical in that it involves matter and changes in matter. Life also involves energy changes. The forces that govern the changes in the matter of our earth have a vital influence on all of life.

Can we separate physics, and space science, and earth science, and oceanography from biology? Satellites sent aloft are sending back information that is changing many of our concepts of the earth. The earth is flattened at the poles and bulges at the equator. Its surface has great raised areas and depressions far more extensive than mountain ranges and valleys. Its crust varies in thickness. Oceanographers are exploring the ocean depths



1-8 The moon "rover" was used to help the astronauts explore the surface of the moon. (NASA)

and plotting great currents that circulate water throughout the expanse of the seas. Do all these factors have a profound influence on life and the distribution of living things over the face of the earth? Only in time will the answers become known. These answers will not come easily—they will be found only through the efforts of many generations of biologists and other scientists to come.

■ *The scientist has begun to recognize his own limitations.* In the Middle Ages, "scientific truths" handed down from earlier times were not to be questioned, much less disputed or disproved. Many who dared to disagree with the established authority were ridiculed, persecuted, or forced to flee. Even a generation ago, science was believed to be much more exact than it is known to be today. Fortunately, we no longer consider a scientific explanation to be a final answer. We know that any concept must be held subject to change and revision in the light of new discoveries.

■ *The public has come to accept and support modern science.* Two hundred years ago, townspeople threw rocks at Dr. Edward Jenner when he vaccinated a boy against smallpox, probably saving his life. One hundred years ago, people ridiculed Louis Pasteur when he tried to convince them that invisible microbes were the cause of infectious disease. Today, both these great scientists of the past would undoubtedly receive Nobel prizes for their outstanding contributions to humanity, for our society not only accepts modern science, it also actively supports research programs.

Scientific methods

A scientific method is a logical and orderly procedure of inquiry and investigation. Actually, it is nothing more than the systematic use of common sense. It is this particular method of inquiry that distinguishes scientific study from curious dabbling and hit-or-miss efforts to solve a problem. However, scientific methods are not magic formulas that always lead to solution of a problem. On the contrary, the best-planned, most carefully done scientific experiment can and often does end in failure. But even numerous failures may lead the scientist to final success, since he analyzes each result in the hope of finding a new direction in which to continue his work before he goes on with his investigation. Often this change of direction leads to an even more important discovery than the scientist originally expected.

A number of methods are used in scientific study, depending on the nature of the problem. We shall consider two of these, since both will be used in your biology course.

1-9 Cecilia Wen-Ya Lo won the first-place scholarship in the Westinghouse Science Talent Search for her research on the process of aging. (courtesy of Westinghouse Corporation)

The research method

In the ***research method,*** the scientist plans an experiment and outlines the procedure he intends to carry out. It is by this method that new knowledge is gained and new concepts are established. You will have opportunities to use the research method in many phases of your study of biology. A research experiment may be performed by the class, by a group, or by an individual in an area of special interest (Figure 1-9).

The steps a scientist follows in investigating a problem are logical and orderly:

- *Define the problem.* First of all, scientific research calls for an inquisitive mind and the ability to recognize a problem. For example, how does a root absorb water from the soil? How does light affect the growth of a stem, causing it to bend toward the light? How does a nerve stimulate a muscle and cause it to contract? What controls the rhythmic contractions of the heart? Each of these questions can be answered through well-planned experiments. Problems arise continually in the study of science, and new problems grow out of solutions. In this way successful research leads to new research and to new knowledge.
- *Collect information relating to the problem.* The scientist does not set out to resolve personally every single aspect of a problem. If he did, science could not progress beyond the limited achievement of a single lifetime. Before beginning an experimentation, the research investigator makes use of all important data and information that relate to the problem. This saves dupli-

cation of effort and repetition of work already done. Thus, an extensive library of research papers, scientific journals, and reference books is an important part of a research center. Your textbook and laboratory guide together with supplementary readings will serve as sources of information in solving biological problems in your course.

■ *Formulate a hypothesis.* When available information fails to yield an explanation of the problem, it becomes necessary for the researcher to proceed further by means of experimentation. At this point, he uses his own creative thinking and reasoning to set forth in statement form a tentative explanation or a trial solution for the problem. This statement is called a ***hypothesis.*** It might also be called a scientific hunch or an educated guess. However, while the hypothesis may seem to be a reasonable solution or result in the light of known facts, it cannot be accepted until supported by a large base of evidence. Thus, the research worker must not only be imaginative enough to work out a hypothesis but also open-minded enough to modify or discard it if the evidence fails to support it.

■ *Experiment to test the hypothesis.* The scientist must set up an experiment in which the hypothesis will either be supported or contradicted. While it is often difficult to do, all factors except the one to be tested must be removed or accounted for. We refer to this one factor as the ***single variable,*** or ***experimental factor.*** In other words, the researcher must limit his experiment to the testing of only one condition – the one involved in the hypothesis. Frequently, an experiment is conducted in duplicate, with all factors the same in the second experiment except for the experimental factor. This second, or ***control,*** experiment demonstrates the importance of the missing experimental factor.

■ *Observe the experiment.* What does the experiment prove? What does it disprove? At this point, the scientist must use critical observation. What are the results in relation to the hypothesis? Bear in mind that the experiment that does not work as planned often yields results even more important than those expected.

■ *Organize and record data from an experiment.* Every phase of the experiment – the way it was planned and set up, the conditions under which it was conducted, significant observations made during its progress, and the results – must be recorded accurately. This record may be in the form of notes, drawings, tables, graphs, calculations, or some combination of these. In modern research, data are often processed by means of computers.

■ *Draw conclusions.* Scientific data are valuable only when they are put to use. This is accomplished by drawing valid conclusions from experimental evidence. Such conclusions must be based *entirely* on facts demonstrated in the experiment. If experimental evidence continues to support the hypothesis over a period of time, the hypothesis may come to be called a ***theory.***

■ *Accurately report research methods, results, and conclusions.* Results of scientific research are frequently published in papers and journals, thus becoming valuable contributions to scientific literature. To publish results is a recognized obligation of research scientists. Through the literature, scientists the world over are kept informed of significant developments in their particular fields, and of new research in progress. This cooperative exchange of information saves effort, time, and money and speeds up scientific progress.

Conducting a controlled experiment by the research method

We can illustrate the steps followed in the research method by considering a simple controlled experiment that you can conduct in the laboratory. The experiment will involve the growth and development of bean seedlings. It will relate to one environmental factor – light. We can define the problem in this way: *Is light necessary for the normal growth and development of a bean seedling?*

Having defined the problem, we should next examine various references in the library for information concerning the relation of light to plant growth and nutrition. Much has been written on the subject. However, you may not find a specific answer to your problem about bean seedlings.

At this point, lacking full information, you formulate a hypothesis, or tentative answer to your question. You may assume, for instance, that *light is necessary for the normal growth and development of bean seedlings.* This hypothesis must now be supported or contradicted by experimentation. A logical procedure would involve the germination and growth of two sets of bean seedlings one set in a dark place and the other placed in full light.

Two beans are planted in each of six three-inch pots filled with loose, sandy soil. Three of the pots are marked *experimental* and are placed in a dark cupboard. The other three pots are marked *control* and are set on a window shelf or in some other place where they will receive full light. The temperature should be as nearly uniform as possible in the two locations. The soil in each of the pots must be watered regularly and uniformly throughout the experiment, which lasts about four weeks.

As the experiment progresses, accurate observations must be made each day of the condition of each seedling. The date on which each seed sprouts should be recorded. You should also determine daily and record in a table the length and diameter of the stems, the number and size of the leaves, and the color of the plants.

It is likely that there will be striking differences between the two sets of plants. Those grown in the light probably will have