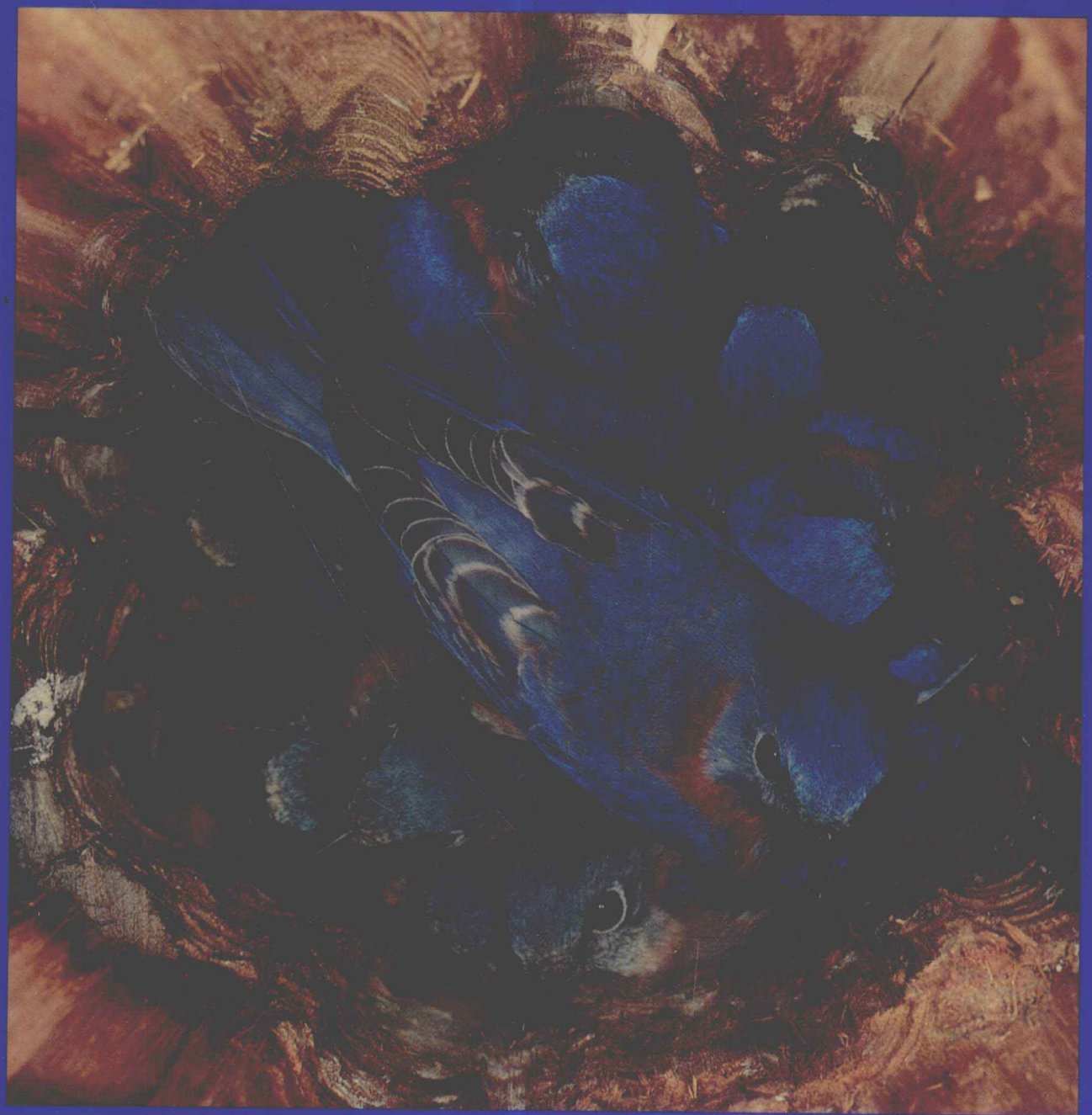

LEVINE / MILLER

BIOLOGY

BIOLOGY

Discovering Life

Joseph S. Levine

Kenneth R. Miller
Brown University

D. C. HEATH AND COMPANY
Lexington, Massachusetts Toronto

Authors' Dedication
To Carol and Bob, Marion and Ray, our parents, who gave us our lives, the best of our values, our love of learning, and our appreciation for the importance of education in a complex world.

Publisher's Dedication
All of us involved with this project will remember with affection Mary Le Quesne, our editor, mentor, and friend. Her enthusiasm, laughter, and love of publishing will remain an inspiration to all who worked with her.

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Joseph S. Levine

Joseph Levine completed his undergraduate work at Tufts University, obtained a Master's degree at the Boston University Marine Program, and received his Ph.D. from Harvard University. Joe developed innovative laboratory and lecture courses in biology at several schools, including Tufts, Harvard, and Boston College. His research on the physiology, ecology, and evolution of visual systems in aquatic animals has appeared in journals ranging from *Science* to *Scientific American*.

Actively involved in several pursuits that combine education with his research interests, Joe has served as advisor for the PBS series "Living Wild" and "NOVA." During a fellowship at WGBH in Boston, he coproduced the prime-time *Science Gazette* and science features for National Public Radio's "Morning Edition," and "All Things Considered." With the NOVA staff, he assembled a proposal for a series on molecular biology entitled "Life: Cracking the Code." He has also served as senior program designer for state aquarium projects in Texas, New Jersey, and Florida, and conceived an AIDS awareness exhibit for the California Museum of Science and Industry in Los Angeles.

Joe is currently vice president of Boston Science Communications, Inc., specializing in the production of educational films, videos, and multimedia educational products, and he is an associate at the Museum of Comparative Zoology at Harvard University.

Kenneth R. Miller

Professor of Biology at Brown University, Ken Miller is a plant cell biologist. Miller completed his undergraduate work in biology at Brown University and was awarded a Ph.D. in biology from the University of Colorado. His teaching credits include Harvard University, the University of Colorado, and Brown University, where he currently teaches biology to both majors and nonmajors.

Ken is editor-in-chief of *Advances in Cell Biology*, editor of *Journal of Cell Science*, and former editor of *Journal of Cell Biology*. He is also chairman of the Education Committee of the American Society for Cell Biology. Professor Miller has published over 50 articles in professional and lay scientific journals. Among his recent published work are a cover story on photosynthesis in *Nature* and articles in *Scientific American*, *Journal of Cell Biology*, *Proceedings of the National Academy of Science*, *Endeavor*, and *Trends in Biochemical Sciences*.

A nationally recognized spokesman for evolution in the evolution–creation controversy, Ken Miller maintains an active involvement in the public examination of this issue.

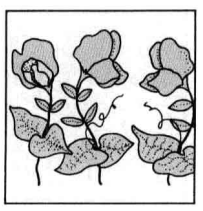
PREFACE

A growing number of people in this country have no understanding of science whatsoever; they either believe in science or they don't believe in science, just as they either believe in ghosts or don't believe in ghosts. They therefore treat science as a belief system—not unlike superstition—rather than as a way of interacting with the world in a rational manner. To remedy this situation in biology without making drastic changes in the body of material generally covered in introductory courses, we have employed three techniques. One is to lead students through narratives of observation, inquiry, discovery, controversy, and social relevance, rather than to present them with a list of "established" facts and conclusions. The second approach, wherever the subject matter permits, is to place the student directly in the midst of current research in a way that gives a sense of involvement and immediacy with the material. The third approach is to structure the entire book with a student's world view in mind. We believe strongly that students are most easily brought into a study of biology by biology itself.

Structure of the Text

Our book opens with an examination of biology and the nature of science (Part One: Introduction to Biology), and then immediately moves on to Organisms and Ecology (Part Two). This contrasts sharply with an approach that buries students in several chapters on chemistry before they are allowed to glimpse biology itself.

We do attach great importance to the study of essential chemistry, and have covered it thoroughly. We have, however, placed biological chemistry in its proper historical and scientific context. Chemistry was originally quite separate from biology, and chemical concepts were incorporated into biological studies only gradually. Evolutionary theory and Mendelian genetics, two cornerstones of nineteenth century biology, for example, developed without the aid of chemistry and were largely responsible for the interest of biologists in the chemical nature of genes and living cells. Our sequence of presentation (coverage of biological chemistry after genetics and evolution) thus allows students to follow in researchers' footsteps and to appreciate the need for understanding the chemical nature of life. We feel from our own experience that this approach not only demystifies chemistry, but grounds this most abstract of subjects in a biological reality to which students can relate.



We also take into account the reality that some students entering introductory classes may not have had sufficient exposure to evolutionary thought. Our solution to this problem is to structure our section on Mendelian Genetics and Evolution (Part Three) differently than most other books. We begin with a historical narrative that explains the Western philosophical world view before Darwin, details the intellectual and philosophical leaps Darwin and his contemporaries had to make, and progresses through a long list of evidence that evolution has occurred. We raise Darwin's vital questions about the nature of inheritance as an introduction to a historical and experimental approach to Mendelian and population genetics. Only then do we discuss the more esoteric details of modern evolutionary population genetics.

Throughout this process, we link biology not only to other sciences, but to philosophy, sociology, and other disciplines in the humanities as well. We present the historical sections in a manner that allows students to trace the development of vital ideas in biology. We regularly introduce experimental evidence to explain the thought processes that have expanded and changed our understanding over time.

We then present the Diversity of Life section (Part Four) in the format of an "Evolutionary History of Life." Here, aided by a unique illustration package, we present two parallel tracks of information: the evolutionary history of major groups of organisms, and the salient anatomical details of each group. By so doing, we have tied this often disjointed material together into a narrative that stresses the evolutionary interactions between organisms and their changing environments and between plants and animals. These chapters should thus be particularly welcomed by professors who emphasize evolutionary processes rather than classification and anatomical details. At the same time, we are confident that the special illustrations we have developed for these chapters

will be valuable teaching and study aids in those classes where anatomy and life-cycles are accentuated.

As mentioned previously, we have tried to place the importance of chemical principles more in context and have used our treatment of genetics covered in Part Three to develop a sense of interest in biochemistry. We hope that students will begin this section, The Molecules of Life (Part Five), wondering about the chemical nature of the gene, interested in how genotype actually determines phenotype, and curious about the mechanisms by which genes exert their effects.

Each of the chapters in Part Five explores one aspect of the connections between the material world and the living world. At first, these connections are on the most basic level: the nature of chemical reactions, the role of energy in biochemistry, and the structure of macromolecules. Gradually, however, these connections become more profound. We have made a special effort to involve the reader in the process of discovery, which led to the double helix model of DNA structure, and this approach extends to advanced topics in molecular biology as well. In addition to writing these chapters to emphasize how we know what we know, we also make the point that there is still a great deal we do *not* understand.

Throughout the text, we have emphasized the unity of living organisms. Plants and animals are used freely as examples for important concepts in genetics, molecular biology, evolution, and ecology. Despite this evenhanded emphasis on the diversity of life, there are a number of key concepts in plant development and physiology that are best dealt with in a specialized way. The four chapters in our Plant Systems Section (Part Six) ask what it is like to be a plant. In their own way, each chapter challenges the reader to imagine the life of a plant and the ways in which plants respond to their environment. By placing this section immediately after material on biological energy and molecular biology, we are able to examine the central role of bioenergetics and molecular biology in the study of plants, and to connect plants to the rest of the living world. The physiological principles emphasized in this section also pave the way for a discussion of animal physiology in the section to follow.

The final section, Animal Systems (Part Seven), includes 13 chapters that cover the field of organismal physiology from basic concepts of homeostasis through animal behavior. While most of these chapters follow more or less traditional organization, each, we feel, brings a fresh, up-to-date, and vigorous approach to the material. Not only do we include the latest discoveries in such rapidly changing areas as development, cancer, and AIDS, but we relate these developments to breakthroughs in other areas covered earlier in the text. Our coverage of immunology begins with a historical look at biology, medicine, and disease, and proceeds through the latest developments in this dynamic and vitally important area. The chapters on the nervous, sensory, and muscular systems lead logically and progressively up to an integrated treatment of animal behavior that concludes the book.

We believe that this overall structure, which many instructors throughout the country have used successfully, is the best way to present biology to the mix of nonscience *and* science concentrators enrolled in the introductory biology course. Nonetheless, we realize that there is more than one way to teach biology effectively. We have therefore organized our sections in a modular fashion that allows skipping around to suit an individually designed presentation.

We hope that this book will bring to your students some of the excitement and passion scientists bring to their work. If we can help you as instructors to pass this knowledge to a new generation of students, the kindness of the people who have shared their gifts with both of us in the past will be partly repaid. More than that, no teacher or former student can ask.

Comprehensive Teaching and Learning Package

The following supplements accompany *Biology: Discovering Life:*

- Study Guide by George Karleskint, Jr. (12009–X)
- Instructor's Guide by Gail R. Patt (12014–6)
- Investigations in Biology by Richard J. Montgomery and William D. Elliott (12010–3)
- Instructor's Guide for Investigations in Biology by Richard J. Montgomery and William D. Elliott (24447–3)
- Test Item File by Bernard L. Frye and Joyce A. Blinn (12011–1)
- D. C. Heath Exam Computerized Test Bank for IBM PC, Apple, and Macintosh
- Transparencies with Transparency Lecture Guide by George Karleskint, Jr. (12012–X)

Acknowledgments

Each of us once thought that textbook writing was a solitary art. From time to time, as we worked quietly on drafts of this book, it was possible to entertain the notion that this might be true. As *Biology: Discovering Life* neared the final stages, however, the folly of this idea became clear. We are enormously grateful for the kindness and support of our many scientific friends and colleagues who contributed time, advice, photographs, and encouragement to this project. We are also grateful for the patient understanding of the friends, family members, and children who endured our seeming lack of interest in anything outside this project for months at a time. In many ways, they have made the greatest sacrifice associated with this project, and we will always be in their debt.

We soon grew to appreciate the talented work of the editors, artists, photo researchers, and production workers who made this book a reality. There were a few disagreements and (in retrospect) laughable squabbles. But every page of this book is the carefully crafted work of a small army of skilled and dedicated individuals. Throughout this project, we have felt ourselves lucky to know and work with dozens of people who are the very best in their fields. We are fortunate to have made these associations, and we know that the book has become a joint product in which many people take justifiable pride.

Our thanks go out to the entire staff at D. C. Heath, especially to the late Mary Le Quesne, the senior acquisitions editor who played a vital role in the development of this project. Her love of the material, her dedication to her work, her warmth of spirit, and her unflagging enthusiasm in the face of terminal cancer inspired us and all of her co-workers at Heath.

We have also learned that during a writing and publishing project as long as this one, there are invariably significant staff changes. Luckily for us and for the quality of this book, the members of our supervisory group at Heath were not only of the highest professional caliber but also dedicated themselves totally to our project. We gratefully acknowledge the extraordinary level of commitment and the highly skilled and successful labors of Kent Porter Hamann, editorial director; Kathi Prancan and Elizabeth Coolidge-Stolz, acquisitions editors; Barbara Withington Meglis, developmental editor; and Cormac Morrissey, production editor. All of these people were brought into the project after it had already taken shape but early enough for the quality of their work to influence it powerfully. We also want to acknowledge the contribution of Cornelia Boynton, Laurel Smith, and Gary Crespo, who lent their remarkable artistic vision to a staggeringly complex illustration program. We thank them all heartily.

J.S.L.
K.R.M.

TO THE STUDENT

You are living in the midst of a revolution—a revolution in our understanding of life. As this revolution progresses, it will forever change the relationship between biology and human society because it will involve all the practical applications of biological knowledge. These applications span the full spectrum of human concerns, from the desperate battle against AIDS, to debates concerning the uniqueness of the human mind, to actions that affect the future of your life and all life on earth.

Part of this revolution has been launched by breakthroughs in our understanding of the molecules that make up living tissue. On this submicroscopic frontier, our challenge is to understand how genes do the many things they do: create our cells, direct those cells to form bones in our legs and thoughts in our brains, change with age, and evolve from generation to generation. Tied into this research, the fledgling biotechnology industry promises to revolutionize the way we grow our food, the way we are born, and the way we die.

At the other extreme of life's phenomena, on a scale so vast that it encompasses our entire planet, our challenge is to protect the global environments that give us life. Ecologists have discovered that some of our actions may be causing a planet-wide climate change whose long-term effects we can scarcely comprehend. Other human activities are destroying Earth's protective ozone layer. And still others are threatening the supplies of clean air, drinkable water, and food so vital to Earth's constantly growing human population.

The biological revolution has already begun to bestow on us a range of potent techniques and capabilities that just a decade ago existed only in the realm of science fiction. But the promise of these newfound powers carries with it the responsibility to use these powers wisely. Genetic engineering raises serious ecological, legal, and moral questions about the creation of new life forms. Biomedicine, too, confronts sobering dilemmas: Is it worth opening an ethical Pandora's box if we can cure genetic disease by altering human DNA? How can we weigh moral concerns about human embryo experimentation against possible practical benefits?

This book will not presume to answer these or other socially vital questions for you. As authors and teachers we hope to provide you with enough information about the biology behind these issues to allow you to examine these problems critically and to participate in essential public debate about them. To accomplish these goals, we intend to propel your understanding of biology beyond media images of laboratory-created monsters, imminent catastrophes in global ecology, and miracle cancer cures.

And finally, we want to share with you the excitement and vitality that we, as biologists, see in our field. In many other disciplines, where exciting times and events seem out of reach, locked in the past, the present may appear ordinary by comparison. But that isn't true in biology today. To prove it, we invite you to partake in the delight and the excitement, the gifts and the dangers, of a revolution still very much in progress.

J.S.L.
K.R.M.

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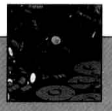
CHAPTER 2

Science and Society



When Mark O'Donnell of Holbrook, Massachusetts, was a boy, he and his friends loved to play in the fields they called "the pastures." The pastures seemed to be a children's wilderness paradise, offering several acres to roam around in and all sorts of things to play with. Among the kids' favorite toys were abandoned barrels filled with a green, jelly-like substance they called "moon glob." Mark and his best friend spent many happy hours rolling in empty barrels and tossing handfuls of moon glob at each other.

At age 27, Mark was diagnosed as suffering from an extremely rare cancer of the adrenal glands. He died a year later. Mark's best friend now has Hodgkin's disease, a painless but usually fatal cancer that attacks cells of the immune system. Within a 3-year period, 10 other young people in that same small town—most of whom played with Mark in the pastures—were also diagnosed with cancer. And on one street not too far from Mark's house, a woman died of breast cancer in nearly every other house.

Then, in 1982, an evening news program listed a chemical plant near the pastures as among the most toxic places in the nation. Within minutes, Mark's mother Joanne got a phone call. "That's what got Mark," her friend said. It didn't take long for Joanne O'Donnell to become the town's most outspoken environmentalist, campaigning to close down the plant. In addition to dumping toxic compounds onto the ground, it turned out, the plant had also regularly poured chemicals into a brook that fed the local reservoir.

THE IMPACT OF SCIENCE ON SOCIETY

The point of the Mark O'Donnell story is that although some issues pertaining to science and technology stay neatly tucked away in laboratories or in textbooks, others thrust themselves into our daily lives. In order that we not become pawns in a chess game whose rules we do not understand, all of us must be familiar enough with scientific information to evaluate what is relevant to us. Joanne O'Donnell wasn't trained as an ecologist. She hadn't even given environmental issues much thought before Mark's illness. Nonetheless, because of events around her, she found herself drawn into a tangle of legal and scientific issues surrounding the toxicity and cancer-causing potential of such compounds as dioxin, arsenic, DDT, and chlordane (Figure 2.1).

The O'Donnells' experience, in addition to providing a tragic story about toxic wastes and personal loss, is also a parable for many more interactions between society and scientific matters. Our lives will be far safer and more enjoyable if we can control the way science and technology affect us, rather than turning to science (and to the courts) to seek redress after something has gone awry.

Joanne O'Donnell has been able to win some battles, but only in a limited sense. True, the plant has been closed, and the Environmental Protection Agency has placed the pastures and the plant high on its superfund cleanup list. It is also true that the company that is alleged to have polluted the local reservoir faces several negligence lawsuits stemming from deaths such as Mark's. That corporation, however, has declared itself bankrupt, and its top officials have maneuvered legally to protect their personal assets. But the O'Donnell family's most treasured assets weren't financial; they were each other. And in addition to the loss of Mark, one of Joanne's daughters has lost her spleen, another has had a tumor removed

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■ Between us, we've taught biology courses for majors and non-majors for more than 25 years. We've discovered that both groups of students share an appreciation for teaching that begins with their own experiences and then leads gradually into the key scientific questions of the day.

We start each chapter by making exactly those sorts of connections. They will engage your students and prepare them for the material that follows.

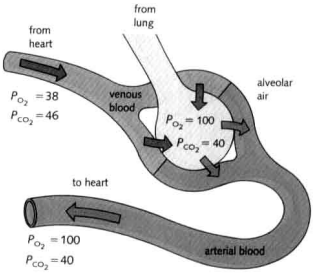


Figure 33.15 Because the lungs are not completely emptied with each breath, oxygen in the alveolus has a partial pressure (PO_2) of 100 mm. The movement of gases between capillaries and alveoli gives blood leaving the alveoli different partial pressures of oxygen and carbon dioxide than the blood that enters the alveoli.

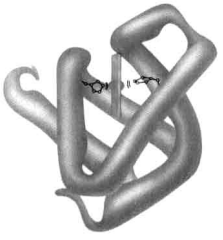


Figure 33.16 Oxygen is stored in muscle and other tissues by binding to myoglobin, a protein containing a single oxygen-binding site.

...re is low. There ...o it is free to dif... ...ssues. ...o and out of the ...n circumstances. ...heric pressure is ... partial pressure ...ailable to diffuse ...ncy of oxygen in ...e, an individual ...ning that a larger ...r, at levels above ...h oxygen into the ...nds, and special ...ry. ...confronted with ... must be trans... ... the blood of the ...mother and off... ... intimate contact ...here oxygen and ...ulation to that of ...s of mother and ...n transfer would ...ieved would be a ...ulations. ...cells of the fetus ...which has a higher ...emoglobin. This ... at the same par... ...noglobin releases ... from mother to fetus is rapid and effective. Shortly before the animal is born and starts to breathe for itself, the body begins to synthesize the adult form of hemoglobin.

Skeletal muscle cells of the body face a similar problem. They need to draw large amounts of oxygen from the blood, and they do so in much the same way. These cells draw oxygen from the circulation and maintain their own stores of oxygen in the tissue. **Myoglobin,** a protein very similar to hemoglobin, is stored in skeletal muscle cytoplasm (Figure 33.16). Each myoglobin molecule binds a single molecule of oxygen, allowing a reserve of oxygen to be built up within the muscle cell. This reserve is released when the partial pressure of oxygen within the cell drops, as it does during vigorous exercise.

The binding curve for myoglobin shows that it, like fetal hemoglobin, has a greater affinity for oxygen than does adult hemoglobin. This ensures that myoglobin will bind to oxygen at partial pressures low enough for hemoglobin to release it. Thus oxygen flows into muscles efficiently. The reddish color of myoglobin, incidentally, is one of the major reasons why the meaty muscle tissue of beef is a deep, bright red. Conversely, the "white meat" of a turkey has very little myoglobin.

■ Have you ever wanted to mark a text to tell students that a topic is related to key information in another chapter?

Well, we do that. Throughout the text you'll find arrows that let the student see that another chapter contains information they might find useful.

THEORY IN ACTION

DNA: The Ultimate Fingerprint?

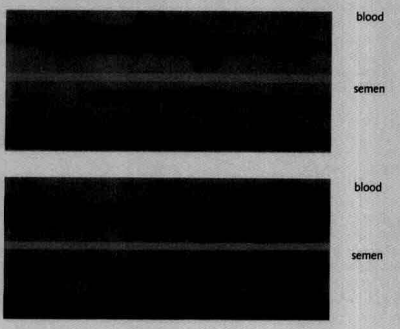
Late in the nineteenth century, law enforcement officers began to use fingerprints as a means of identifying criminals. Fingerprints are ideal for this purpose, because they differ so widely from one individual to the next. But fingerprints are useful only when a criminal leaves a number of clean, complete prints that can be matched with police records. In most crimes, fingerprint evidence is not good enough to be used for identification. Today, however, molecular biology has developed a new tool that may become the ultimate weapon of criminology: the *DNA fingerprint*.

DNA fingerprinting makes use of the fact that certain DNA regions between genes are extremely variable from one individual to the next. Many of these "hypervariable" regions contain multiple copies of simple base sequences, and the numbers of copies differ from one individual to the next: One person might have 40 repeats between two genes, another 31, and another 15. By constructing a small DNA fragment known as a *probe*, which is complementary to one of these simple sequences, researchers can examine a gel of total DNA and then use the probe to locate fragments of different sizes on that gel. If the probe recognizes a large number of fragments from around the genome, a single gel can produce a "fingerprint" that is unique for one individual. If two probes are used, the resulting gel pattern is so specific that it can be distinguished from the pattern of any other individual in the world.

DNA fingerprints can be prepared from cells found in a drop of blood or semen and even from fragments of skin caught under the fingernails of a crime victim. In 1988 this technique came to the aid of a 27-year-old computer operator at Disney World in Florida who had been attacked, beaten, and raped in her home in Orlando in 1986. Although she caught a brief glimpse of her assailant's face during the rape, she faced the terrifying prospect of having to convince a jury that her brief eyewitness identification of the suspect, 24-year-old Tommie Lee Andrews, was absolutely certain. Andrews claimed that he was at home during the evening the rape occurred, and he even produced a witness to substantiate that claim. It was a classic case of the victim's word against that of the accused. The prosecuting attorneys sought the aid of a molecular biologist to perform the "DNA fingerprinting" test on a semen sample taken by police the night of the rape. When the DNA fingerprint of this sample was compared with a blood sample taken from Andrews, the results were conclusive: It was a perfect match. The jury returned a verdict of guilty, resulting in a jail sentence of 22 years for Andrews.

DNA fingerprinting is not, however, considered "absolute" evidence because there are no uniform standards and procedures for the fingerprinting process. When uniform standards are developed, DNA fingerprinting should prove to be the ultimate weapon of criminology.

The first use of DNA fingerprinting in the United States is shown in this photograph of DNA patterns matching semen samples from a rape victim with blood samples from an accused suspect. Two different restriction enzymes were used, and in each case the result was a match between semen from the rapist and blood drawn from the accused.



■ No text is complete unless it is up-to-date and immediate. The feature to the left is indicative of what we try to do throughout the text: maximize the personal impact of science on the individual student.

When DNA fingerprinting was first used to convict a criminal in the United States, we brought that case into the classroom.

We wrote a feature that described the crime, explained the evidence, and showed the actual gels presented in court. Ken used this feature in his biology class and discovered that it galvanized students. We bet that it will keep yours on the edge of their seats, too.

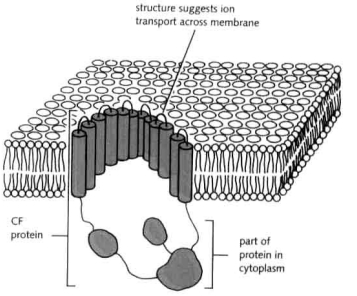


Figure 23.17 The sequence of the cystic fibrosis gene suggests that it may be a membrane protein involved in ion transport. This drawing shows a structural model for this protein in a biological membrane.

■ We have tried to collect the best of recent and lesser-known stories to share with you and your students. We discuss biomedical advances and their real-life consequences. Would you want to know if you are likely to develop a fatal disease later in life? Stories like this place science in perspective, helping students realize how science can create ethical dilemmas.

CURRENT CONTROVERSIES

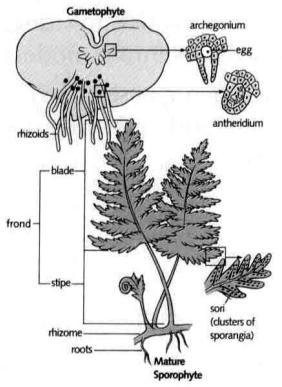
Would You Really Want to Know?

The availability of a test for Huntington's disease is a great medical breakthrough. But it confronts the children of Huntington's sufferers with a dilemma: *to test or not to test*. Universal application of the test might make it possible to eliminate the disease. If all potential carriers were to be tested, and if all agreed not to have children if they tested positive, the incidence of the disease might be cut dramatically. Many young adults living in fear and uncertainty would have the relief of learning that they will never develop the disease, and those not so lucky might be grateful for years of advance warning to plan for the onset of the disease.

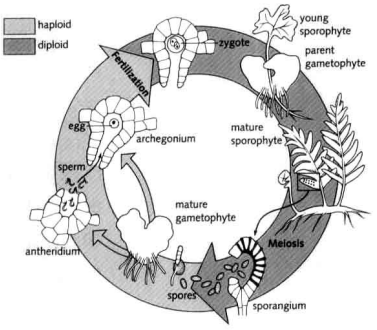
But many people who may one day succumb to Huntington's have decided that they do *not* want to take the test. Some of these people have said that they prefer uncertainty to the possibility of discovering that they *do* have the disease. Others have said that they will have children regardless of their status on the Huntington's test, seeing nothing tragic about bringing into the world a child who might develop the disease. After all, Huntington's sufferers lead full lives until the disease develops. In fact, about 50 percent of the possible Huntington's carriers who were offered the test in the Boston area in 1989 declined to be tested. Molecular biology may produce powerful new tools with which we can search for genetic diseases, but deciding how to use those tools will remain a matter of individual choice.

Teaching diversity is tough, which is why we present diversity by relating it to evolutionary history; to create a coherent context that allows us to integrate diversity—past and present—with plate tectonics, climate change, and interactions among plants and animals. To organize these relationships we use two types of illustrations: "period boxes" that summarize information about major stages in earth's history, and "taxon" boxes of taxonomic and anatomical information for each major group.

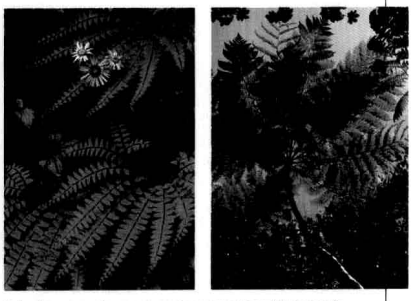
Ferns: Division Pterophyta



Anatomy: Leafy fronds, composed of *blade* and *stipe*, belong to diploid fern sporophytes, which are larger and more independent than those of mosses. Fronds unfurl from creeping *rhizomes* that grow underground or along the surface. Clusters of sporangia called *sori* form on the undersides of mature fronds. Well-developed roots extend into the soil.



Life cycle: Haploid spores are released from sporangia to be carried on the wind. The spores germinate into small, haploid gametophytes. Sperm produced in antheridia swim to eggs in archegonia; the zygote produces a diploid sporophyte that grows out of and soon dwarfs its parent.



Living ferns range from small species common in moist-temperate environments to giant tropical treeferns.

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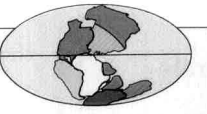
But the key innovation that spurred the reptilian radiation was the **amniotic egg,** a watertight egg produced by internal fertilization and wrapped in three protective membranes. Amniotic eggs serve land vertebrates much the same way seeds serve land plants—by making it easier for them to reproduce without standing water. Amniotic eggs protect developing embryos from desiccation, nourish them as they grow, provide a space for the storage and ultimate disposal of waste products, and enable the egg to exchange respiratory gases with the surrounding air.

THE PERMIAN PERIOD

The Permian period was a time of great environmental stress and innovation for all plants and animals, as geological changes in Pangaea produced cooler, drier climates. A mass extinction claimed more than 50 percent of all terrestrial animal families and more than 95

The Permian Period

Era	Period
Cenozoic	Quaternary
	Tertiary
Mesozoic	Cretaceous
	Jurassic
	Triassic
Paleozoic	**Permian**
	Carboniferous: Pennsylvanian
	Carboniferous: Mississippian
	Devonian
	Silurian
	Ordovician
	Cambrian
Proterozoic	(No period recognized)



During the Permian, the plates composing Pangaea continued to grind against one another, lifting larger and larger areas above sea level. The climate became cooler and drier, the great continental seas retreated, and many swamps dried up completely. Two plant relics from this period are ginkgoes (left) and cycads (right). The ginkgo, thought by Western scientists to have been extinct for millions of years, was rediscovered in China where it had been maintained in horticulture.

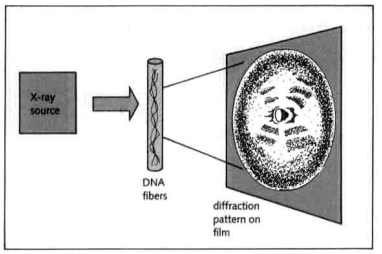
A few scientists, however, believed that DNA was such an interesting molecule that X-ray diffraction should be attempted even if perfect crystals couldn't be formed. One such person was Rosalind Franklin, a young scientist working with Maurice Wilkins, a crystallographer in London. Franklin drew a thick suspension of the fiber-like DNA molecules up into a glass capillary tube and used this DNA sample to scatter X rays. In the tube, she hoped, the thick suspension of DNA molecules would be forced to line up so that the molecules were parallel to the tube. Like spaghetti drawn through a straw, the molecules were all arranged in the same direction—not perfect enough to give a crystal-like pattern, but just good enough to yield a few clues about the structure of the DNA molecule.

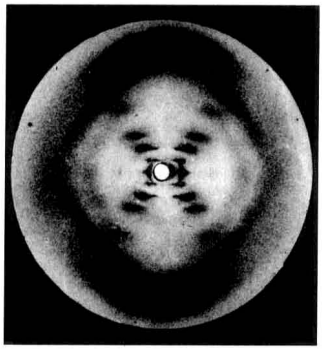
Interpreting the X-ray Pattern

One of the X-ray patterns produced by Franklin's DNA samples is shown in Figure 22.3. The pattern contains two critical clues to the structure of the DNA molecule (graphically summarized in the figure).

Clue number 1: The two large dark patches at the top and bottom of the figure showed that some structure in the molecule was arranged at a right angle to the long axis of DNA and repeated at a distance of 3.4 Å (see Appendix: The Metric System). In other words, something in the molecule was arranged like the rungs of a ladder.

Clue number 2: The X-like mark in the center of the pattern showed that something in the molecule was





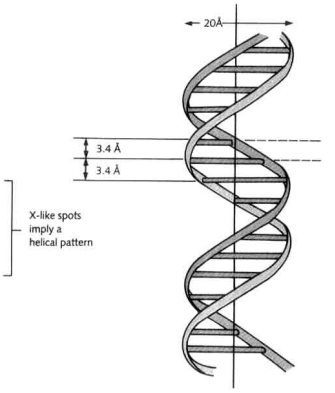


Figure 22.3 (left) DNA fibers were taken up in a thin tube so that most of them were oriented in the same direction. An X-ray diffraction pattern was then recorded on film. (bottom) X-ray diffraction pattern of DNA in the "B" form, as taken by Rosalind Franklin in 1952. Franklin's X-ray pattern contained two important clues to the structure of DNA. The large spots on the top and bottom of the pattern indicate that there is a regular spacing of 3.4 Å along the length of the fiber. The "X"-shaped pattern in the center indicates that there is a zigzag feature in the molecule, which might be consistent with a helix.

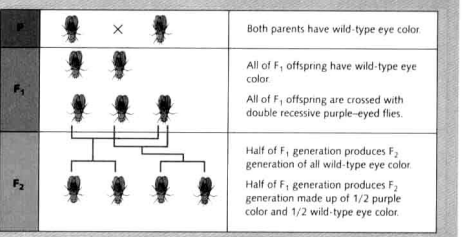
■ We explain the details of one of the key advances in 20th century biology—the development of the Double Helix model. Rather than skip over Franklin's X-ray photograph, we explain what it says about the structure of DNA.

We present students with clues to the structure of DNA—clues just like those the actual scientists considered in the early 1950s—and challenge students to organize these clues into a model.

Students enjoy being active participants who can understand and interpret experimental results.

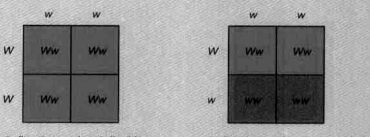
THEORY IN ACTION

Problems



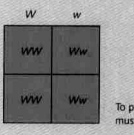
with wild-type eye color, and the other half produced 50 percent flies with wild-type eyes and 50 percent flies with purple eyes. *Determine the genotype of the original parents.*

By reasoning backwards from the last cross, we can solve the problem. Purple is a recessive trait, so each of the purple-eyed flies must have been genotype *ww*. Because half of the F_1 flies that were mated to the purple flies produced offspring with 50 percent purple eyes, these F_1 flies must have had a copy of the *w* gene. Their own eye color was wild type, so they must also have had a copy of the wild-type gene, making them genotype *Ww*. The other half of the F_1 generation did not produce any purple-eyed flies in their F_2 offspring. This means that their genotype must have been *WW*. What would the genotypes of the two original fly parents have to have been to produce an F_1 generation that was half *WW* and half *Ww*? The answer is that they must have been *WW* and *Ww*.



F_1 flies that produced all wild-type flies when mated with purple flies must have been genotype *WW*.

F_1 flies that produced 1/2 purple flies and 1/2 wild-type flies when crossed with purple flies must have been genotype *Ww*.



To produce these two types of F_1 flies the parents must have been genotype *WW* and *Ww*.

It is also possible to use genetics to predict future events. You will remember that Mendel discovered that tall is dominant over short in garden peas. Two tall peas are crossed and 100 seeds are collected. Two seeds are planted and grown under identical conditions. One produces a tall plant and the other a short plant. On the basis of these results, *determine how many of the remaining 98 plants can be expected to grow into tall plants.*

Remember that we were not told the genotypes of the original parents—only their phenotypes (they were both tall). However, because they were both tall, we know that each had at least one of the dominant genes for tallness (*T*). The single seed of the first filial generation that grew into a short plant had to be genotype *tt*, because the *t* gene is recessive. The only way in which a short plant could have been produced was for each of the parents to have had at least one *t* gene. Therefore the two parents were both genotype *Tt*. Simple genetic analysis tells us that 25 percent of the seeds in a cross between two such plants will grow to display the short phenotype. Because 75 percent of 98 = 73.5, 73 or 74 of the remaining seedlings can be expected to be tall.

■ Instructors use genetics to solve problems and make predictions.

We decided to show examples of *how* a student might solve a genetics problem. We begin with a simple problem, similar to what might be assigned, and work the solution through, step-by-step.

We emphasize both the predictive power of genetics and its limitations. We think you'll find that this gives students an advantage in understanding the key principles of inheritance.

■ In a single diagram students get three important pieces of information about epithelial tissue: its appearance in the microscope, its cellular structure, and its location in the body. This one-stop approach to illustration makes teaching and learning much easier.

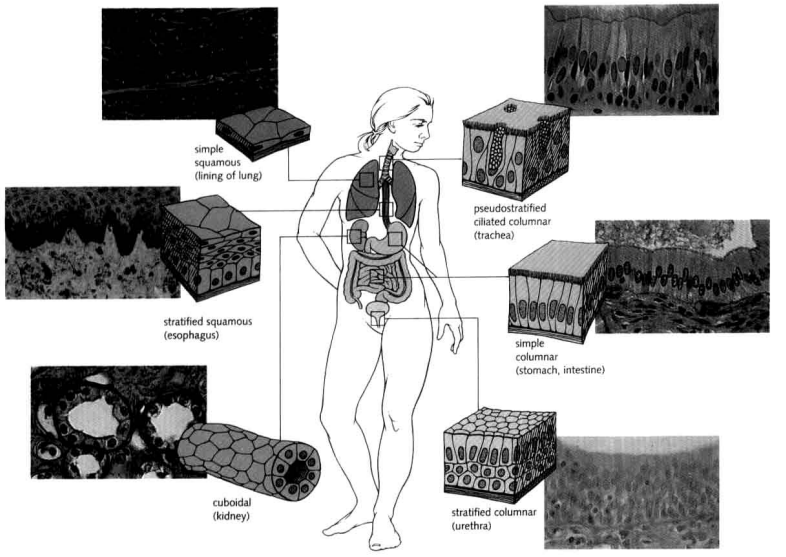


Figure 31.2 Epithelial tissues are found throughout the body. They are placed into categories based on the structural organization of the cells of which they are made. Photomicrographs of six major types of epithelial tissue. Clockwise (from the upper left), simple squamous epithelium (from the lung), pseudostratified columnar epithelium (trachea), simple columnar epithelium (stomach), stratified columnar epithelium (urethra), simple cuboidal epithelium (from kidney), and stratified squamous epithelium (esophagus).

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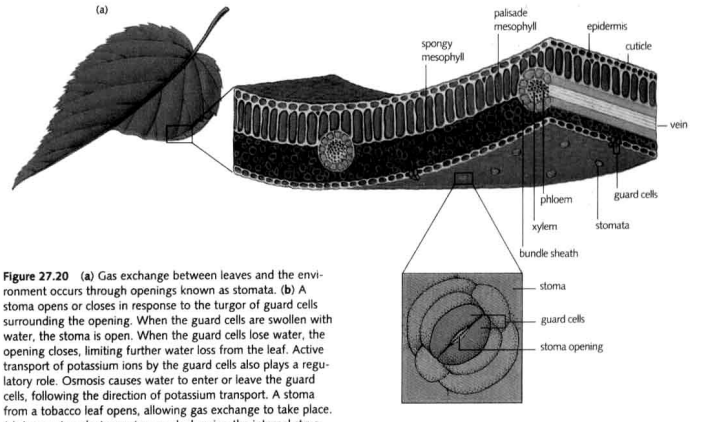
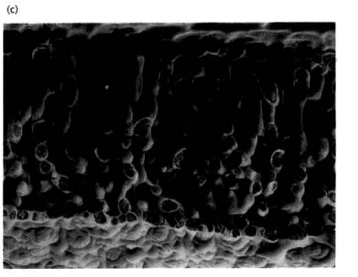
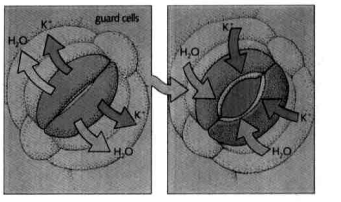


Figure 27.20 (**a**) Gas exchange between leaves and the environment occurs through openings known as stomata. (**b**) A stoma opens or closes in response to the turgor of guard cells surrounding the opening. When the guard cells are swollen with water, the stoma is open. When the guard cells lose water, the opening closes, limiting further water loss from the leaf. Active transport of potassium ions by the guard cells also plays a regulatory role. Osmosis causes water to enter or leave the guard cells, following the direction of potassium transport. A stoma from a tobacco leaf opens, allowing gas exchange to take place. (**c**) A scanning electron micrograph showing the internal structure of a turnip leaf. Stomata are present on both surfaces of this leaf, although they are more numerous on the underside.





■ This sequence of drawings, at three levels of magnification, gives the reader a feeling of intimacy with the biological system—and that is exactly our goal: to draw students into the process of discovery.

J.S.L.
K.R.M.

BRIEF CONTENTS

CONTENTS