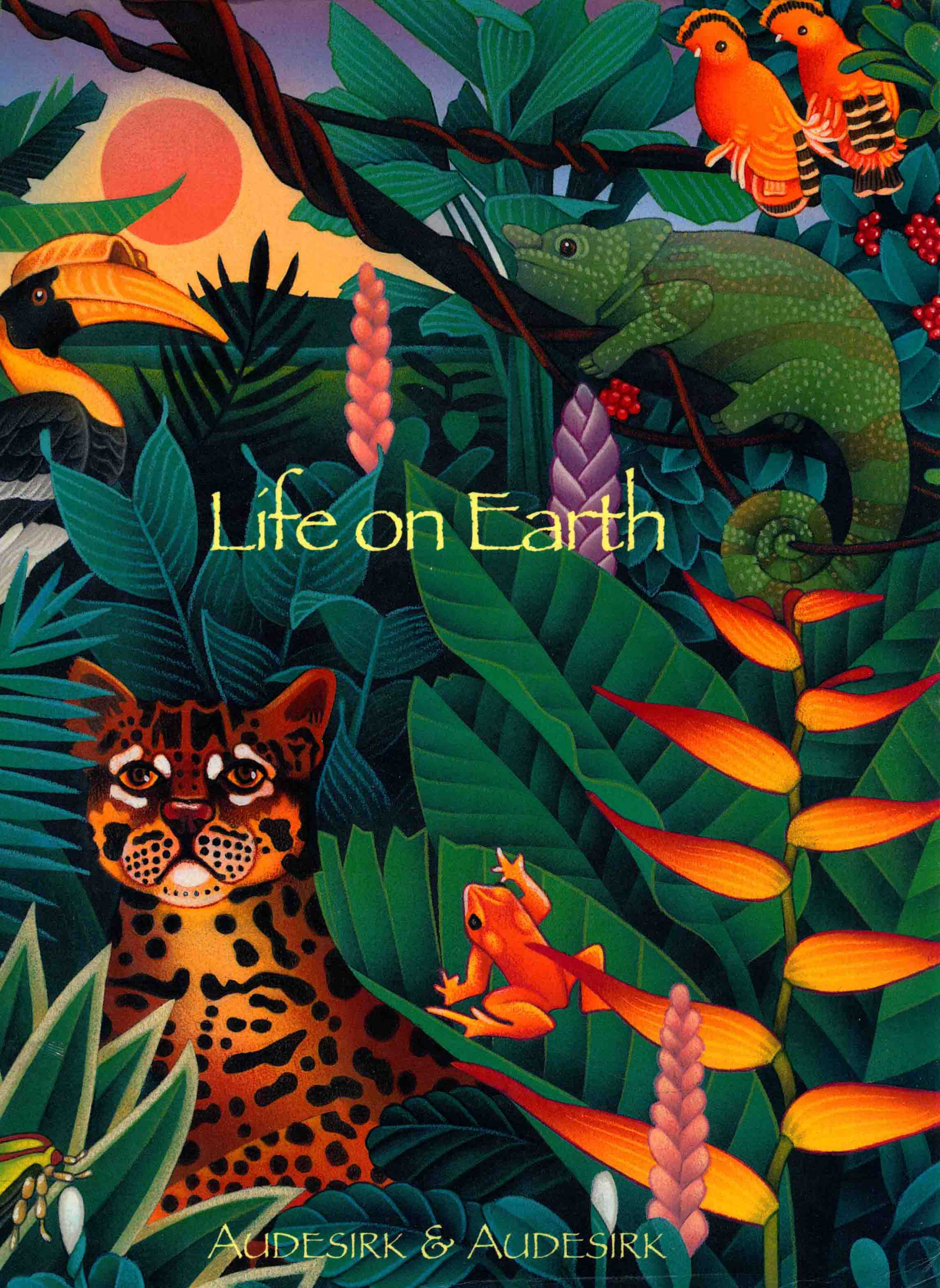

Life on Earth

Audesirk & Audesirk

Life on Earth

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Life on Earth

About the Authors

Terry and Gerry Audesirk both grew up in New Jersey, where they met as undergraduates. After marrying in 1970, they moved to California, where Terry earned her doctorate in marine ecology at the University of Southern California and Gerry earned his doctorate in neurobiology at the California Institute of Technology. While living in Southern California, both Terry and Gerry learned to scuba dive and were fascinated by the diversity and beauty of marine life. As postdoctoral students at the University of Washington's marine laboratories, they worked together on the neural bases of behavior using a marine mollusc as a model system. They are now professors of biology at the University of Colorado at Denver, where they have both taught introductory biology for over 10 years along with courses in neurobiology. In their research lab, they investigate the mechanisms by which neurons are harmed by low levels of environmental pollutants such as lead. This program is funded by the National Institutes of Health.

Terry and Gerry share a deep appreciation of nature and the outdoors. They enjoy hiking in the Rockies, running near their home in the foothills west of Denver, and attempting to garden at 7000 feet in the presence of hungry deer and elk. They are long-time members of many conservation organizations. The birth of their daughter, Heather, has added another love to their lives, and they now spend much of their free time with her.

Life on Earth is the natural outgrowth of the authors' enjoyment of writing, their fascination with all aspects of biology, and their eagerness to share this fascination with their students.

Dedication

To our daughter, Heather,

and to our parents, Lori, Jack, and Joe

Preface

Because we have a young daughter, we often hear the question "Why?" It's an exciting question, because it provides us with an opportunity to share some of what we know, or to learn more by looking up the answer to our daughter's question. The question "why?" begins a person's exploration of his or her world. For those fortunate enough to continue asking such questions, the exploration and the delight of learning become life-long and continuously enriching experiences. As teachers and scientists, we are continuously learning about life on Earth. In writing this textbook, we have had the good fortune both to learn more and to share our interest in biology with an extended classroom of thousands of students.

A course in introductory biology may be a student's first real exposure to the fascinating complexity of life. As teachers, we recognize how easily a student may become mired in the overwhelming number of new facts and terms, while losing sight of the underlying principles of biology and their relevance to daily life. *Life on Earth* has been carefully written to integrate the necessary biological facts into a broader conceptual framework that stresses unifying themes and the ways in which an understanding of biology can enrich and enlighten day-to-day living. Why study biology? Maybe we're biased, but what can be more fascinating than learning about life on Earth?

Life on Earth

Focuses on Concepts

The subheadings within each major chapter section have been cast as sentences so that they introduce key concepts in each section of text. Our "At a Glance" section opens each chapter with an outline that brings these statements together, presenting an overview of the chapter and its most important ideas. Figure titles tell the student at a glance what idea the figure illustrates, before the details are described in the caption. Concepts are further stressed in highlighted in-text summaries and in end-of-chapter summaries.

Makes Biology Relevant

There is a danger that students will stop asking the question "why?" if the equally important question "so what?" isn't answered. In fact, there is no science that can tell us more about ourselves and our world than can biology. Knowledge of biology illuminates everyday life: How can two brown-eyed parents have a blue-eyed child? Why do smokers cough so much? What causes a fever? A knowledge of biology is also crucial to understanding modern concerns and controversies such as population growth, the spread of diseases such as AIDS, the destruction of tropical rain forests, and the promise and perils of genetic engineering. In this text, we make a conscious effort to relate concepts in biology to everyday experiences and to important issues facing society. These applications are interwoven into the text, introduced in end-of-chapter essay questions, and highlighted in boxed essays such as:

Earth Watch — a series of environmental essays addressing issues such as biodiversity, ozone depletion, and population growth.

Health Watch — a series of essays investigating topics such as how ulcers form, how kidney dialysis works, and how drugs and alcohol can affect a developing child.

Communicates the Scientific Process

One cannot understand biology without knowing how science works. Biology is not just a compendium of facts and ideas; it is the outgrowth of a dynamic process of inquiry and human endeavor. In many places throughout the text, accompanying descriptions of biological facts and concepts, are descriptions of how those findings were achieved. The scientific process is further highlighted in Scientific Inquiry essays:

Scientific Inquiry — students will learn, for example, how fossils are dated, how the structure of DNA was discovered, and how the gene for Huntington's disease was discovered.

Stresses Unifying Themes

Two themes are interwoven throughout the text: evolution and adaptation to the environment. As Theodosius Dobzhansky so aptly put it, "Nothing in biology makes sense, except in the light of evolution." Life on Earth has been forged in the crucible of evolution, and any modern biology text must reflect that fact. Many of the chapter introductions have an evolutionary theme, and many chapters end with a feature new to this edition:

Evolutionary Connections — lively discussions that link chapter concepts into the broader perspective of evolution.

Adaptation to the environment flows naturally from the concept of evolution; the environment exerts selective pressure on organisms that helps shape their evolution. Nevertheless, not all structures are optimal solutions to environmental challenges. Many apparently unlikely biological designs are due to genetic drift, chance catastrophes, and the fact that the raw material for evolution consists of random mutations affecting previously existing structures. In the words of Sydney Brenner, "Anything produced by evolution is likely to be a bit of a mess," and we have tried to show that, too.

Our own concern for the environment also threads its way throughout this text. Whenever appropriate, we have tried to present students with the biological rationale for making sound environmental decisions.

Stimulates Exploration

For every "why?" that is answered, many more questions are raised. The knowledge and understanding of science that students gain from this text will allow them to continue to seek answers throughout their lives. Thought-provoking questions end each chapter, along with interesting and informative references, where topics can be explored in more detail. A free supplement for students, *The New York Times Themes of the Times* brings together a collection of recent, topical, biological articles from the pages of *The New York Times*. The *ABC News/Prentice Hall Video Library* for instructors features brief clips from programs like *20/20*, *World News Tonight*, and *Nightline*. Finally, the text challenges the student to enter the information age with its own home page on the World Wide Web. *Life on the Internet: Biology - A Student's Guide* is available as a supplement to help students navigate through the web to access the regularly updated resources on the *Life on Earth* home page:

Net Watch — an icon at the end of each chapter highlights the specific address for each chapter's resources.

Responds to the Challenges of a One-Semester Course in Biology

Biology is absolutely unique in the diversity and range of its subject matter. This embarrassment of riches provides a special challenge to the instructor attempting to introduce biology, particularly in a one-semester course. Many share our concern that, when everything is covered superficially, explanation and real understanding of concepts may be sacrificed, reducing biology to a massive compendium of facts to be memorized and then quickly forgotten. In response to this dilemma, many instructors choose to cover fewer topics, but cover them well. *Life on Earth* is tailored to this approach. But which topics should be covered? The areas explored in this text have been chosen in response to surveys of introductory biology instructors nationwide. *Life on Earth* is designed to provide students, particularly non-biology majors, with a good working knowledge and understanding of areas of biology that will touch their lives.

We first introduce the basic chemistry of the molecules of life, cell structure, and the processes by which energy is captured and released. We then move on to inheritance, human genetics, and genetic engineering and biotechnology, followed by a unit that thoroughly explains the mechanisms and results of evolution. Our physiology unit emphasizes the human body, providing an owner's manual that explores crucial topics such as reproduction and development, birth control, and the immune system and diseases, including AIDS and cancer. Our complete ecology unit is a sort of user's guide to the Earth. In addition to the principles that govern population growth and the interactions that produce and sustain diverse natural ecosystems, we incorporate coverage of human impacts into each area of ecology.

Acknowledgments

Life on Earth is truly a team effort, and we wish to acknowledge and thank our teammates.

The dauntingly complex task of putting together a book of this magnitude has been handled with unflagging dedication and zeal by the skilled development team at Prentice Hall. Ray Mullaney, Editor in Chief of Engineering, Science, and Mathematics development, made sure the text was clear, consistent, and student-friendly. Ray continued to oversee the production of the text, contributing substantially to its design, photographic selection, and accuracy. Debra Wechsler, Senior Production Editor, supervised production of the text and patiently dealt with the minutiae of assuring accuracy in the art program and the translation from typed draft to final printed page. Tobi Zausner and Kathy Ringrose skillfully and doggedly tracked down excellent photos. Margo Quinto tackled the job of copyediting with meticulous care. We also wish to thank Heather Scott, our talented Art Director, for creatively guiding the text and cover design; Patrice Van Acker, who coordinated the art program; and Richard Foster, for his artful formatting of these pages. Mary Hornby competently and conscientiously has overseen the production of our print supplements, test bank, and transparencies. Linda Schreiber did a fantastic job of coordinating the multimedia program, especially our exciting new laser disc and CD-ROM.

Colleagues at other institutions have helped us enormously. Many, listed in the following pages, have stimulated us to rethink our presentation with careful, thoughtful reviews. Essays were contributed by Joseph Chinnici, Mark Shotwell, and Gisele Muller-Parker. A wonderful supplements package was engineered by Joseph Chinnici, Kristin Uthus, Rhoda Perozzi, Gayle Sauer, Linda Butler, Andrew Stull, Steven Brunasso, Mike McKinley, and Blanche Haning. We thank Bill Stark, Richard Mortensen, Gerald Summers, Rhoda Perozzi, Florence Juillerat, Jerri Lindsey, Scott Freeman, and Dan Doak for contributing thought-provoking end-of-chapter questions.

Marketing is being handled with talent and enthusiasm by Kelly McDonald, our Executive Marketing Manager. We also would like to thank Paul F. Corey, Editor in Chief of Science, for his insight and support. Finally, but most importantly, our editor, Sheri Snavely, has nurtured this project through thick and thin, smoothing rough spots and boosting our morale with her good humor, optimism, and energy.

Terry and Gerry Audesirk
Golden, Colorado

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Coordinated by Linda Butler, University of Texas at Austin
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The Prentice Hall Laser Disc for Biology
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For the Student

Audesirk *Life on Earth* World Wide Web Home Page
Developed by Andrew Stull and Steven Brunasso, California State University at Fullerton
This unique tool is the first to harness the resources of the Internet for easy integration into the classroom. Designed to launch student exploration, resources are regularly updated and linked to text chapters (see Net Watch icons at the end of each chapter).

Life on the Internet: Biology—A Student Guide
By Andrew Stull, California State University at Fullerton
The perfect tool to help your students take advantage of our Life on Earth home page on the World Wide Web and open up the world of the Internet for exploration! Tied specifically to our home page, this unique resource gives clear steps to access our regularly updated biology resource area as well as an overview of general navigation strategies. (0-13-244088-1)

Study Guide
By Joseph Chinnici, Virginia Commonwealth University
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New York Times Themes of the Times Supplement
Coordinated by Linda Butler, University of Texas at Austin
This unique newspaper-format supplement brings together recent articles on dynamic biology applications from the pages of the world-renowned *New York Times*. This free supplement, available in quantity through your local representative, encourages students to make connections between the classroom and the world around them.

For the Laboratory

Explorations in Basic Biology, Seventh Edition
By Stanley Gunstream, Pasadena City College
This best-selling laboratory manual can be used with Life on Earth or any introductory biology text. It includes 40 self-contained, easy-to-understand experiments that blend traditional experiments with new investigative exercises. (0-13-372939-7; Instructor's Manual: 0-13-393927-8)

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By Stanley Gunstream, Pasadena City College
Specifically designed for introductory biology courses where the human organism is emphasized. (0-13-575770-3; Instructor's Manual: 0-13-717588-4)

How to Use this Text: A Guide for Students

Life on Earth has been designed as one of the tools to launch your exploration of the exciting world of biology! Our goal is to help you master the basic concepts of biology and then begin applying them to the world around you. Take a few moments now to see how our text can help you succeed.

At a Glance

At a Glance overviews the chapter ahead and helps you organize your study.

8 Harvesting Energy from Food: Glycolysis and Cellular Respiration

AT A GLANCE

Glucose Metabolism: An Overview

Glycolysis
Glucose Must Be Activated by ATP before Its Energy Can Be Harvested

Fermentation
Some Cells Ferment Pyruvic Acid to Lactic Acid
Other Cells Ferment Pyruvic Acid to Alcohol

Cellular Respiration
Pyruvic Acid Is Transported into the Mitochondrial Matrix
Pyruvic Acid Is Broken Down by Reactions in the Mitochondrial Matrix
Energetic Electrons Are Carried to Electron Transport Systems in the Inner Mitochondrial Membrane
Chemiosmosis Captures Energy Stored in a Hydrogen Ion Gradient and Produces ATP
ATP Is Transported from the Mitochondrial Matrix and Diffuses into the Cell Cytosol
Cellular Metabolism Influences the Way Entire Organisms Function

An Anna's hummingbird feeds at a flower in California.

When a hummingbird sips nectar from a flower, it eats the products of photosynthesis. Photosynthesis in the plant's leaves had converted the energy of sunlight into the chemical energy of organic molecules such as the sugar in nectar. To supply its enormous energy needs—the highest of any animal—the hummingbird must eat its weight in nectar daily. Then its cells must efficiently extract energy from the glucose in the nectar. When the hummingbird's cells break down the high-energy glucose molecules in the presence of oxygen, they produce the low-energy molecules the plant started with—carbon dioxide and water—making energy available for muscles and growth (Fig. 7-1).

However, the hummingbird's cells cannot directly use the chemical energy derived from this process. Its wing muscles require energy stored in the molecule adenosine triphosphate (ATP). Its brain uses ATP in conducting nerve signals, and its ovaries use ATP in making eggs. The plant, for its part, uses ATP to make the petals, pigments, and fragrance that attract the bird and the leaves and chlorophyll molecules that trap the sun's energy. In this chapter, we explore the metabolic processes by which organisms convert the energy of organic molecules into the usable energy of ATP, processes called glycolysis and respiration.

Most cells can metabolize a variety of organic molecules to produce ATP. We focus on the metabolism of the single molecule glucose for three reasons. First, virtually all single-celled organisms, and every cell of multicellular organisms, metabolize glucose for energy at least part of the time. Some, such as nerve cells in your brain, rely predominantly on glucose as a source of energy. Second, glucose metabolism is less complex than the metabolism of most other organic molecules. Finally, when cells use other organic molecules as energy sources, they usually convert the molecules to glucose or other compounds that enter the pathways of glucose metabolism (see "Health Watch: Metabolic Transformations—Why You Can Get Fat by Eating Sugar").

Glucose Metabolism: An Overview

During photosynthesis, photosynthetic organisms harvest and store the energy of sunlight in glucose. During glucose breakdown, that energy is released and converted to

Opening Stories/Vignettes

Opening Stories/Vignettes in most chapters relate the opening photograph to the concepts that will be developed in the chapter.

Focus on Key Concepts

As you read, identify and focus on the key concepts. Can you rephrase the main ideas in your own words?

Conceptual Headings

Conceptual Headings provide a context for the discussion to follow and give you a clear review of key concepts.

In-text Summaries

In-text Summaries help you check your understanding of complex processes, especially in the early chapters where the fundamental concepts of biology are laid out. Stop and read these summaries as you move through a chapter as a help in digesting new material.

see that cells have evolved elaborate mechanisms that ensure that each daughter cell inherits all the materials it needs to continue the flow of life.

The Essentials of Cellular Reproduction

When a cell divides, it must transmit to its offspring cells two essential requirements for life (Fig. 9-1): hereditary information to direct life processes and materials in the cytoplasm that the offspring need to survive and to utilize their hereditary information.

Cell Division Transmits a Complete Set of Hereditary Information to Each Daughter Cell

The hereditary information of all living cells is **deoxyribonucleic acid (DNA)**. Like many large biological molecules, a molecule of DNA consists of a long chain of smaller subunits (see Chapter 3). DNA has four different types of subunits, called nucleotides. Segments of DNA a few hundred to many thousand nucleotides long are the units of inheritance—the genes—that carry the genetic information to produce specific traits. The sequence of nucleotides in a gene encodes information for the synthesis of the RNA and protein molecules that are needed to build a cell and carry out its metabolic activities. We will see in Chapters 10 through 13 how DNA encodes genetic instructions and how a cell regulates which genes it uses at any given time.

For any cell to survive, it must have a *complete set of genetic instructions*. Therefore, when a cell divides, it cannot simply split its set of genes in half and give each daughter cell half a set. Rather, the cell must first *duplicate its DNA*, much like making a photocopy of an instruction manual. Each daughter cell then receives a complete "DNA manual" containing all the genes.

Cell Division Transmits Essential Cytoplasmic Materials to Each Daughter Cell

Like the blueprints for a house, the in
by DNA are useless without materials
newly formed cell must receive the m
read its genetic instructions and to
enough to acquire new materials fro
and to process them into new cellula
thermore, as we described in Chapter 5
thesize either mitochondria or chloro
these organelles arise only by the div
existing mitochondria and chloroplas
cell divides, its cytoplasm is divided ab
the two daughter cells. This simple m
provides both daughter cells with all
trients, enzymes, and other molecules

The Activities of a Cell from One the Next Constitute the Cell Cycl

Newly formed cells usually acquire n
environment, synthesize more of their
grow larger. After a variable amount of
the organism, the type of cell, and the
the cell divides. This general descript
eukaryotic and prokaryotic cells. Pr

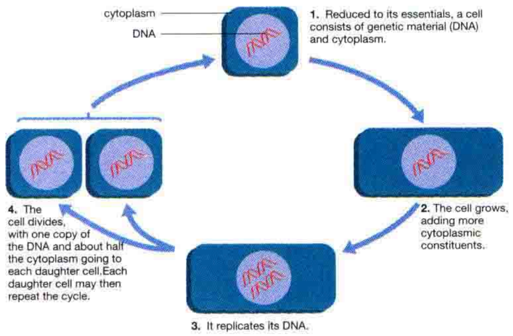


Figure 9-1 A generalized cell cycle.

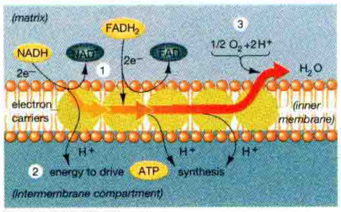


Figure 8-6 The electron transport system of mitochondria

(1) The electron carrier molecules NADH and $FADH_2$ deposit their energetic electrons with the carriers of the transport system located in the inner membrane. (2) The electrons move from carrier to carrier within the transport system. Some of their energy is used to pump hydrogen ions across the inner membrane from the matrix into the intermembrane compartment. This movement out of the inner membrane creates a hydrogen ion gradient that can be used to drive ATP synthesis (for details, see "A Closer Look at Chemiosmosis in Mitochondria"). (3) At the end of the electron transport system, the energy-depleted electrons combine with oxygen and hydrogen ions in the matrix to form water.

inner membrane, into the intermembrane compartment (see the section on chemiosmosis, below).

Finally, at the end of the electron transport system, oxygen and hydrogen ions accept the energetically depleted electrons: Two electrons, one oxygen atom, and two hydrogen ions combine to form water. This step clears out the transport system, leaving it ready to run more electrons through. Without oxygen, the electrons would "pile up" in the transport system, with the result that the hydrogen ions would not be pumped across the inner membrane. The hydrogen ion gradient would soon dissipate and ATP synthesis would stop.

Chemiosmosis Captures Energy Stored in a Hydrogen Ion Gradient and Produces ATP

Hydrogen ion pumping across the inner membrane generates a large concentration gradient; that is, a high concentration of hydrogen ions in the intermembrane compartment and a low concentration in the matrix. The inner membrane is impermeable to hydrogen ions except at protein pores that are part of ATP-synthesizing enzymes. In the process known as **chemiosmosis**, hydrogen ions move down their concentration gradient from the intermembrane compartment to the matrix through these ATP-synthesizing enzymes. The flow of hydrogen ions provides the energy to synthesize 32 to 34 molecules of ATP from ADP and inorganic phosphate in the matrix. The box "A Closer Look at Chemiosmosis in Mitochondria" examines chemiosmosis in more detail.

ATP Is Transported from the Mitochondrial Matrix and Diffuses into the Cell Cytosol

The ATP that was synthesized from ADP and inorganic phosphate in the matrix during chemiosmosis is transported across the inner membrane from the matrix to the intermembrane compartment. It then diffuses out of the mitochondrion to the cytosol through the outer membrane, which is very permeable to ATP. These ATP molecules provide most of the energy needed by the cell. ADP simultaneously diffuses from the cytosol across the outer membrane and is transported across the inner membrane to the matrix, replenishing the supply of ADP.

SUMMARY

ELECTRON TRANSPORT AND CHEMIOSMOSIS

Electrons from the electron carriers NADH and $FADH_2$ enter the electron transport system of the inner mitochondrial membrane. Here their energy is used to generate a hydrogen ion gradient. Movement of hydrogen ions down their gradient through the pores of ATP-synthesizing enzymes drives the synthesis of 32 to 34 molecules of ATP. At the end of the electron transport system, two electrons combine with one oxygen atom and two hydrogen ions to form water.

Cellular Metabolism Influences the Way Entire Organisms Function

Many students feel that the details of cellular metabolism are hard to learn and don't really help them to understand the living world around them. Have you ever read a murder mystery and wondered how cyanide could kill a person almost instantly? Cyanide reacts with one of the proteins in the electron transport system, immediately blocking the movement of electrons through the system and bringing cellular respiration to a screeching halt. Under more normal conditions, metabolic processes within individual cells have enormous impacts on the functioning of entire organisms. To take just two familiar examples, let's consider the migration of ruby-throated hummingbirds and track events in the Olympics.

Hummingbird Migration Requires Efficient Energy Storage and Use

As the days shorten in August, many birds in North America prepare to migrate to Central and South

Key terms

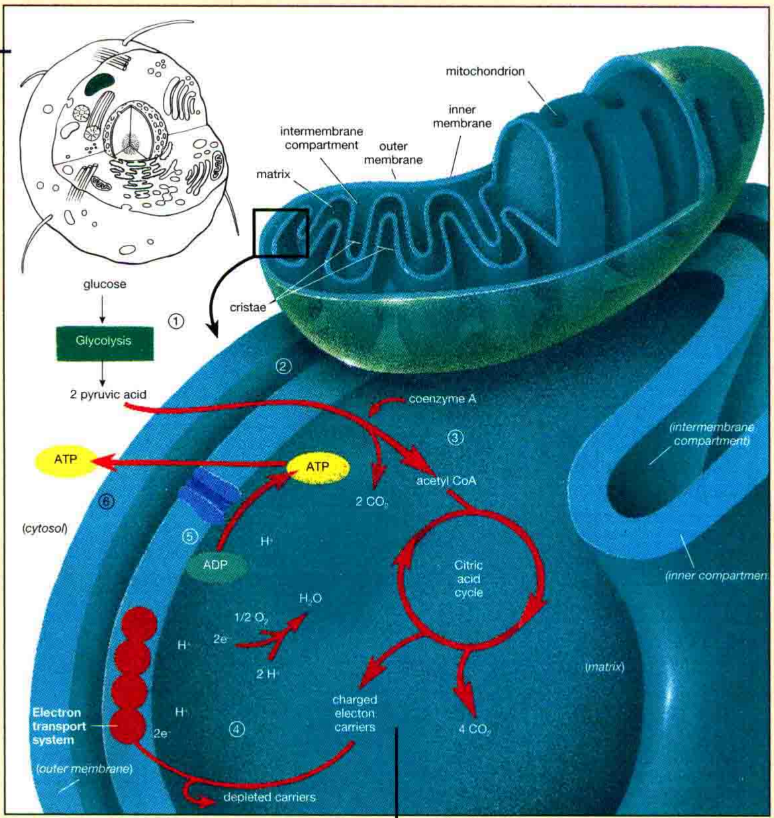
Key terms are boldfaced throughout.

Visualize Key Concepts

If you can visualize something related to a concept, you'll remember it more easily. Our art and photographic program will help you grasp concepts, so study the pictures as well as the text.

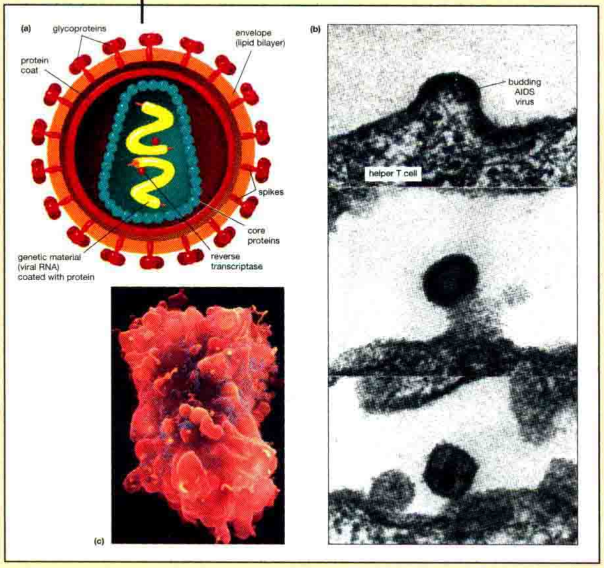
Micro to Macro Figures

To understand biology you must be able to visualize structures at several different scales. **Micro to macro figures** help you bridge this gap.



Compound Art

Compound art brings together different views of a topic.



Process Art

Process art conveys key steps in processes, such as cellular respiration, as shown here.

Dynamic Photographs

Dynamic photographs provide vivid illustrations of concepts throughout.

Relate Concepts to the World Around You

Think about biology in the world around you. You have come into this course already knowing a lot about life. The concepts you are learning will give you a better understanding of your own life and of the world around you. Applications and stories are an important part of this text, and we hope that these features will spark your curiosity and make the study of biology as fascinating to you as it is to us.

E A R T H   W A T C H

Has the Human Population Exceeded Earth's Carrying Capacity?

A glance at the age structure of less-developed countries, where most of the world's population resides, shows a tremendous momentum for continued growth. World population in the year 2010 is predicted to be over 7 billion and growing. A modest United Nations (UN) projection is that the human population may stabilize in the year 2150 at 11.5 billion (Fig. E28-3). Can Earth support over twice its current population?

Earlier we defined carrying capacity as the m
ulation that could be indefinitely sustained.
population requires that the ecosystem not be
ways that lower its ability to provide necessary
this definition we have already exceeded Earth'
pacity for people. The upper limit of the pla
capacity is determined by the ability of its pla
vest the energy from sunlight and produce high
ecules that organisms can use as food. Stanfo
biologist Peter Vitousek estimates that human a
already reduced the productivity of Earth's fore
lands by 12%. Each year, millions of acres of
tive land are being turned into desert through
and deforestation, especially in less-develop
Earth's desert area is projected to increase by
year 2000 as a result of human activities. In a

In the years between 1990 and 2010, the world population is projected to increase by 33%. During this same period, the available fish, cropland, pastureland, and forests will all decline by 10% to 30% per person. The UN Food and Agricultural Organization reports that Africa's food production for each person has dropped by 20% since 1960; another 30% drop in the next 25 years is predicted. Each year the United States is losing 1 million acres of

Earth Watch

Earth Watch essays present environmental issues such as biodiversity, ozone depletion, and population growth.

H E A L T H   W A T C H

The Placenta Provides Only Partial Protection

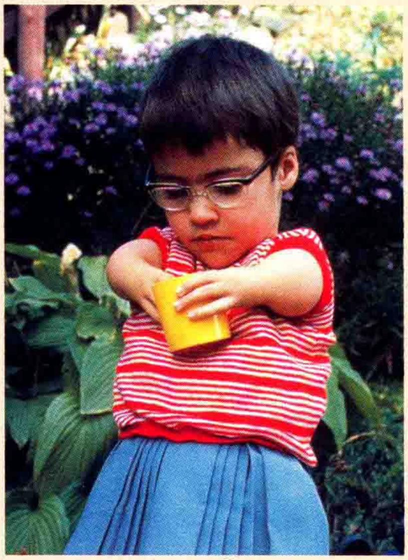
When your grandparents were bearing children, doctors assumed that the placenta protected the developing fetus from most of the substances in maternal blood that could harm it. We know now that this is far from true. In fact, most medications and drugs and even some disease organisms readily penetrate the placental barrier and affect the fetus.

Infections May Cross the Placenta

The German measles virus can cross the placenta and attack the fetus, causing potentially severe retardation and other defects. The virus causing genital herpes (during active outbreaks) and the bacterium causing syphilis can cause mental or physical defects in the developing fetus. The virus causing AIDS may also cross the placenta, so infants may be born with this incurable disease.

Drugs Readily Cross the Placenta

A tragic example of drugs crossing the placenta is the tranquilizer thalidomide, commonly prescribed in Europe in the early 1960s (Fig. E27-3). Thalidomide's devastating effects on embryos were discovered only when many babies were born with missing or extremely abnormal limbs. More recently, in the late 1980s, the anti-acne drug Accutane was found to cause gross deformities in babies born to women using it. Although these are extreme examples, ***any drug, including aspirin, has the***



Health Watch

Health Watch essays investigate issues such as prenatal diagnosis, sexually transmitted diseases, and osteoporosis.

The New York Times Themes of the Times

The New York Times **Themes of the Times** supplement brings together a collection of recent biology articles from this award-winning newspaper. Can you relate what you are learning in class to the issues discussed in recent articles?

The ABC News/Prentice Hall Video Library

The ABC News/Prentice Hall Video Library makes available brief clips from programs like *20/20*, *World News Tonight*, and *Nightline*. Will knowing more about the science behind the issues change the way you view the nightly news?

Understand the Process of Science

The processes by which scientists answer questions are as important as the questions themselves. *Life on Earth* emphasizes how we know what we know and gives you insight into the dynamic process of discovery.

Scientific Inquiry

Scientific Inquiry essays examine the people, the processes, and the methods of biology with topics such as DNA fingerprinting in forensics, Nancy Wexler on the trail of Huntington's disease, the use of isotopes in biology and medicine.

S C I E N T I F I C   I N Q U I R Y

DNA Fingerprinting in Forensics—The Case of the Telltale Palo Verde

The polymerase chain reaction (PCR) procedure has caused a revolution in many fields of biology, but nowhere has the impact of this technique been felt more than in forensics, the collection of information to be used as evidence in court proceedings. The technique that is proving most useful has been nicknamed "DNA fingerprinting," because it may generate patterns of DNA fragments unique to each individual. This procedure involves the amplification of a set of DNA fragments of unknown sequence, a set that is likely to differ from one individual to the next. When these fragments are amplified and separated from one another on a gel, the pattern of bands is referred to as a DNA fingerprint. In theory, it represents a characteristic "snapshot" of the unique genome of an individual, allowing it to be distinguished from that of every other individual in the population. The quantity of DNA needed to analyze using PCR is exceedingly small; this amount of DNA can easily be obtained from a single spot of dried blood, from the cells clinging to the base of a hair shaft, from skin fragments under a victim's fingernails, or other small tissue samples collected at a crime scene.

Here is an example of the forensic use of DNA fingerprints that did not involve the suspect's DNA, but rather that of plants at the crime scene. On the night of May 2,

verdes show considerable genetic variation from one tree to the next. Otherwise, it would be impossible to unambiguously link a given pod to any particular tree. Fortunately, he found considerable differences in DNA between individual plants, allowing for discriminatory fingerprints.

Helentjaris then was given the two seed pods from the suspect's truck along with pods collected by investigators from 12 different palo verde trees near the factory. The investigators knew which of the 12 trees was near the body but did not tell Helentjaris. He extracted DNA from seeds taken from each pod and performed the PCR reaction, producing 10 to 15 distinct bands from each pod. The result of this experiment was unmistakable: The pattern from the pod found in the truck exactly matched the pattern from only one of the 12 trees, the one nearest the body. In an important additional test, Helentjaris found that this pattern was also different from that of 18 pods collected from trees at random sites around Phoenix. This result was admitted as evidence in the trial, the first time a DNA fingerprint of a plant had been used in a court case. This information was crucial in demolishing the suspect's alibi, and at the end of the 5-week trial the suspect was found guilty of first-degree murder. Riven the two seed pods from the suspect's truck along with pods col-

See the Connections

There are important patterns and themes that unify the discipline of biology. *Evolution* and *adaptation to the environment* are two related themes you'll revisit throughout the text. How do you see these themes at work?

Evolutionary Connections

Evolutionary Connections close many of the chapters, tying the subject matter of each chapter into the broader perspective of evolution. You'll also notice that many of the chapter introductions have an evolutionary theme.

E V O L U T I O N A R Y   C O N N E C T I O N S

Kin Selection and the Evolution of Altruism

Altruism is any behavior that is potentially harmful to the survival and future reproduction of an individual organism but enhances the reproductive potential of other organisms. Altruism includes worker bees' rearing the offspring of queen bees. Note that altruism does not imply conscious, voluntary decisions to engage in selfless behavior. Rather, most altruistic behaviors have a strong instinctive component; that is, many animals have altruism programmed in their genes.

From an evolutionary viewpoint, how can this be? Surely, if a mutation arose that caused altruistic behavior, and the bearers of that mutation lost their lives or failed to reproduce because of their self-sacrificing behaviors, their "altruistic alleles" would disappear from the population. Maybe, or maybe not. To understand the evolution of altruism, we will need to introduce a new concept: **inclusive fitness**. As formulated by W. D. Hamilton, the inclusive fitness of an allele is the fitness conferred on *all* organisms that have the allele. Therefore, *if an altruist benefits related members of its own species that bear the same altruistic allele, then the altruistic allele may be favored by natural selection.*

To see how altruism might increase the inclusive fitness of an allele, let's consider the Florida Scrub Jay. Year-old jays usually do not mate and reproduce. Instead, these yearlings remain at their parents' nest and help out with next year's brood. Let's assume, for simplicity, that this altruistic behavior is controlled by a single "altruistic" allele and that in the distant past helper jays had the altruistic allele, and nonhelpers had another, "selfish," allele.

At least for one year, altruistic yearlings do not reproduce; some probably die from predation or accidents and never reproduce at all. How, then, can this behavior be adaptive? It all has to do with relatedness and the probability of successful reproduction. First, an animal's offspring inherit 50% of its genes (the other 50% of the offspring's genes come from the other parent). On the average, an animal also shares 50% of its genes with its siblings. Therefore, *a scrub jay is just as related to its siblings as it would be to its own offspring*. The second factor influencing scrub jay reproduction is that ideal habitat for jays is limited. Inexperienced yearling jays would probably have a hard time acquiring a good nest site and would be hard put to feed their offspring. Their best "reproductive bet," then, is to put their energy into helping their parents. Selfish yearling jays that try to nest on their own will probably contribute fewer genes to the next generation than the altruistic yearlings do. This phenomenon, whereby the actions of an individual increase the survival or reproductive success of its relatives, is called kin selection.

As this example suggests, *kin selection can favor the evolution of altruism if the altruistic behavior benefits relatives that bear the same altruistic allele*. In most cases, an animal will not know if another carries the altruism allele, but the animal must at least be able to distinguish relatives from strangers: Relatives stand a good chance of possessing the altruism allele, but you never can tell with strangers. A yearling jay that helped out at the nest of unrelated adult jays would probably waste its time and effort.

Identification of relatives isn't too hard to imagine in the case of jays and their parents. Many biologists objected to other proposed instances of altruistic behaviors, however, arguing that animals cannot evaluate degrees of relatedness. Two findings seem to address this objection. First, many social groups, including wolf packs and baboon troops, are actually family groups. Therefore, an animal would not have to identify relatives in order for its altruistic behaviors to benefit them the most. Second, many animals, including birds, monkeys, tadpoles, bees, and even tunicate larvae, can indeed identify relatives (Fig. 17-19). Given the choice between relatives and strangers, these animals preferentially associate with their relatives, *even if they were separated at birth and have never seen those relatives before*. If animals selectively form related groups, then altruistic behaviors will most likely benefit relatives. Although it is not the only mechanism, kin selection has been a powerful selective force in the evolution of altruism in many species, probably including humans.

Figure 17-19 **Cannibalistic animals don't eat close relatives**

Spadefoot toad tadpoles, found in transient water holes of the Arizona desert, are cannibalistic. Many of their prey, however, are released unharmed after being tasted briefly. Researchers have discovered that the tadpoles can indeed distinguish, and spit out, their own brothers and sisters, preferring to eat unrelated members of their own species.