

Biology

MILLER • LEVINE

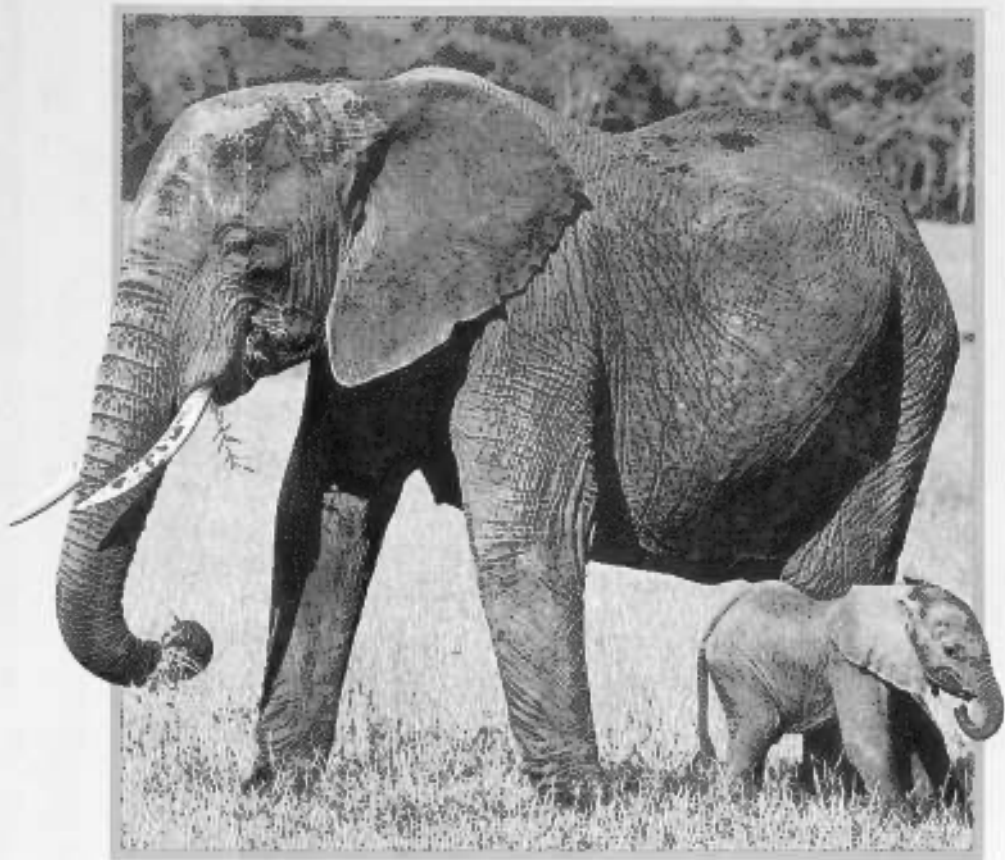
NEW EDITION



PRENTICE HALL



Biology



This book is dedicated to the African elephant, the largest living land mammal, which was placed on the endangered species list in October 1989.





Biology



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The illustration on the cover depicts a group of African elephants.

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SECOND EDITION

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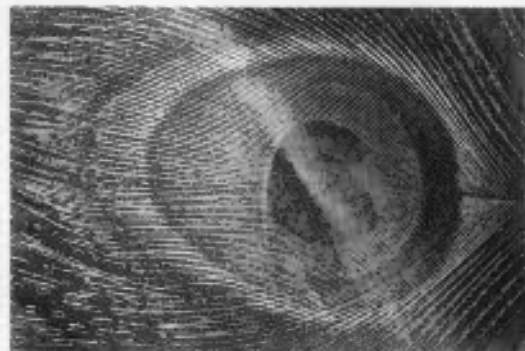
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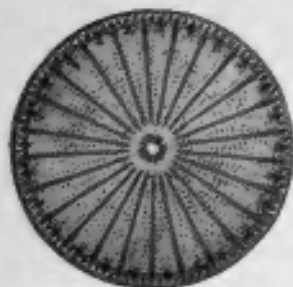
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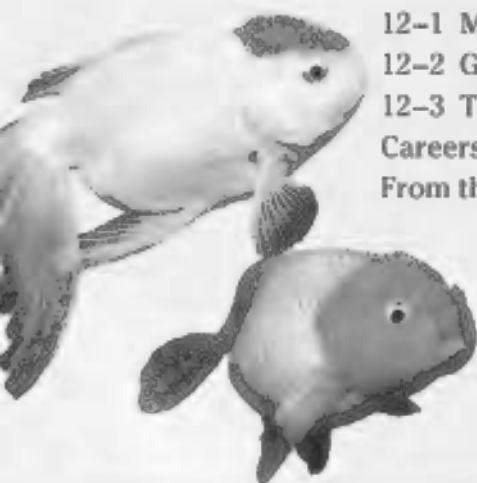
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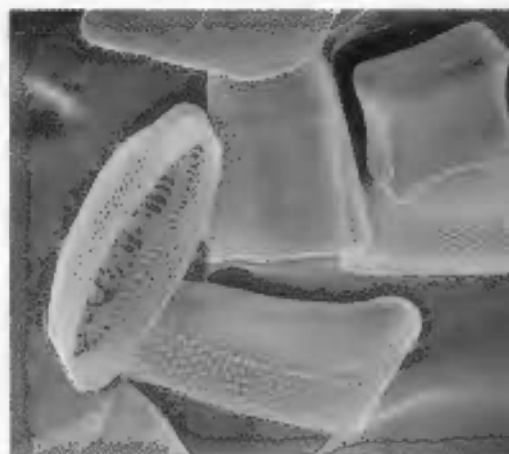
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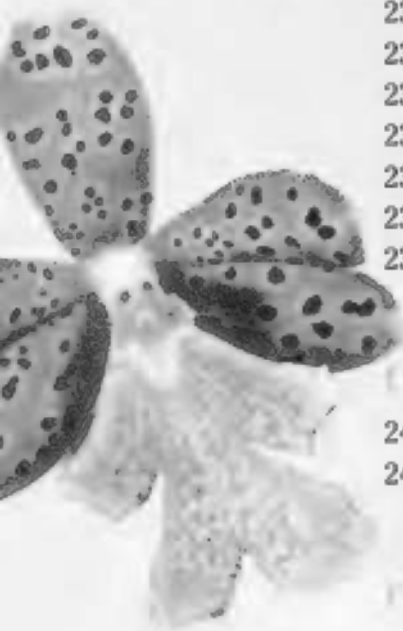
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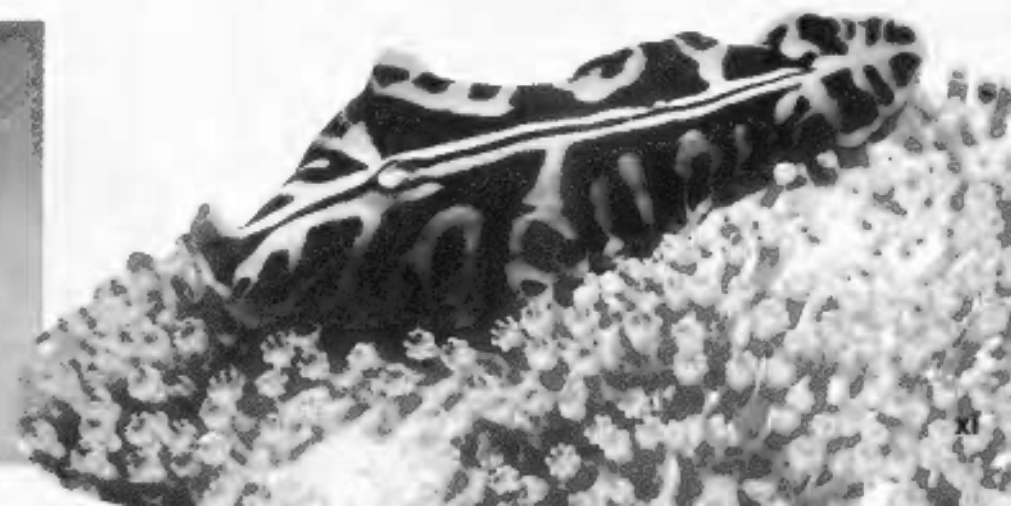


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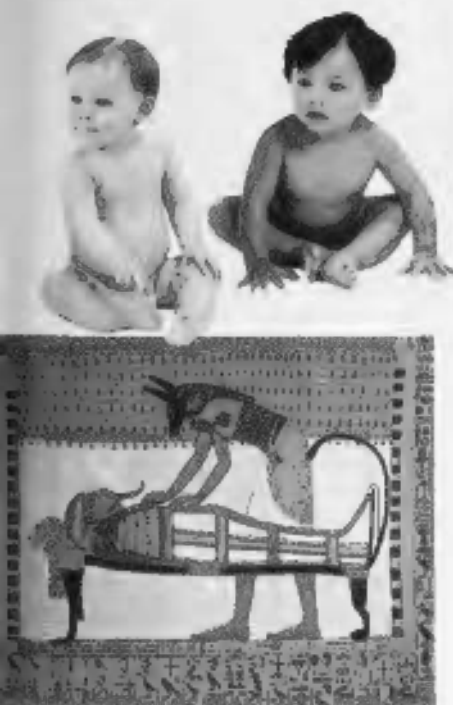
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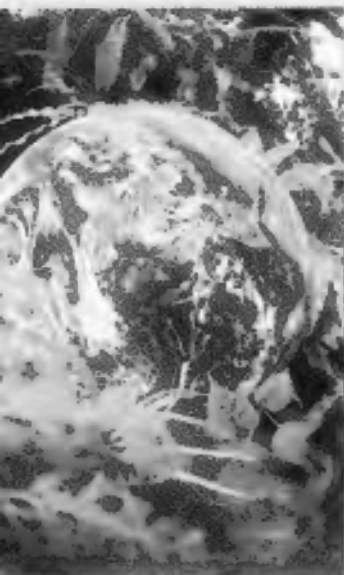
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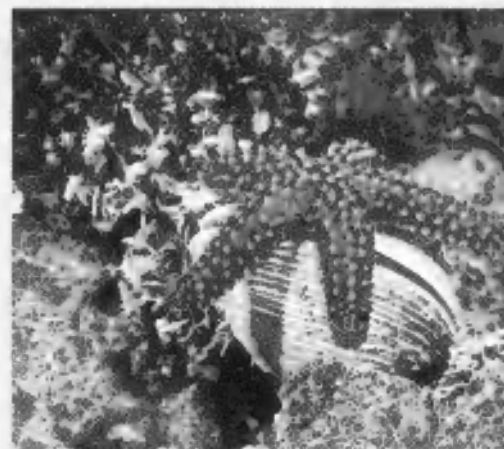
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Welcome!

You are about to enter a wonderfully exciting, and sometimes unbelievable, world—the world of living things. In the pages of this textbook you will come to understand the nature of life as we know it today. You will also gain an appreciation of the scientific process that has resulted in the body of knowledge we know as biology.

Your journey through biology will be guided in large part by your teacher and this textbook.

There is much to learn between these covers! Great care has been taken to write and present the concepts of biology in a way that makes your learning easier.

But you have an important role to play in the process—to learn to use your textbook effectively. The following pages illustrate some of the features that were designed with you, the student, in mind.



Unit Openers and Chapter Openers provide a visual preview of the material to come. Enjoy these photographs as you begin thinking about the material you will study in the unit and as you begin making connections among the chapters in the unit.

The **Chapter Outline** represents the major divisions found in the chapter. Read the outline in order to familiarize yourself with the organization and content of the chapter.

Skim the section using the subsection titles and the visuals with their captions. Then as you read more carefully, focus on the **Section Objectives** and the **boldfaced Key Idea**. These features will enhance your ability to organize the material you read.



As you read each section, complete the **Chapter Outline** by filling in the details. The handwritten outline you see below is an example of how Section 41–2 might be completed.

CHAPTER OUTLINE

41-1 The Circulatory System

- The Heart
- How the Heart Works
- The Heartbeat
- Blood Vessels
- Pathways of Circulation
- Blood Pressure
- The Lymphatic System

41-2 Blood

- Blood Plasma
- Blood Cells

41-3 The Excretory System

- The Kidneys
- Control of Kidney Function

I. Blood

A. Function of blood

1. Transports nutrients, dissolved gases, enzymes, hormones, wastes
2. Regulates body temperature, pH, electrolytes
3. Protects body
4. Restricts fluid loss

B. Blood Plasma

1. 90% water, 10% dissolved fats, salts, sugars, proteins

- a. albumins
- b. globulins
- c. fibrinogens

C. Blood Cells

1. Red blood cells
2. White blood cells
3. Platelets and blood clotting

Check your understanding of concepts by completing the **Section Review** questions.



As the authors note, the results of this study are consistent with the findings of other studies that have shown that the use of a decision support system can improve the performance of a task. The authors also note that the results of this study are consistent with the findings of other studies that have shown that the use of a decision support system can improve the performance of a task.



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[illegible]

considerable uncertainty, especially in the highly variable weather conditions that the region is subject to. The authors note that the model is not intended to be used for the purpose of predicting the exact timing of the onset of the rainy season, but rather to provide a general indication of the likely timing of the onset of the rainy season.

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From the perspective of speed and its effect on performance

a time means "not"
 I'll never be home
 only a small
 what's going on
 nothing at all
 a feeling of awe, respect
 always have I say
 have, we are right
 for months on end
 got a double
 ice
 to please
 all over a subject
 now?

1. The four millionaires are all in different villages. For the

- Two fish specimens are shown in adjacent columns. The fish on the left is a male, and the fish on the right is a female. The male fish is shown in a more active pose, with its mouth open and its fins spread. The female fish is shown in a more passive pose, with its mouth closed and its fins tucked. The fish are shown in a naturalistic setting, with a background of water and rocks.

[illegible]

1. How many strands come from each end with us the
 2. How many strands come from each end with us the

5. When you did your trial in the classroom, how many students were assigned within the group? How many stayed over the control? How many did not?

1. How does the speaker justify his choice to spend his days in the mill? Is he really that desperate for a job?
2. Why does the speaker prefer the low light in the mill to the sun? "There is light" is the only light he has had.
3. Why does the speaker prefer the low light in the mill to the sun? "There is light" is the only light he has had.
4. How does the speaker describe the work at the mill? Is it really that bad?

Use Science, Technology, and Society to further apply the biology you are learning and the thinking skills you are developing to evaluate current topics in your world.

Experience biology as a process as well as a body of knowledge. Think about the scientific approach not only as you conduct **Laboratory Investigations** but as you read about the scientific discoveries of others.



The key concepts in each section of a chapter are listed in **Summarizing the Concepts** to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of the chapter.

Vocabulary terms are important to your understanding of biology. The key terms listed in **Reviewing Key Terms** are those you should be especially familiar with. Review the terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

Test your knowledge of the facts presented in the chapter by answering the **Content Review** questions. These facts form the basis of fundamental concepts.

Evaluate your understanding of the concepts by answering the **Concept Mastery** questions.

Apply your factual knowledge and your concept understanding by answering the **Critical and Creative Thinking** questions.

CONTENT REVIEW

Multiple Choice

1. Which of the following is a characteristic of a population?
 - a. birth rate
 - a. growth rate
 - a. carrying capacity
 - a. density
2. Which of the following is a characteristic of a population?
 - a. birth rate
 - a. growth rate
 - a. carrying capacity
 - a. density
3. Which of the following is a characteristic of a population?
 - a. birth rate
 - a. growth rate
 - a. carrying capacity
 - a. density
4. Which of the following is a characteristic of a population?
 - a. birth rate
 - a. growth rate
 - a. carrying capacity
 - a. density

True or False

1. A population is a group of individuals of the same species that live in the same area at the same time.
2. A population is a group of individuals of the same species that live in the same area at the same time.
3. A population is a group of individuals of the same species that live in the same area at the same time.
4. A population is a group of individuals of the same species that live in the same area at the same time.

Short Answer

1. Explain the difference between a population and a community.
2. Explain the difference between a population and a community.
3. Explain the difference between a population and a community.
4. Explain the difference between a population and a community.

CONCEPT MASTERY

Applying Concepts

1. Applying concepts: If a population is growing, what factors might be causing it to grow?
2. Applying concepts: If a population is declining, what factors might be causing it to decline?
3. Applying concepts: If a population is stable, what factors might be causing it to be stable?
4. Applying concepts: If a population is fluctuating, what factors might be causing it to fluctuate?

Critical and Creative Thinking

1. Applying concepts: If a population is growing, what factors might be causing it to grow?
2. Applying concepts: If a population is declining, what factors might be causing it to decline?
3. Applying concepts: If a population is stable, what factors might be causing it to be stable?
4. Applying concepts: If a population is fluctuating, what factors might be causing it to fluctuate?

Your enjoyment and understanding of *Biology* by Kenneth Miller and Joseph Levine will be enhanced if you follow the suggestions presented here. We hope you will keep our three R's of biology in mind as you journey through the world of living things:

- Relevance**—to connect biology with your everyday life.
- Respect**—to develop a high regard for the environment.
- Responsibility**—to help you make informed decisions.

A black and white portrait of Kenneth R. Miller, a man with a beard and mustache, wearing a light-colored shirt. He is looking directly at the camera.

Kenneth R. Miller was born in 1948 in Rahway, New Jersey. He attended the public schools there and graduated from Rahway High School in 1966. He was already interested in science—often experimenting with a chemistry set in his basement and winning second prize in a science fair with a project on *Euglena*. Miller attended Brown University on a scholarship to study biology and earned his degree in 1970. He was awarded a National Defense Education Act fellowship and earned a Ph.D. in biology at the University of Colorado in 1974. After teaching at Harvard University for six years, he is now Professor of Biology at Brown University in Providence, Rhode Island, where he teaches courses in general biology and cell biology.

Miller is a cell biologist whose research specialty is the structure of biological membranes. His most recent work involves electron microscope studies of photosynthetic membranes from plants and photosynthetic microorganisms. He has published more than 43 scientific papers in journals such as *Nature*, *The Journal of Cell Biology*, and *Scientific American*. Miller is also an editor for two scientific journals and has written and lectured on educational issues in biology. He is the former Chairman of the Education Committee of the American Society for Cell Biology.

Along with his wife, Jody, and two daughters, Miller lives on a small farm in Rehoboth, Massachusetts. He coaches Little League softball, is a competitor in the masters' swimming program, and enjoys bicycling.

Joseph S. Levine was born in 1951 in Mount Vernon, New York, and graduated from Mount Vernon High School in 1969. He earned a Bachelor's degree from Tufts University, a Master's degree from the Boston University Marine Program in Woods Hole, and a Ph.D. from Harvard in 1980. He taught at Boston College for six years and was awarded a fellowship in Science Broadcast Journalism at WGBH-TV in Boston.

Levine is president of Boston Science Communication, Inc., specializing in educational films and videos. He has published in magazines ranging from *Science* to *Smithsonian* and has written two books on aquatic subjects. While at WGBH, he co-produced the prime-time television program *Science Gazette*, as well as science features for National Public Radio's *Morning Edition* and *All Things Considered*. Working with the NOVA staff, he assembled a proposal for an eight-hour series on molecular biology entitled *The Secret of Life*, for which he is currently writing the companion book. He has also designed exhibit programs for major public aquaria in Texas, New Jersey, and Florida, as well as an AIDS-awareness exhibit for the California Museum of Science and Industry.

Levine lives in Boston, where his century-old home occupies as much of his time as he allows. There, he gardens and collects tropical fishes, as he has since he was a child. Levine also enjoys bicycling, windsurfing, and skiing, and he treasures rare opportunities to scuba dive or to hike through wilderness areas.



TO
THE
STUDENT

Dear Reader:

We wrote this book so that you would have the opportunity to read about the science of biology. We hope that you will come away well-informed and enlightened about the living world around us. But we had a second goal as well: to convey some of the wonder and excitement felt by those who have been lucky enough to be involved in scientific work.

Science is not a dehumanized process carried out in white-walled laboratories. It is a human activity, subject to all the faults and frailties of our species. But most of all, there is a secret that scientific institutions and textbooks have often managed to conceal: **Science is fun!** Despite the constant frustrations of delicate equipment, difficult observations, and complicated experiments, scientists *enjoy* what they do.

The openness of science means that everything is subject to proof, and many of today's widely held ideas may have to be abandoned in the future. Scientific textbooks seem to be full of information—almost as if everything interesting has already been observed, measured, and cataloged. Wrong! Many people in the nineteenth century believed that science had progressed about as far as it could and that everything from then on would just involve filling in the details. Yet nearly everything in this book is based on discoveries in the twentieth century, and much of it from just the last ten years. Has biology solved all of its important scientific problems? Of course not!

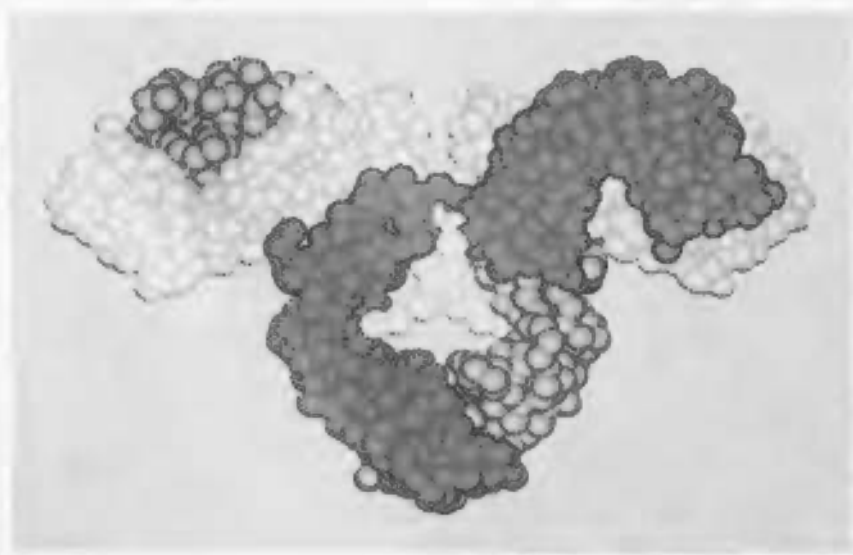
We believe that our present knowledge represents only a fraction of what the world holds for us to discover. Quite frankly, the interesting work is just beginning—and nothing would reward us more than knowing that a few of you who have used this book might decide to come along for the ride.

KENNETH R. MILLER
JOSEPH S. LEVINE

The World of Life

A computer-generated image of the chemical substance chlorophyll looks like an elaborate sculpture of strands and points of colored light. Chlorophyll is not alive; nor is any of the vast multitude of chemicals found in living things. However, when assembled correctly, these chemicals are capable of undergoing the complex interrelated chemical processes that we know as life.

What exactly is life? To answer this question we must gather, organize, and interpret information about living things. We must also examine concepts from the realms of other sciences such as chemistry, mathematics, geology, and physics. Through these endeavors we shall come closer to understanding and appreciating the complex nature of life.



CHAPTERS

1

The Nature of Science

2

Biology as a Science

3

Introduction to Chemistry

4

The Chemical Basis of Life



CHAPTER 1

The Nature of Science



Storks flying south to their winter home in Kenya

Toward the end of August, you may have taken a walk through your neighborhood. That neighborhood may be one of buildings and pavement, lawns and trees, fields and pasture, or even sand and cactus. Such walks often inspire questions. Why do days get shorter at this time of year? Why does grass stop growing in the fall? Why do some plants flower in spring and others in autumn? How do geese know when to fly south for the winter? How do they even know which way is south?

Like yourself, scientists ask themselves similar questions about their world. Sometimes they find answers—as you do. Sometimes the answer remains to be discovered. And sometimes there is no answer. The important point is not finding the answer but asking the question. For making observations and asking questions is at the very heart of the process known as science.

1-1 What Is Science?

1-2 The Scientific Method

- Observing and Stating a Problem
- Forming a Hypothesis
- Testing the Hypothesis
- Recording and Analyzing Data
- Forming a Conclusion
- Replicating the Work
- Hypotheses and Theories
- The Scientific Method—
An Everyday Experience
- A Universal Language—
The Metric System

1-3 Science: "Facts" and "Truth"

- How to Study Science
- Science and Human Values

1-4 Safety in the Laboratory

1-5 The Spaceship Called Earth

1-1 What Is Science?

Section Objective

- Identify the main goal of science.

Asking questions about the world around us is part of human nature. How did life begin? Where did plants and animals come from? Why do animals behave as they do? Every culture in the world has tried to answer these questions—often through myths and legends.

The Pitjendara tribe of central Australia, for example, finds answers to questions about nature on an enormous mound of stone called Ayer's Rock. The rock, which towers more than 300 meters above the flat desert around it, has been carved by centuries of exposure to wind and rain. Erosion has etched gullies and caverns into the rock, and has produced striking formations on its surface. See Figure 1-1.

According to the Pitjendara, the images etched on Ayer's Rock tell stories that depict the adventures, the loves, and the battles of ten enormous creatures. The rock contains the likenesses of two snakes, Liru and Kunia. The Pitjendara believe that the two snakes fought an epic battle that created many features on the southern face of Ayer's Rock. Elsewhere on the rock, a sand-lizard man left his mark digging for water. Through these and other stories, the Pitjendara explain the formation of the world and the processes of birth, life, and death.

The stories of the rock also detail the connections between the tribe and animals important in their everyday lives: snakes,



Figure 1-1 To the Pitjendara, these etchings on Ayer's Rock represent the human brain.

Figure 1-2 Ayer's Rock in central Australia is the largest individual rock in the world. Why might people who live their entire lives in this area develop myths and legends about Ayer's Rock?



Figure 1-3 These stone statues were created by people living on Easter Island in the Pacific Ocean. The statues may well represent the Easter Islanders' belief that the first humans hatched from eggs brought to Earth by a bird-man.



desert lizards, and kangaroos. The stories even explain the origins of dreams. We might say that the rock provides the Pitjendara with answers that other societies seek through a process known as science.

People like the Pitjendara live their entire lives in a single culture. Thus, they often find it difficult to imagine that their particular stories about the world might be in error. Today, however, we can visit and read about many cultures. And when we assemble stories from around the globe, it becomes obvious that all these stories cannot be true.

Is there some other way to explain the world around us? One way is to assume that all events in nature have natural causes. We can then try to arrange a series of observations or tests to learn what those causes are. **Science** is the word that we apply to this process. **The goal of science is to understand the world around us.** There are, however, many important fields of human endeavor that study the world around us but are not considered sciences. Such fields include language, history, art, music, and philosophy. The character that distinguishes science from nonscience is an approach known as the scientific method.

1-1 SECTION REVIEW

1. What is the goal of science?
2. Compare the study of science with the study of literature. How do they differ? How are they similar?

1-2 The Scientific Method

The simplest definition of the **scientific method** was offered by biologist Claude Villee. He called it "Organized common sense." That is exactly what science should be. **In practice, the scientific method consists of several steps:**

- Observing and stating a problem
- Forming a hypothesis
- Testing the hypothesis
- Recording and analyzing data
- Forming a conclusion
- Replicating the work

To the true scientist, however, the scientific method is more a frame of mind—a frame of mind that involves curiosity. For without curiosity about nature, there would be no interest in why the sun appears to rise and set, why the seasons change, or why a snake sheds its skin. Another important characteristic of the scientific spirit is the refusal to accept an explanation without evidence or proof. This "prove it!" attitude encourages scientists to investigate phenomena and to develop new explanations and ideas.

Observing and Stating a Problem

The process of science starts with an observation. For example, we might notice that the leaves of maple trees turn bright red and yellow in autumn. As curious scientists, we would then be interested in discovering why this color change takes place.

Section Objectives

- Describe the steps in the scientific method.
- Compare a control setup and an experimental setup.
- Identify the basic units of length, mass, volume, and temperature in the metric system.

***Figure 1-4** The changing colors of the leaves in Vermont is an event to which people travel from all over the country to enjoy. What hypothesis could you suggest to explain why the leaves of many trees change color in autumn?*



Forming a Hypothesis

We proceed to gather information that helps us generate a **hypothesis**. A hypothesis is a possible explanation, a preliminary conclusion, or even a guess about some event in nature. For example, we can observe that maple leaves change color when the air gets colder. We might then hypothesize that color changes in maples are related to changes in temperature.

Testing the Hypothesis

Next we must test our hypothesis. Some hypotheses may be tested simply through further observation. As you will discover in Chapter 13, Charles Darwin spent most of his life in the field observing nature to test his hypotheses about evolution. Most hypotheses, however, must be tested by experiments. The “autumn leaves” hypothesis falls into this category.

Our observations indicate that leaves change color in the autumn. And our hypothesis is that the color change is related to changes in temperature. We must now perform a test to find out if this is a correct explanation. One experiment we might do is to take a small maple tree growing in a pot and place it in a growth chamber during the month of July. We would lower the temperature to typical autumn levels, about 14°C during the daytime and 3°C at night. If our hypothesis is correct, we might see the leaves begin to change color almost immediately.

Suppose we ran this experiment and the leaves did change color. Would we know for certain that changes in temperature alone were responsible for the color change? After all, there are many differences between the tree in our experiment and a tree in the woods. Did the leaves on our tree turn red because the tree was planted in a small pot? Or because the light inside the growth chamber was different from natural light?

These uncertainties point out the need for a more complicated experiment using at least two trees. We should choose two similar trees and pots of the same size, water the trees at the same time, and place them in identical chambers. We should then conduct an experiment in which one chamber is kept at normal summer temperatures while the other chamber is cooled to autumn temperatures.

Why must we go to the trouble of observing a second tree? This two-part test represents what is called a **controlled experiment**. Controlled experiments allow researchers to isolate and test the effects of a single factor, or **experimental variable**. In this case, the treatment of the first tree serves as our **control setup** by testing the effects of the pot and growth chamber. The treatment of the second tree, our **experimental setup**, is identical to the control setup in every respect except one—the variable of temperature. See Figure 1-5. Now if we observe a difference between the experimental setup and the control setup, we can be more certain that it is due to the lower temperatures in the experimental chamber.



Figure 1-5 Whenever possible, an experiment should have both a control setup and an experimental setup. Which part of the experiment contains the variable? What is the variable in this experiment?

Recording and Analyzing Data

If we were actually to perform this experiment, we would keep careful records of observations and information, or **data**. In this case, such data might include the time it took for each leaf to change color, the total number of leaves on each tree that changed color or fell off, and so on. We might arrange our data in the form of tables and graphs, such as those shown in Figure 1-6. You can see why researchers use these visual representations of experimental data to analyze their results.

EXPERIMENTAL SETUP: Autumn Temperatures											
Day	1	3	5	7	9	11	13	15	17	19	21
Number of Green Leaves	50	50	50	49	49	48	48	48	48	47	47

CONTROL SETUP: Spring Temperatures											
Day	1	3	5	7	9	11	13	15	17	19	21
Number of Green Leaves	50	50	49	49	49	49	49	47	47	47	47

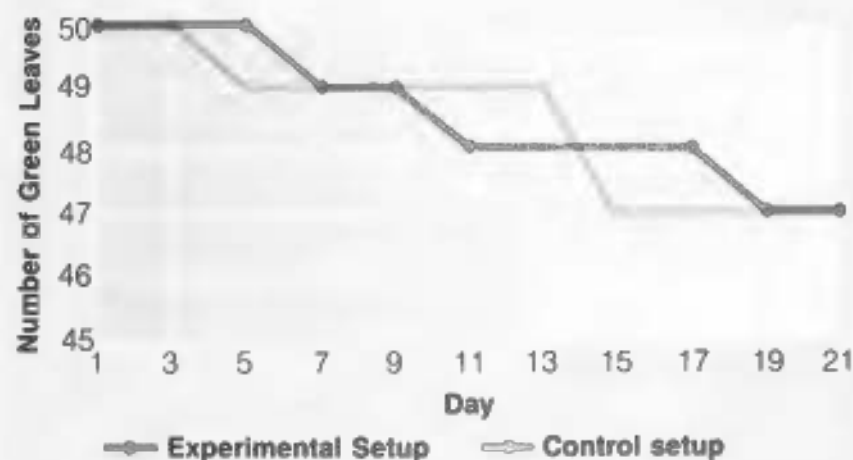


Figure 1-6 Information gathered from an experiment is usually organized in data tables (top). Then the data may be graphed in order to provide a visual representation that is easy to interpret (bottom). Using the data tables and the graph, what conclusions can you reach about the autumn leaves hypothesis?

Forming a Conclusion

If we find that the leaves on our experimental tree change color and those on the control tree do not, we may decide that we have confirmed our original hypothesis: Cold temperatures cause leaves to change color. If the leaves of neither tree change color or if the leaves of both trees change color, we might reject the hypothesis as wrong and start all over with a

new idea. This is often the case in science because many guesses about the natural world prove incorrect. But this is also the way science advances, for it points the way to further experiments. If the leaves on neither tree change color, for example, it is possible that temperature alone is not responsible. Perhaps trees also respond to changes in the length of day, decreases in rainfall, or the action of strong winds. These new hypotheses suggest additional experiments that expand our understanding.

Although such experiments are probably impossible for you to perform yourself, scientists have been able to do them and have arrived at an answer to our original hypothesis: Do the colder temperatures of autumn cause a color change in the leaves of maple trees? If you have examined the data in Figure 1–6, you know part of their conclusion: Colder temperatures alone do not cause the color change. Scientists now know that colder temperatures combined with a change in the length of day both play a role in the color change in maple leaves. In addition, many scientists believe that a biological clock within the maple tree also plays a role. But how does this biological clock work? And what chemical triggers the clock? These are questions that as yet remain unanswered. If you should choose to pursue biology as a career, perhaps you will consider these questions once again.

Replicating the Work

The best scientific experiments can be replicated, or reproduced. In other words, it must be possible for either the original experimenter or other researchers to duplicate, or reproduce, the experimental results. Reproducibility in science takes many forms. We might want to replicate the experiment ourselves several times. Or we might want to put several trees in each growth chamber. Such actions would assure us that our results were not due to chance.

Another form of reproducibility is the replication of work by others. If interesting results come from an experiment, a researcher will publish a report of the work in a scientific journal. The report must contain enough detail so that other scientists can copy the experiment precisely to see if the same results continue to occur.

Hypotheses and Theories

When a hypothesis is tested and confirmed often enough that it is unlikely to be disproved by future tests, it may become worthy of being called a **theory**. In scientific usage, the word theory means a great deal more than it does in common speech. Scientific theories are not just hunches or hypotheses. They are powerful, time-tested concepts that make useful and dependable predictions about the natural world.

The Scientific Method— An Everyday Experience

Because many experiments discussed in this book were performed by people called scientists, you might think that science is a special process used only by certain people and useful only under special circumstances. That is not true at all. We all use the scientific method every day!

Let's suppose, for example, that a car will not start. A mechanic will form and test hypotheses about the problem. Perhaps the battery is dead. One experiment would be to crank the starter to see what happens. If the starter motor works but the car still doesn't turn over, it could be that the car is out of gas. A glance at the fuel gauge would test that idea. Again and again, the mechanic would apply the scientific method until the problem is solved. The same technique can find a fault in an electrical circuit or balance a load of laundry in a washing machine. Remember, science is just organized common sense.

A Universal Language—The Metric System

Science works best when scientists everywhere read each other's papers, check each other's experiments, and argue about what those experiments mean. Because most experiments involve measurements, researchers need a universal system of measurement in which to present their findings. **Scientists use the metric system of length, volume, mass, and temperature when describing experiments and data.** The **metric system** is a decimal system based on certain standards and scaled on multiples of 10. The metric system is also known as the International System of Units, or SI.

Figure 1-7 The metric system is easy to use because it is based on units of ten. How many centimeters are there in 100 meters?

COMMON METRIC UNITS

Length

1 meter (m) = 100 centimeters (cm)
1 meter = 1000 millimeters (mm)
1 meter = 1,000,000 micrometers (μm)
1 meter = 1,000,000,000 nanometers (nm)
1 meter = 10,000,000,000 angstroms ($\text{\AA}$)
1000 meters = 1 kilometer (km)

Mass

1 kilogram (kg) = 1000 grams (g)
1 gram = 1000 milligrams (mg)
1000 kilograms = 1 metric ton(t)

Volume

1 liter (L) = 1000 milliliters (mL) or
1000 cubic centimeters (cm^3)

Temperature

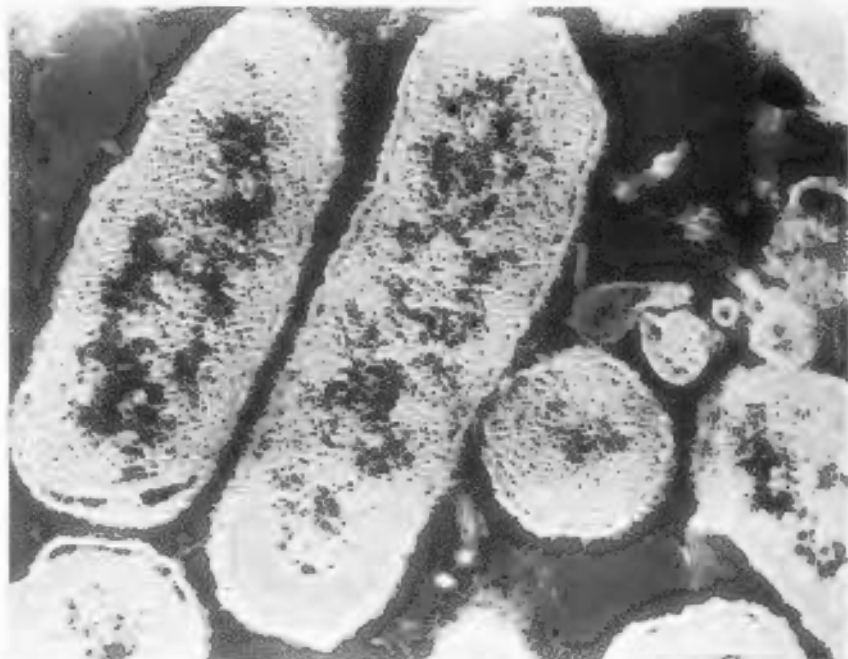
0°C = freezing point of water
 100°C = boiling point of water

kilo- = one thousand
centi- = one hundredth
milli- = one thousandth

micro- = one millionth
nano- = one billionth



Figure 1-8 Which unit of length would you use to measure this tall African giraffe (left)? This microscopic bacterium (right)?



LENGTH The basic unit of length in the metric system is the **meter (m)**. One meter is roughly equivalent to 39.4 inches, a little longer than a yard. To measure objects and distances much larger or smaller than a meter, the metric system uses units larger or smaller than a meter by multiples of 10. A centimeter (cm) is 1/100 of a meter—about the width of the nail on your pinky. As you may have guessed, the prefix *centi-* means one hundredth. A millimeter (mm) is 1/1000 of a meter. The prefix *milli-* means one thousandth. Even smaller units of length—such as those used to describe living cells, pieces of cells, and molecules—are shown in Figure 1-7 on page 11. To measure distances much greater than a meter, scientists use a unit called the kilometer (km). One kilometer contains 1000 meters. What does the prefix *kilo-* mean?

Figure 1-9 Solids are usually measured in cubic centimeters. One cubic centimeter is the volume of a cube measuring one centimeter on each side. Keep in mind the illustration is not drawn to scale.



Cubic Centimeter (cc or cm³)

VOLUME Volume is the amount of space an object occupies. The basic metric units of volume are the **liter (L)** for liquids and the **cubic centimeter (cc, or cm³)** for solids. A liter contains slightly more liquid than a quart. To measure small volumes of liquids, scientists use fractions of a liter called milliliters (mL). There are 1000 milliliters in a single liter. A cubic centimeter is the volume of a solid that measures 1 cm by 1 cm by 1 cm. Keep in mind that 1 milliliter is equal in volume to 1 cubic centimeter, or 1 mL = 1 cc.

MASS AND WEIGHT **Mass** is a measure of the amount of matter in an object. **Weight** is a measure of the pull of gravity on that mass. In outer space, the weight of an object may vary with its position, but its mass always remains the same. On Earth's surface, however, an object's mass and weight can



usually be considered constant and are often used interchangeably. The basic metric unit scientists use to describe mass is the **kilogram** (kg). One kilogram is equal to approximately 2.2 pounds. The mass of small objects is measured in grams (g). One gram is 1/1000 of a kilogram. How many milligrams (mg) are there in a gram? In a kilogram?

TEMPERATURE The metric system measures temperature using the **Celsius** (SEHL-see-uhs) **scale** ($^{\circ}\text{C}$). On this scale, water freezes at 0°C and boils at 100°C . Each Celsius degree, therefore, represents exactly 1/100 of the temperature range between the freezing and boiling points of water. Normal human body temperature is about 37°C , and comfortable room temperature is about 21°C .

Figure 1-10 The African elephant is among the largest land creatures ever to walk the Earth (left). The harvest field mouse is one of the smallest mammals on Earth (right). What unit would you use to measure the mass of the elephant? The harvest mouse?

Figure 1-11 You can see by the way this chameleon walks lightly across the hot road that temperature has an effect on almost all living things. Scientists measure temperature in degrees Celsius.

1-2 SECTION REVIEW

1. List each step in the scientific method.
2. Define hypothesis. Compare a hypothesis and a theory.
3. What is the only difference between a control setup and an experimental setup?
4. Must the steps in the scientific method always be followed in the same order? Explain your answer.
5. If an experiment does not confirm the hypothesis it was designed to test, has that experiment "failed"?



PROBLEM SOLVING IN BIOLOGY

DIMENSIONAL ANALYSIS

Many times in science you will need to convert one unit of measurement to another. For example, you might be given a problem in kilometers but need the answer in centimeters. The process of converting one unit to another is called dimensional analysis.

Dimensional analysis involves determining three important facts: in what unit your measurement is given, in what unit it should be expressed, and what relationship between the units will allow you to make the conversion. The relationship between the units is called a conversion factor. A conversion factor expresses an exact relationship between the original unit and the desired unit. It is a fraction whose value is 1. For example,

$$\frac{60 \text{ minutes}}{1 \text{ hour}} \text{ or } \frac{1 \text{ liter}}{1000 \text{ milliliters}}$$

Although the numerator (top) of the fraction

and the denominator (bottom) of the fraction are different, their actual values are the same. You see that 60 minutes equals 1 hour and 1 liter equals 1000 milliliters.

Any number can be multiplied by 1 without changing its value. Multiplying a measurement by a conversion factor, then, does not change the value of the measurement. This means that you can convert the given unit to the desired unit by multiplying by an appropriate conversion factor. You must, however, choose the correct form of the conversion factor. The unit to be converted must cancel out and the desired unit remain. Thus, the denominator of the conversion factor must contain the same unit as the one given to enable them to be canceled. Similarly, the numerator must contain the unit to be in the answer.

The following example shows how a typical dimensional analysis problem is solved.

Sample Problem Your friend runs 2500 meters while you run 3 kilometers. Using kilometers, which one of you has run a longer distance?

- | | | |
|----------------|---|--|
| Step 1: | Determine the given unit and the desired unit. | given: meters
desired: kilometers |
| Step 2: | Find the relationship between the units and consider the possible conversion factors. | 1000 meters = 1 kilometer
therefore:
$\frac{1 \text{ kilometer}}{1000 \text{ meters}} = 1 \text{ or } \frac{1000 \text{ meters}}{1 \text{ kilometer}} = 1$ |
| Step 3: | Choose the conversion factor whose denominator has the same units as your given value. | $\frac{1 \text{ kilometer}}{1000 \text{ meters}} = 1$ |
| Step 4: | Write the original value next to the conversion factor with a multiplication sign between them. Cancel like terms (shown in red). | $2500 \cancel{\text{ meters}} \times \frac{1 \cancel{\text{ kilometer}}}{1000 \cancel{\text{ meters}}}$ |
| Step 5: | Multiply the resulting equation. | $2500 \times \frac{1 \text{ kilometer}}{1000} =$
$\frac{2500 \text{ kilometers}}{1000} = 2.5 \text{ kilometers}$ |

Your friend has run 2.5 kilometers and you have run 3 kilometers. You have run the longer distance!

Practice Problems

Now try your hand at some dimensional analysis problems. You may choose to use a calculator or computer to do the arithmetic calculations.

1. In order to compare the results of several experiments, you need to have all your data in the same unit. Convert the following measurements to the same unit.

16 kilograms	0.002 kilograms
888 grams	155 milligrams

2. A recipe calls for 300 milliliters of water. You add 0.25 liters. Have you put in too much, too little, or the right amount?
3. Determine which of the following measurements is largest: 1800 centimeters, 2.1 meters, 0.0017 kilometers.
4. You are told that you need a jar with a volume of at least 150 cm^3 . The label on the jar you find says 0.16 liters. Can you use it?
5. Calculate the number of seconds in 1 year. Then calculate the number of seconds in a decade.

1-3 Science: "Facts" and "Truth"

Scientific knowledge is a constantly changing body of observations. Many "scientific facts" of the past are now known to be false. For much of human history, for example, people "knew" that the Earth was flat, that the sun revolved around the Earth, and that rain fell through holes in heaven from a huge water tank in the sky. Those were the "facts" of an earlier time.

Now, of course, we "know" that the Earth is round (more or less), that the Earth and other planets revolve around the sun, and that rain falls from clouds made of water vapor. These are the scientific "facts" of today—the best explanations of the world around us that scientists have developed so far.

But new discoveries will be made. New theories will be born. Without a doubt, some of what you learn this year will have to be changed one day. Yet this does not mean that science has failed. On the contrary, it means that science continues to succeed in advancing our understanding of the world. Science is not a collection of eternal truths. Rather, it is a process, a way of looking at and understanding the world. And science will continue to change as long as humans wonder about the universe.

Section Objectives

- Relate the process of science and change.
- Identify successful study habits.

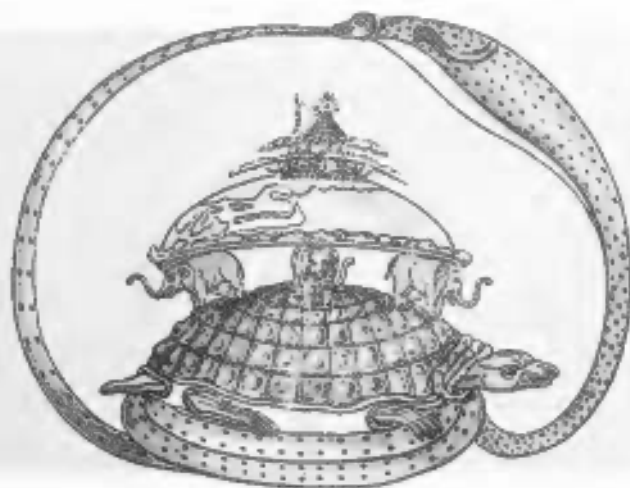


Figure 1-12 As knowledge grows, facts can change. This print depicts a Hindu legend that tells that the Earth is supported by three elephants resting on the back of a giant tortoise.



Figure 1-13 The giant panda (top, left), the white rhinoceros (top, right), and the mountain gorilla (bottom) all look very different. So it might seem that the best way to study these animals is to memorize individual facts about each one. However, if you organize them as a group of mammals, then you will find it easier to learn about them. For all mammals share certain characteristics, no matter how different they may appear. These three particular mammals have another important thing in common—they are endangered species.



How to Study Science

We, as scientists, sincerely hope that you will find your study of science to be both interesting and rewarding. For an understanding of science is essential to all of us in today's high-tech world. To make your learning easier and more enjoyable, we suggest you study science in a special way. First, do not try to memorize the contents of this book as a list of separate facts. Learning science this way will only make the process more difficult than it needs to be. Isolated facts will show little connection with each other in your mind. It will be as though you wrote each fact on a separate index card and then shuffled dozens of index cards together.

It makes much more sense to arrange facts you need to know in groups according to subject. As you read this book, work at understanding, rather than just memorizing, the topics we talk about. When you study the parts of the cell, for example, don't just memorize their names. Think about what each

part does. Remember how each part works with other parts within the cell as a whole. Learning this way is like organizing the index cards of facts into groups that have meaning for you. Then when you need a particular fact, you can look for it under its proper subject heading. That will make it much easier to remember what you need.

Second, remember that science is a process. In addition to learning the scientific facts of today, try to appreciate the process of discovery. Try to see the thinking behind the experiments we describe. Try to understand the kinds of questions scientists ask as they struggle to make sense out of the world. Follow along as we describe the discovery of genes and the development of evolutionary theory. If you can learn to think the way scientists think, you will get a lot more than facts from this course. You will develop the ability to understand the process of science and to be at home in a world that will change constantly throughout your life.

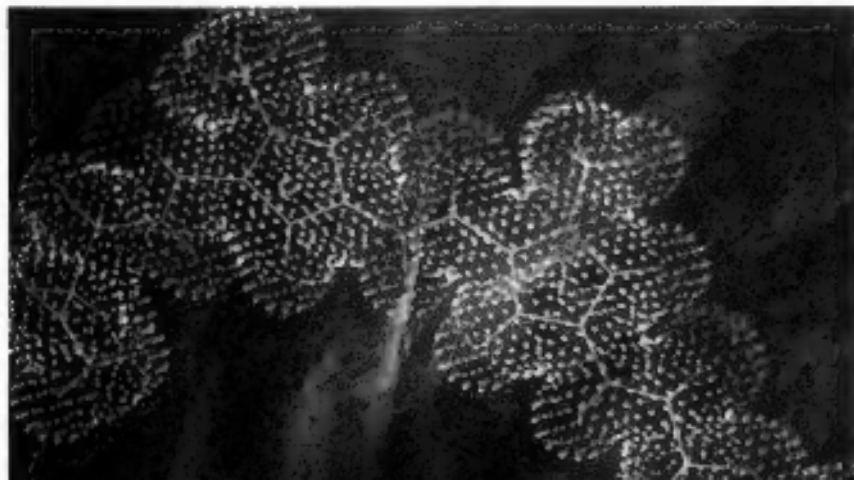
Science and Human Values

An important goal in science is to be objective. But scientists are no different from the rest of us when it comes to emotions or personal opinions. Scientists, after all, are people too—people with likes, dislikes, and occasional biases.

In today's world, scientists have important things to say about questions that are raised regarding health, society, and the environment. Shall we build a nuclear power plant? Dam a river? Develop forest lands into homesteads? Should chemical wastes be buried, burned, or dumped at sea? Are there ways to use chemical wastes for our benefit? Should certain experiments involving humans be forbidden? All of these questions rely on science for at least part of their answers.

But scientific data can be misinterpreted or misapplied by scientists who want to prove a particular point. And decisions made by scientists with personal prejudices may or may not be in the public interest. What this means to you is that understanding science is even more important today than ever before. If enough people understand the nature of science, the dangers posed by misinterpreted or misleading information will be reduced.

Figure 1-14 No doubt about it — we live in a high-tech world. Computers are now used to show the chemical structure of molecules such as this portion of a human protein (left). Advances in physics, such as superconductors (right), may revolutionize the ways in which we travel and transmit electricity. As a citizen, you will have to make important decisions about the role of science in society. In order to do this, you must be able to read, understand, and evaluate scientific information.



Luckily, men and women of science are taking action. Biologists, chemists, and physicists are speaking out about safety problems involved with nuclear power. Biologists and chemists are warning of the dangers posed by too many chemicals in food and water. And biologists are describing the serious threat to our environment posed by acid rain. We will touch on these and other matters in this book, and we hope that you will keep track of such issues, both in your local community and in the world at large.

1-3 SECTION REVIEW

1. Science will not sit still and allow itself to be memorized. You cannot "learn" biology, stick it away in some mental closet, and pull it out years later. Why is this the case?
2. What is the best way to study science? Why?
3. Why is it important that everyone understand the process of science and the nature of scientific facts?

Section Objective

- Identify and apply proper rules when working in the laboratory.

1-4 Safety in the Laboratory

Biology does not happen in books or in scientists' minds. Biology is most alive and exciting where the experiments that test hypotheses actually take place—in the laboratory and in the field. That is why your course in biology will probably include several laboratory exercises. Only in the laboratory can you perform experiments to learn about the process of science at first hand. Only in the laboratory can you see, touch, and manipulate living systems to understand them more thoroughly.

In the laboratory—as in any place where there are chemicals, flames or heating elements, hot liquids, and electricity—it is important to follow certain basic safety precautions. These precautions are not directed only at you as students. Scientists with many years' experience know that laboratory safety is of prime importance. The experiments you will carry out this year have been tried and tested many times. When properly performed, they are both interesting and educational. However, if laboratory materials are handled carelessly, accidents can happen.

The single most important rule for you in the laboratory is simple: Always follow your teacher's instructions and the textbook directions exactly. If you are in doubt about what to do, always ask first. Use Figure 1-16 to familiarize yourself with safety symbols and the rules of laboratory safety. Read the rules and make certain that you understand them. If you are not sure that you understand a rule completely, ask your teacher to explain it.

Figure 1-15 What important safety precautions are these students taking while working in the laboratory?



LABORATORY SAFETY: RULES AND SYMBOLS

Glassware Safety



1. Whenever you see this symbol, you will know that you will be working with glassware that can easily be broken. Take particular care to handle such glassware safely. And never use broken glassware.
2. Never heat glassware that is not thoroughly dry. Never pick up any glassware unless you are sure it is not hot. If it is hot, use heat-resistant gloves.
3. Always clean glassware thoroughly before putting it away.

Fire Safety



1. Whenever you see this symbol, you will know that you will be working with fire. Never use any source of fire without wearing safety goggles.
2. Never heat anything—particularly chemicals—unless instructed to do so.
3. Never heat anything in a closed container.
4. Never reach across a flame.
5. Always use a clamp, tongs, or heat-resistant gloves to handle hot objects.
6. Always maintain a clean work area, particularly when using a flame.

Heat Safety



Whenever you see this symbol, you will know that you should put on heat-resistant gloves to avoid burning your hands.

Chemical Safety



1. Whenever you see this symbol, you will know that you will be working with chemicals that could be hazardous.
2. Never smell any chemical directly from its container. Always use your hand to waft some of the odors from the top of the container toward your nose—and only when instructed to do so.
3. Never mix chemicals unless instructed to do so.
4. Never touch or taste any chemical unless instructed to do so.
5. Keep all lids closed when chemicals are not in use. Dispose of all chemicals as instructed by your teacher.

6. Immediately rinse with water any chemicals, particularly acids, off your skin and clothes. Then notify your teacher.

Eye and Face Safety



1. Whenever you see this symbol, you will know that you will be performing an experiment in which you must take precautions to protect your eyes and face by wearing safety goggles.
2. Always point a test tube or bottle that is being heated away from you and others. Chemicals can splash or boil out of the heated test tube.

Sharp Instrument Safety



1. Whenever you see this symbol, you will know that you will be working with a sharp instrument.
2. Always use single-edged razors; double-edged razors are too dangerous.
3. Handle any sharp instrument with extreme care. Never cut any material toward you; always cut away from you.
4. Notify your teacher immediately if you are cut in the lab.

Electrical Safety



1. Whenever you see this symbol, you will know that you will be using electricity in the laboratory.
2. Never use long extension cords to plug in an electrical device. Do not plug too many different appliances into one socket or you may overload the socket and cause a fire.
3. Never touch an electrical appliance or outlet with wet hands.

Animal Safety



1. Whenever you see this symbol, you will know that you will be working with live animals.
2. Do not cause pain, discomfort, or injury to any animal.
3. Follow your teacher's directions when handling animals. Wash your hands thoroughly after handling animals or their cages.

1-4 SECTION REVIEW

1. What is the most important general rule to follow when working in the laboratory?
2. Where is the nearest fire extinguisher located in your laboratory or classroom?
3. What sort of instruments might you be more likely to find in a biology laboratory than in a chemistry laboratory?

Figure 1-16 You will see these safety symbols in the *Laboratory Investigations* in this textbook and in your *Laboratory Manual*. Make sure you understand the meaning of each symbol. If you are not sure what a symbol means, ask your teacher.

The Odd Couple: A Messy Lab and a Keen Mind

Some of us professional scientists, despite our efforts, aren't very neat workers in the lab. Oh, sure, we can keep things sterile when they need to be. But as a rule, some of us are a little messy and disorganized. Does that fit in science? Does it match our description of the scientific method? It may not match, but the messy scientist is in good company. One messy scientist was a man named Alexander Fleming.

History records at least two of Fleming's sloppy mistakes. The first was in 1922. He was suffering from a bad cold and accidentally allowed a few drops from his runny nose to drip on a plate of bacteria he was growing. Instead of discarding the dish, Fleming watched it for days. What happened? Lo and behold—the bacteria died! Fleming had discovered lysozyme, a chemical

in tears and mucus that helps protect the body against bacteria.

More important work followed. Six years later, Fleming was growing more bacteria. He saw that some of his plates had been contaminated with a greenish mold (*Penicillium*) that grows on bread. Once again Fleming's sloppiness was to blame. But his careful eye and keen mind made something of the event. He saw a clear spot on the culture dish, indicating that the bacteria near the mold had died.

The mold was making something that was killing the bacteria. That something turned out to be a chemical that has saved millions of lives: penicillin. Science works that way. It is a very human enterprise—one that even has room for us messy scientists!



Section Objective

- Compare planet Earth to a spaceship traveling through the universe.

1-5 The Spaceship Called Earth

Seen by astronauts from space, Earth is incredibly beautiful. It shines blue, white, and purple against the black, airless void. Since the beginning of human history, poets have written about the beauty of Earth. Artists have created paintings of Earth's magnificent wilderness lands and wild animals. Today, scientists from several fields are warning us that we must learn to protect our planet and preserve its living treasures. Our species has rapidly developed the ability to change the Earth much for the better and much for the worse. We have saved many species from extinction. At the same time, we have destroyed hundreds of other species. We have made gardens bloom in deserts and can now feed more people than ever before. But we have also turned fertile land into dust bowls. We have tremendously increased human life spans and can treat or cure many diseases that were once fatal. Yet we have also manufactured chemicals that once seemed useful but now threaten our health and the health of other species.

Earlier in human history, the Earth seemed to be without end. There were always new wildernesses to settle, new resources to use, and plenty of places to dump our garbage. Now we know that there is limited land—and limited amounts of clean air, water, and other resources. There are also a limited number of places we can use as trash heaps. **The Earth is no longer a planet without end. It is more like a giant spaceship with a living cargo, carrying limited amounts of vital supplies.**

As you read this book, you will learn about the basis of life and about the process by which life has evolved. You will take a tour through the kingdoms of the different kinds of organisms with whom we share our planet. You will learn just how closely all forms of life on Earth are connected. We hope you will also learn how important it is to preserve that life. More than ever before in history, we must work to protect our environment against destruction. Properly applied, science can provide us with the knowledge and tools we need to meet this challenge. We think you will agree that the joys of a ride on spaceship Earth are more than worth the responsibilities we have as its most powerful passengers.

1-5 SECTION REVIEW

1. How does our modern view of Earth's resources differ from older impressions?
2. What are some of the great successes of human endeavors on Earth? What are some of the failures?

Figure 1-17 Humans have changed the Earth both for the better and for the worse. Vaccines help to prevent many diseases that were once fatal. Modern farming methods can now feed more people than ever before. At the same time, however, we have seen numerous species of living things destroyed by the actions of humans. And we have allowed toxic wastes to seep into our soil and waterways.



PROBLEM

What effect does the amount of water given to seeds have on the rate of seed germination?

MATERIALS (per group)

200 mustard seeds
3 petri dishes with covers
2 50-mL beakers
graduated cylinder
glass-marking pencil

PROCEDURE**Part A**

1. In this investigation you will determine whether the amount of water given to mustard seeds has an effect on the number of seeds that germinate, or sprout. Before you begin, propose a hypothesis predicting the effect that varying amounts of water might have on mustard seed germination. The steps that follow will help you test your hypothesis.
2. Place 50 mustard seeds in each of two petri dishes.
3. Using the graduated cylinder, pour 5 mL of water into one petri dish. Then pour 30 mL of water into the other petri dish. Cover each petri dish. Use the glass-marking pencil to indicate the volume of water in each.
4. Set both petri dishes aside for 48 hours. After 48 hours, count the number of seeds in each petri dish that have begun to germinate. Record your observations in a data table similar to the one shown here.

Part B

1. Place 50 mustard seeds in each of the two beakers.
2. Using the graduated cylinder, pour 5 mL of water into one beaker and 30 mL of water into the other. Cover each beaker with the top or bottom of the remaining petri dish. Then, using the glass-marking pencil, indicate on the cover the volume of water in each beaker.

3. Set the beakers aside for 48 hours. After 48 hours, count the number of seeds in each beaker that have begun to germinate and record your results in your data table.

OBSERVATIONS

Type of Container	Volume of Water	
	5 mL	30 mL
Petri dish		
Beaker		

1. Did the mustard seeds float in any of the containers? If so, were these seeds more likely to germinate?
2. In which container did the germinated seeds have the longest roots?

ANALYSIS AND CONCLUSIONS

1. How did the number of germinated seeds in the petri dishes compare to the number of germinated seeds in the beakers?
2. Did the amount of water in the petri dishes appear to affect the number of germinated seeds? Did these results confirm your hypothesis?
3. Did the amount of water in the beakers appear to affect the number of germinated seeds? Did these results confirm your original hypothesis?
4. Sometimes the results of different parts of an experiment provide different interpretations. When this occurs, scientists often look to see if a hidden variable, which might affect the overall results of an investigation, was introduced. What hidden variable might account for the results you observed in the petri dishes and in the beakers? (*Hint: Other than water, what substance may have played a role in your experiment?*)

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

1-1 What Is Science?

- Science is a process that uses observations and tests to identify the causes of events in nature.

1-2 The Scientific Method

- The main steps in the scientific method are observing and stating a problem, forming a hypothesis, testing the hypothesis through observation or experimentation, recording and analyzing data, forming a conclusion, and replicating the work.
- A hypothesis is a possible explanation about a particular event in nature.
- In order to ensure that the results of an experiment were due to the variable being tested, scientists must run both an experimental setup and a control setup.
- When a hypothesis has been tested and confirmed many times, it may then be considered a theory that can make dependable predictions about nature.

- The metric system is the system of measurement used by scientists all over the world.
- Although mass and weight are considered interchangeable on the surface of the Earth, mass is actually a measure of the amount of matter in an object and weight is a measure of the pull of gravity on that object.

1-3 Science: "Facts" and "Truth"

- Successful science study habits involve relating facts to each other and to the underlying concepts being discussed rather than simply memorizing a list of facts.

1-4 Safety in the Laboratory

- Always follow all written instructions or instructions from your teacher whenever working in the science laboratory.

1-5 The Spaceship Called Earth

- Planet Earth can be compared to a giant spaceship carrying a living cargo and limited amounts of food, water, and other resources.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meaning. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

1-1 What Is Science?

science

1-2 The Scientific Method

scientific method
hypothesis

variable
control setup
experimental setup
data
theory
metric system

meter
liter
cubic centimeter
mass
weight
kilogram

Celsius scale

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. A proposed solution or explanation of a scientific event in nature is called a
a. conclusion. c. control setup.
b. hypothesis. d. theory.
2. The factor being tested in an experiment is the
a. data. c. variable.
b. hypothesis. d. theory.
3. The metric system is based or scaled on powers of
a. 10. c. 1000.
b. 100. d. none of these.
4. The basic unit of length in the metric system is the
a. meter. c. millimeter.
b. kilometer. d. centimeter.
5. The basic unit of mass in the metric system is the
a. gram. c. liter.
b. kilogram. d. pound.
6. A cubic centimeter is equivalent to a
a. liter. c. milligram.
b. gram. d. milliliter.
7. Which of the following relationships between an object on Earth and that same object on the moon is true?
a. mass changes; weight remains the same
b. neither mass nor weight changes
c. both mass and weight change
d. weight changes; mass remains the same
8. If you see the symbol of a flask in a laboratory experiment, you are being cautioned to
a. put on goggles.
b. take extra care with glassware.
c. make sure your measurements are very precise.
d. use heat-resistant gloves.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. Recorded observations are called data.
2. The control experiment is that part of the experiment without the variable.
3. A kilometer contains 1000 centimeters.
4. A milliliter contains 1000 cubic centimeters.
5. The prefix centi- means one hundred.
6. In science, facts never change.
7. The goal of science is to understand the world around us.
8. The kilogram is the unit of mass you would use to measure objects smaller than a gram.

Word Relationships

Replace the underlined definition with the correct vocabulary word.

1. The ability to reproduce results is an important part of any experiment.
2. After observing an event in nature, a scientist may develop a possible explanation or a preliminary conclusion regarding the cause of that event.
3. The liter is a measure of the amount of space an object occupies.
4. Scientists often measure length in hundredths of a meter.
5. The amount of matter in an object can be measured in milligrams.

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Why is it important to have only one variable in an experiment?
2. Scientists throughout the world use a standard system of measurement. Why is a standard measurement system necessary?
3. Why must science textbooks be revised every few years?
4. Compare planet Earth to a giant spaceship.
5. Describe the approach that separates the process of science from other fields of study.
6. Which metric unit would you use to measure each of the following:
 - a. volume of a glass of milk
 - b. length of your textbook
 - c. mass of a mouse
 - d. temperature of the Gulf of Mexico
 - e. mass of a killer whale
 - f. volume of a marble

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Designing an experiment** How would you use the scientific method to find the best place in your class to grow African violets?
2. **Making predictions** Develop a time line in which you predict some of the important advances that may occur in science during the next century.
3. **Interpreting diagrams** Examine the illustration of a control setup and an experimental setup. What is the variable in this experiment? Why?
4. **Recognizing fact and opinion** Suppose your friends believe that astrology is a science. How would you convince them that they are wrong?
5. **Relating concepts** The French biologist Louis Pasteur once said, "Chance favors only the mind that is prepared." Explain this statement by relating it to the process of science.
6. **Using the writing process** You have been elected to the Senate. The most important issue that has to be resolved is whether the United States will convert to the metric system. Write a 3-minute speech detailing your reasons for adopting or rejecting the metric system.
7. **Using the writing process** The year is 2050. Write a help-wanted ad that will encourage high school graduates to volunteer for a 2-year mission to planet Mars. The main task of the graduates will be as technicians helping out in various scientific experiments. All graduates will be trained before the mission begins.



CHAPTER 2

Biology as a Science



Without any prior knowledge about trees, it would be difficult for an observer walking through a winter forest to know whether these trees were living or nonliving.

How do you tell whether something is alive? With some living things, it's easy. You could check for breathing, or a pulse, or a response to a pinch or a poke. But such tests would not work for all living things. Is moss growing on a rock alive? How about rust spreading over a piece of metal? If you came upon a tree in the middle of winter when its leaves were gone, how would you tell whether the tree was living or dead?

What we are really asking in such questions is simple. We would like to know what distinguishes life from nonlife. The answer to such questions, however, is not always that clear. So we shall do the next best thing to providing the answer. In this chapter we shall list the characteristics that living things share.

2-1 Characteristics of Living Things

- Living Things Are Made Up of Cells
- Living Things Reproduce
- Living Things Grow and Develop
- Living Things Obtain and Use Energy
- Living Things Respond to Their Environment

2-2 Biology: The Study of Life

- Branches of Biology
- Tools of a Biologist
- Laboratory Techniques of a Biologist

2-1 Characteristics of Living Things

Section Objectives

- List and describe the characteristics of living things.
- Define homeostasis.

Making up a list of the characteristics of living things is not as easy as it might sound. In fact, scientists have argued for centuries over the basic characteristics that separate life and nonlife. Some of these arguments are still unresolved. For example, in Chapter 17 you will discover that the line between life and nonlife becomes blurred when we consider whether or not viruses are living things.

Despite these arguments, there do seem to be some generally accepted characteristics common to all living things. We can state with some confidence that all living things

- Are made up of one or more units called cells
- Reproduce
- Grow and develop
- Obtain and use energy
- Respond to their environment

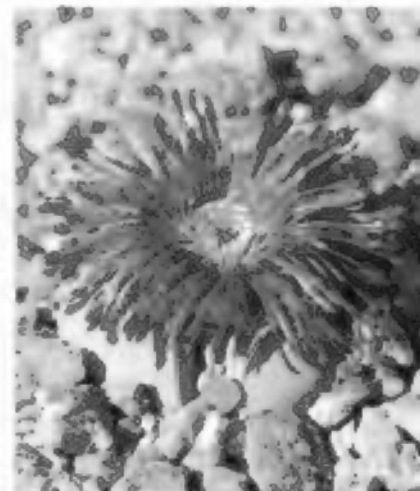
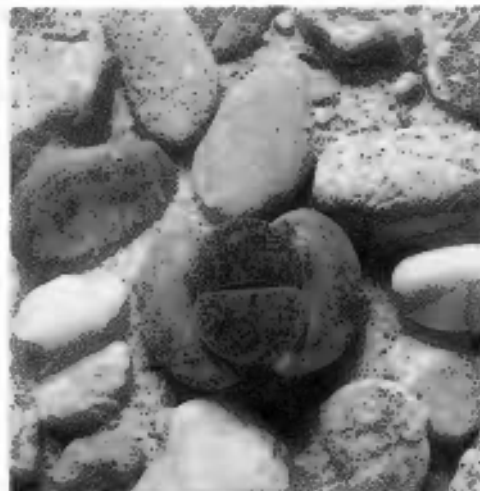
It will help in our understanding of living things to consider each of these characteristics in detail.

Living Things Are Made Up of Cells

Living things are made up of small self-contained units called cells. Each cell is a collection of living matter enclosed by a barrier that separates the cell from its surroundings. Most cells can perform all the functions we associate with life.

Cells are remarkably diverse. A single cell by itself can form an entire living organism. Organisms consisting of only a

Figure 2-1 This Lithops plant, commonly called the living stone, certainly does not appear to be alive (left). Yet you would have no trouble determining that it is a living organism if you saw it flowering (right).



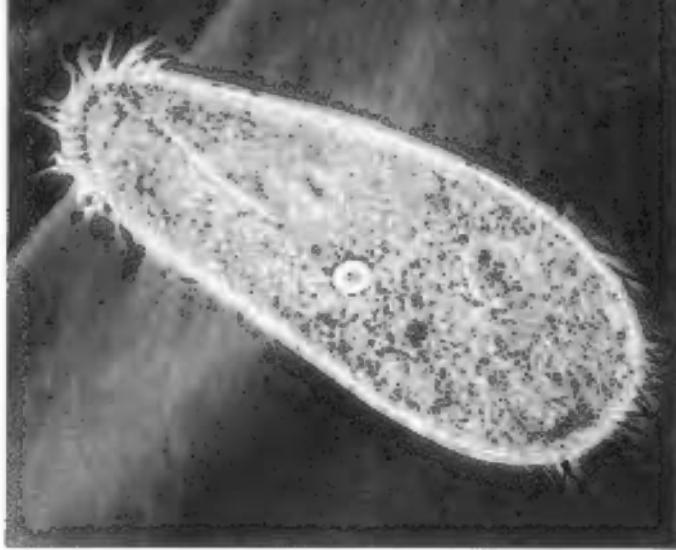


Figure 2-2 Biologists classify organisms as unicellular or multicellular. This unicellular protozoan (left) is a single-celled organism, whereas the multicellular tree sloth (right) is made up of trillions of cells.

Figure 2-3 Orangutans, like many other animals, reproduce sexually. In sexual reproduction, one cell from each parent unites to form the first cell of the new organism.



single cell are called **unicellular**. See Figure 2-2. (The Latin prefix *uni-* means one, so unicellular means single-celled.) Most of the organisms you are familiar with, such as dogs and trees, are **multicellular**. (The Latin prefix *multi-* means many, so multicellular means many-celled.) Multicellular organisms contain hundreds, thousands, even trillions of cells or more. We will discuss cells in more detail in Chapter 5.

Cells are never formed by nonliving things. They are found in nonliving matter only if that matter was once alive. Wood, for example, is made up largely of the walls that separated individual cells in the living tree.

Living Things Reproduce

Living things can reproduce, or produce new organisms of the same type. Because all individual organisms eventually die, reproduction is necessary if a group of similar organisms (what we will later call a species) is to survive.

There are two basic kinds of reproduction: sexual and asexual. **Sexual reproduction** requires that two cells from different individuals unite to produce the first cell of a new organism. See Figure 2-3. You are reading this textbook because a cell from your mother united with a cell from your father to form that first cell that would grow and develop into you. Most familiar organisms—from maple trees to birds and bees—reproduce sexually. In **asexual reproduction**, a single organism can reproduce without the aid of another. (The prefix *a-* means without, so asexual means without sex.) Asexual reproduction can be very simple: Some single-celled organisms merely divide in two to form two organisms.

Living Things Grow and Develop

All living things, at one stage or another in their lives, are capable of growth. An acorn, when it sprouts, produces roots, stems, a trunk, and leaves that continue to grow for years. As it grows, the plant takes in substances from the air and soil and



transforms these substances into living tissue. And long after the tree stops getting larger, it continues to add new material to replace existing parts that wear out.

A snowball, on the other hand, may seem to “grow” if you roll it over fresh snow. But a snowball grows bigger only if someone adds new snow onto its surface. A snowball won’t grow bigger by just sitting there. And it certainly cannot change liquid water or solid ice into new snow from which it can grow larger.

During growth, most living things go through a cycle of change called development. The single cell that starts an organism’s life divides and changes again and again to form the many and varied cells of an adult organism. You are probably well aware of growth and development since you are now in the midst of one of the most intense spurts of growth and development that you will ever encounter in your life.

As development continues, organisms experience a process called aging. During aging, an organism becomes less efficient at the process of life. The ability to reproduce comes to an end. For virtually all organisms, death is the inevitable end of the life span of every individual. Death, too, is a process of change that separates living and nonliving things.

Living Things Obtain and Use Energy

Living things obtain energy from their environment, or their surroundings, and use that energy to grow, develop, and reproduce. All organisms require energy to build the substances that make up their cells. Any process in a living thing that involves putting together, or synthesizing, complex substances from simpler substances is called **anabolism** (uh-NAB-uh-lihz-uhm).

Plants obtain their energy from sunlight in a process called photosynthesis, which you will study in Chapter 6. (The prefix *photo-* refers to light, and the suffix *-synthesis* means put together. Thus photosynthesis means put together with light.)

Figure 2-4 All living things grow and develop. Usually growth simply means getting larger, not changing form. But that is not always the case. This caterpillar (left) will grow and develop into an adult Cecropia moth (right).

Figure 2-5 According to this chart, what is the maximum life span of a blue whale?

MAXIMUM LIFE SPANS		
Organism		Life Span
Adult mayfly		1 day
Marigold		8 months
Mouse		1-2 years
Dog		17 years
Blue whale		100 years
Tortoise		152 years
Bristlecone pine		5500 years



Figure 2-6 This katydid obtains the energy it needs to live from the food it eats. How does the green plant the katydid is munching on obtain its energy?

Animals cannot perform photosynthesis. Animals take in energy in the form of food. Food is broken down during a process called digestion, which you will study in Chapter 39. The final breakdown of complex substances into simpler ones, usually resulting in the release of energy, is called **catabolism** (kuh-TAB-uh-lihz-uhm).

Living things must practice both anabolism and catabolism at the same time, just as a business or a household must take some money in as income and pay some money out as expenses. The total sum of all chemical reactions in the body—the balance of anabolism and catabolism—is called **metabolism**.

Living Things Respond to Their Environment

Living things respond to their environment. Such responses can be rapid, usually through changes in behavior, or slow, usually through changes in metabolic processes or through growth. Anything in the environment that causes an organism to react is called a stimulus. Organisms react to many stimuli, including light, temperature, odor, sound, gravity, heat, water, and pressure. What stimuli are you responding to at this very moment?

The ability of living things to react to stimuli is known as irritability. (No, that does not mean that living things are grouchy. At least not all the time!) Both plants and animals exhibit irritability and can react to a variety of stimuli. Plants, however, usually respond to stimuli more slowly than animals. Plant leaves and stems, for example, grow toward light and away from the pull of gravity. Plant roots, on the other hand, respond to gravity by growing down into the soil.

In general, living things respond to stimuli in ways that improve their chances for survival. **The process by which organisms respond to stimuli in ways that keep conditions in their body suitable for life is called homeostasis.** (The prefix

Figure 2-7 Living things respond to stimuli from their environment. What stimuli is the bat responding to? What will be the logical response of the frog?





Figure 2-8 This Australian reptile, called the frilled dragon, is basking on a rock in the sun. How does this behavior of the reptile help it achieve homeostasis? What might the reptile do if its body overheats?

homeo- means similar or same. The suffix *-stasis* means standing or stopping.) **Homeostasis** (hoh-mee-oh-STAY-sihs) refers to an organism's ability to maintain constant or stable conditions that are necessary for life. Just as a thermostat in your home turns on the heat when it gets down to a certain temperature, your body has a thermostat that maintains a constant internal temperature. If you get too hot, you sweat and cool off. And if you sweat for a long time, the resulting thirst persuades you to replace the water your body has lost.

You might point out that nonliving things also respond to the environment. However, the responses of nonliving things are purely mechanical (like a spring that jumps when compressed and released) and are not related to survival.

2-1 SECTION REVIEW

1. List and describe five characteristics that separate living and nonliving things.
2. Compare sexual reproduction and asexual reproduction.
3. Define metabolism, using the terms catabolism and anabolism in your definition.
4. Try to think of a nonliving thing that satisfies each characteristic of living things. Does any nonliving thing have all the characteristics of life?

2-2 Biology: The Study of Life

Quite literally, biology means the study of life. (The prefix *bio-* means life, and the suffix *-logy* means study of.) Biology, then, is the science that seeks to understand, explain, and even control the living world. Biology, like any other science, advances by observing the world, asking questions, and forming hypotheses that can be tested by experiment. **A biologist is anyone who uses the scientific method to study living things.**

Section Objectives

- Compare the different branches of biology.
- Describe the different types of microscopes and their limits of resolution.
- Discuss the advantages and disadvantages of different types of microscopes.

Branches of Biology

The broad field of biology contains many branches, or divisions. Some divisions are quite general: zoologists study animals (the prefix *zoo-* means animal); botanists work with plants (the Greek prefix *botanikos-* means green plants); and microbiologists work with microscopic organisms (the prefix *micro-* means small). Other subdivisions of biology are more focused. Paleontologists, for example, work with extinct organisms (the prefix *paleo-* means ancient), and ethologists study animal behavior (the prefix *ethos-* means custom).

In the course of this textbook we will examine many fields of biology. Here, we can begin our investigation by considering examples of the types of questions that are asked by different kinds of biologists.

QUESTIONS AT THE MOLECULAR LEVEL Some biologists study life at the molecular level. Molecular biologists, for example, may study the basic chemical units of life. Molecular geneticists investigate the workings of DNA, the molecule that controls heredity and directs all the activities of the cell. Other researchers might study the effects of drugs on molecules in cells in order to understand why entire organisms react to those drugs as they do.

QUESTIONS AT THE CELLULAR LEVEL Some biologists study questions that deal with organisms at the cellular level. Cell biologists, for example, might study the way normal cells become cancer cells when exposed to radiation or to the chemicals found in cigarette smoke. Or they might try to explain how a single cell divides and changes to form all the cell types in an

Figure 2-9 Biology is filled with terms that may seem unfamiliar to you but are actually quite simple. Many scientific terms are derived from Latin or Greek words that may be added in front of another word as a prefix or after another word as a suffix. Using this chart, determine the meaning of the word *cytology*.

Prefix	Meaning	Prefix	Meaning	Suffix	Meaning
anti-	against	herb-	pertaining to plants	-cyst	pouch
arth-	joint, jointed	hetero-	different	-derm	skin, layer
auto-	self	homeo-	same	-gen	producing
bio-	related to life	macro-	large	-itis	inflammation
chloro-	green	micro-	small	-logy	study
cyto-	cell	multi-	consisting of many units	-meter	measurement
di-	double	osteo-	bone	-osis	condition, disease
epi-	above	photo-	pertaining to light	-phase	stage
exo-	outer, external	plasm-	forming substance	-phage	eater
gastro-	stomach	proto-	first	-pod	foot
hemo-	blood	syn-	together	-stasis	stationary condition

adult organism. Other cell biologists might study how cells communicate with nearby cells.

QUESTIONS AT THE MULTICELLULAR LEVEL Going beyond individual cells, some biologists study multicellular organisms. Zoologists, for example, might be interested in the changes within animals that tell them when to sleep or eat or even when to mate. Paleontologists might try to explain how certain animals changed over time, or evolved. Ethologists might ask why the males of a particular kind of organism are more brightly colored than the females.

QUESTIONS AT THE POPULATION LEVEL Some biologists even go beyond individual organisms in their studies. These biologists are interested in groups of organisms that make up populations and how such populations interact with their environment. Some ecologists, for example, might want to know how the construction of a new road or dam, or the cutting down of forests, will affect nearby plant and animal life. Other ecologists might be concerned with the effects of pesticides or industrial wastes on organisms that live in our waterways.

QUESTIONS AT THE GLOBAL LEVEL Many biologists take a more worldwide view of biology and are concerned with organisms and their environment on a global scale. Global ecologists, for example, might try to estimate the effects on the Earth's climate of burning coal and oil. Or they might try to explain why the fishing off New England is excellent one year and poor the next.

Whether studying questions at the molecular level, the global level, or any level in between, biologists are making important contributions. They are both studying and trying to preserve the wonderful things that are alive on planet Earth—not just for their own use, but for the use of those who will live on this planet after us.

By now it may appear as if biology is a field strictly for scientists with a long list of college degrees. It is true that most biologists do have a bachelor's degree and often go on to graduate school. But it is just as true that anyone can be a biologist. The only real qualifications are hard work, energy, and curiosity. A biologist must be curious about life and have the energy to ask questions in a scientific way—and then try to answer those questions. As you will read in this textbook, many of the greatest names in the history of biology were amateurs, meaning that they did not practice science as a “job.” Such people include Charles Darwin, who established the theory of evolution, and Gregor Mendel, who discovered the basic units of heredity. Today other amateurs, including high school and college students, continue to make important contributions to scientific research and the science of biology. No license is required!



Figure 2-10 Many bird species have elaborate courtship (mating) behaviors. These albatross are exhibiting a form of courtship behavior called sky pointing. What type of biologist might study courtship behavior?

Figure 2-11 These Japanese citizens are taking part in an antipollution march in Tokyo. The effects of air pollution on health are among the global questions biologists often try to assess.



Tools of a Biologist

To accomplish their diverse goals, biologists may choose to use a wide variety of tools. In the laboratory, biologists may use pipettes and graduated cylinders to measure and transfer liquids. Solids, on the other hand, are usually measured on mechanical or electronic balances. Many experiments are performed inside enclosures, called hoods, that protect researchers from dangerous fumes or help to control contamination.

In almost all areas of biology, the computer has become an invaluable tool that can be used to perform complex tasks and analyze quantities of data. Many tools, however, are more specific to the type of biological work being undertaken. Global ecologists, for example, may use orbiting satellites to provide detailed maps of the temperature, moisture content, or vegetation of large areas. We shall discuss many more tools and the ways in which they are used throughout this textbook.

When you think of biology, there is probably one tool that comes to mind above all others. For almost all biologists need to examine organisms or parts of organisms that are too small to be seen with the unaided eye. **To study small organisms, researchers have developed several kinds of microscopes. Microscopes are instruments that produce larger-than-life images, pictures, or even videotapes.**

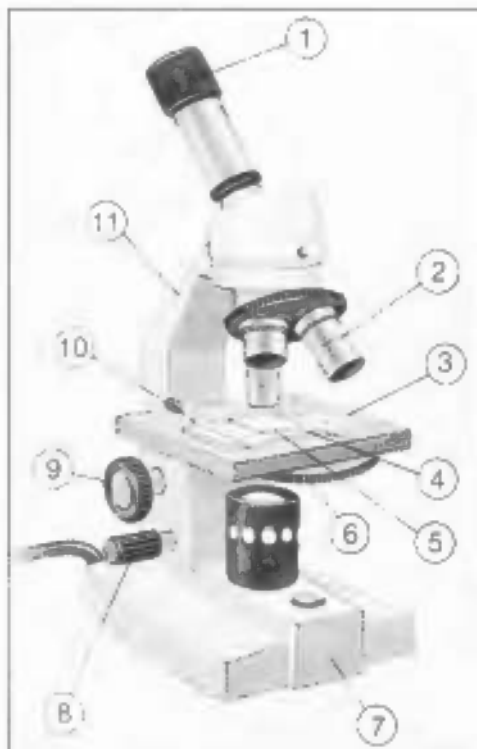
THE COMPOUND LIGHT MICROSCOPE The most familiar microscope to high school students is the **compound light microscope**. A typical compound light microscope is shown in Figure 2-12.

Compound light microscopes are important to biologists because they allow them to observe many kinds of cells and single-celled organisms while they are still alive. That is, an organism does not have to be killed to be observed under a compound light microscope.

To use a compound light microscope, you sandwich the object to be viewed between a transparent glass slide and a thin cover slip. This sandwich is then placed on the stage of the microscope so that light passing through it travels through two lenses. The lens at the bottom of the microscope tube, which is closest to the specimen being observed, is called the objective lens. The lens at the top of the microscope tube, through which you look, is called the ocular lens. When you look through the ocular lens in a compound light microscope, you may see an image of the object magnified up to 1000 times.

LIMITS OF RESOLUTION There are limits to what we can see with the compound light microscope. As we increase the magnifying power of a light microscope, we see more and more detail—up to a certain point. Beyond that point, called the **limit of resolution**, objects get blurry and detail is lost. For standard light microscopes, the limit of resolution is about 0.2 micrometers. (A typical cell is about 10 micrometers across.)

Figure 2-12 This diagram is of a typical compound light microscope. What is another word for the eyepiece?



Compound Light Microscope

1. Ocular lens (eyepiece)
2. Objective lens
3. Stage
4. Glass slide
5. Coverslip
6. Diaphragm (regulates light intensity)
7. Base
8. Fine adjustment knob
9. Coarse adjustment knob
10. Stage clips
11. Arm

When the limit of resolution was first discovered, many people thought that if microscopes were made better, this problem would disappear. However, even a "perfect" microscope will have a limit of resolution. The reason for this has to do with the way light behaves. When light passes through a tiny opening or a lens, it is diffracted, or scattered in a way that makes it hard to form a clear image. When we look at something in the compound light microscope at 1000 times magnification, we have enlarged it just enough to see the limit of resolution of the best light microscopes we can make.

USING A COMPOUND LIGHT MICROSCOPE There are objects—such as dust, feathers, and pollen grains—that can be seen in the light microscope without any special preparation. But many cells and cell parts are so similar in appearance to their surroundings that they cannot be easily seen through the microscope. Researchers have developed several techniques to make such objects visible.

Many specimens are stained before they are observed under a microscope. Stains are used to color cells or parts of cells to make them clearly visible. Some stains color everything in a cell, whereas others color only a part of the cell. One such special stain, known as Feulgen, turns DNA a beautiful pinkish color. Some stains, which "stick" only to certain compounds, can be made to glow in the dark to highlight specific cell parts.

Because many stains kill living cells, special types of light microscopes that do not require staining are used to observe living specimens. Examples of these are the phase contrast microscope, the dark field microscope, and the Nomarski microscope. Each uses a different property of light rays to improve the contrast (clarity) of the image. See Figure 2-14.

ELECTRON MICROSCOPES Although light microscopes are very useful, their limit of resolution restricts their usefulness for studying very small objects such as viruses and individual molecules. Is there a way to see things smaller than light

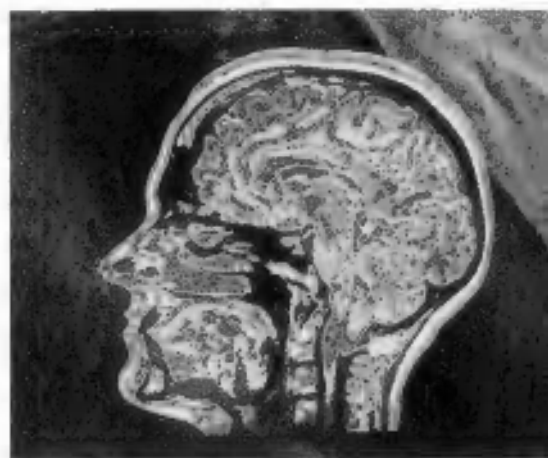
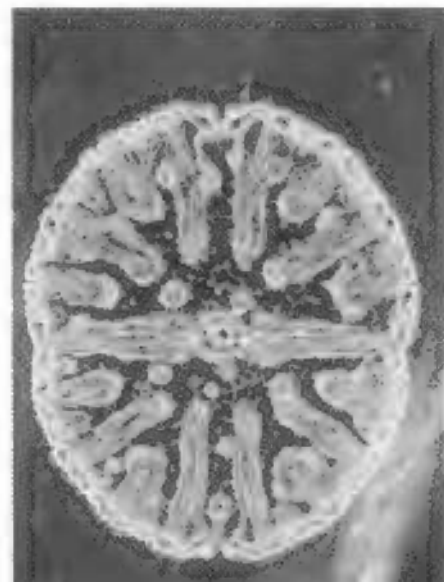
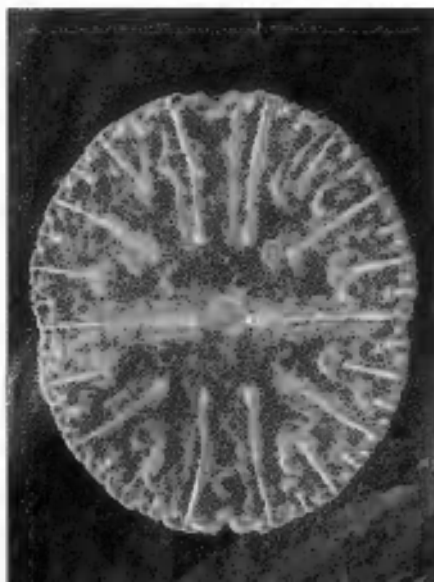


Figure 2-13 Modern science has provided biologists with many tools unknown in centuries past. This image of a patient's brain was made by a medical scanner called a nuclear magnetic resonance scanner (NMR). What sort of tools do you think biologists will be using a century from now?

Figure 2-14 Notice the variations in this image of an alga as seen through a Nomarski microscope (left), a dark field microscope (center), and a phase contrast microscope (right).



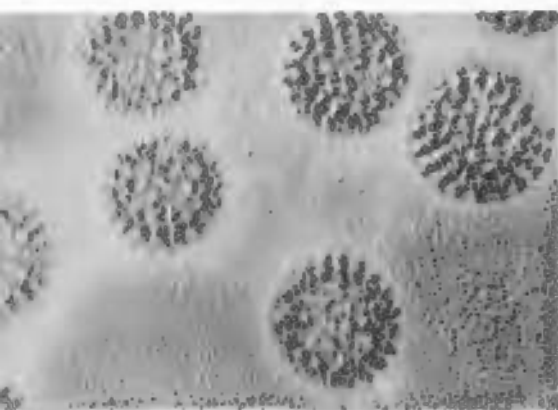


Figure 2-15 A transmission electron microscope (TEM) sends a beam of electrons through an object to produce an image (top). This image of viruses, which has had color added by a computer, was taken through a TEM (bottom).

Figure 2-16 A scanning electron microscope (SEM) bounces electrons off the surface of an object to form an image. This image of bacteria, which has been colored green through the use of a computer, was taken by using an SEM.

can reveal? Indeed, there is. In the 1920s, physicists in Germany realized that electromagnets could bend streams of electrons in much the same way that glass lenses bend beams of light. They then learned to use electromagnets to build devices called electron microscopes. These same physicists used electromagnets to bend electrons to produce another tool you are probably familiar with: television.

The limit of resolution of electron microscopes is about 1000 times finer than the light microscope. There are several different types of electron microscopes.

Transmission electron microscopes (TEMs) shine a beam of electrons at a sample and then magnify the image of that sample onto a fluorescent screen at the bottom of the microscope. The electron beam can also be used to expose photographic film to produce a permanent image of the specimen. See Figure 2-15.

Scanning electron microscopes (SEMs) get their name from a pencil-like beam of electrons that scans back and forth across the surface of a specimen. Electrons that bounce off the specimen are picked up by detectors that provide the information to form an image on a television screen. Rather than showing details inside living things, SEMs show realistic (and often dramatic) three-dimensional pictures of their surfaces. See Figure 2-16.

LIMITATIONS OF ELECTRON MICROSCOPES Electron microscopes are extremely useful when studying very small organisms and parts of organisms. But they do present one serious drawback. Because of the nature of electrons, specimens must be placed in a vacuum, or a chamber from which all the air has been removed. Specimens for TEM work must also be stained with special chemicals, treated with other chemicals, and then cut into very thin slices. Specimens for SEM work do not need to be sliced; but like specimens for TEMs, they must be placed in a vacuum. As you can conclude, in either case the living cells must be killed before they can be observed under an electron microscope.



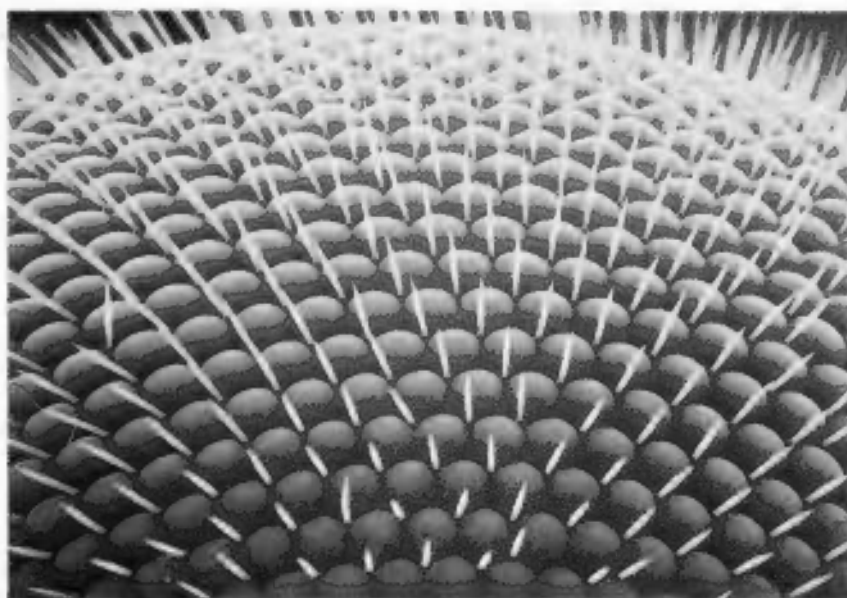


Figure 2-17 On this fruit fly (left), notice the two large red structures, which are the eyes. Then look at the head of the fruit fly as seen through a scanning electron microscope, magnified 60 times (right). The two rounded structures on each side of the head are the eyes. A high power view in the scanning electron microscope produced this detailed three-dimensional image of the eye of the fruit fly (bottom).

WHICH MICROSCOPES ARE BETTER? All the microscopes we have discussed do different things. The light microscope allows us to observe living cells but it cannot make the tiniest details visible. TEMs reveal innermost details of the cell interior but only after the cell has been killed, sectioned, and stained. SEMs allow us to study the surfaces of objects in three-dimensional detail. All types of microscopes, therefore, provide us with different glimpses of what living cells are like. No one microscope is better than the rest. Each is a tool to be used, when appropriate, by a working biologist.

Laboratory Techniques of a Biologist

You have already read about the laboratory technique called staining, in which parts of a cell are stained so that they appear more visible under a microscope. Throughout this textbook, we will discuss many other laboratory techniques used by biologists. But it will be helpful now for you to learn about some common laboratory techniques.



Figure 2-18 Blood samples are placed into a centrifuge in order to separate the various components of the blood.

CENTRIFUGATION Suppose a scientist wants to study one particular part of a cell or the same cell part from many similar cells. How can parts of a cell be obtained? One method is called centrifugation (sehn-trihf-yoo-GAY-shuhn). See Figure 2-18. One common centrifugation technique is to place the cells under study in a blender to break them apart. Breaking apart cells in a blender is called cell fractionation. The broken bits of cells are then placed in a liquid in a tube. The tube is inserted into a centrifuge, which is a device that can spin the tube up to 20,000 times per minute. While spinning, the cell parts begin to separate—with the heaviest parts settling near the bottom of the tube and the lightest parts rising toward the top. A scientist can then remove the specific part of the cell to be studied by selecting the appropriate layer.

MICRODISSECTION Another way to remove parts of a cell, as well as to insert material into a living cell, is a technique called microdissection. In this process, special tools that are so small they can be used only by looking through a microscope are used to dissect or remove specific parts of a cell. In the same way, substances can be added to a living cell.

CELL CULTURES Sometimes scientists want to study a particular kind of cell but to do so they need large numbers of that exact cell. To obtain many identical copies of that cell, the scientist might prepare a cell culture. In this technique, a single cell is placed in a dish that contains the nutrients the cell needs. The cell is allowed to reproduce so that in time an entire population is grown from that single original cell.

2-2 SECTION REVIEW

1. List four branches of biology. What sorts of questions might researchers in each branch study?
2. What type of research could be performed only by using a compound light microscope?
3. Name an advantage and a disadvantage of each type of microscope.
4. Compare a TEM and an SEM. What type of information does each provide?
5. How does the resolution of a microscope affect the observations made by a microbiologist?
6. It has been said that many great discoveries lie in wait for the tools needed to make them. What does this statement mean to you? If possible, include an example in your answer.

Yellow Fever: The Scientific Method in Action

Near the turn of the century, American soldiers stationed in the vicinity of Havana, Cuba, began to die in great numbers. They died not from enemy bullets but from a disease known as yellow fever. At one point, more soldiers died from the disease than from fighting in the Spanish-American War that had brought them to Cuba in the first place! The situation became so serious that the United States sent a commission headed by Dr. Walter Reed.

At first, people thought the disease was spread by contact with infected individuals or through infected materials such as bedsheets and clothing. So they boiled the clothes and sheets of sick people before using them again and prevented other soldiers from coming into contact with the infected soldiers. But none of these measures was of any help.

One Cuban doctor, Carlos Finlay, believed that the disease was spread by mosquitoes, which were plentiful in Cuba. Reed did not immediately agree, but he devised what turned out to be a terrifying experiment to test Finlay's hypothesis. Ideally, Reed would have used animals for his experiment. But because no animals that could contract yellow fever were available, the lives of several extraordinarily brave human beings were put at risk.

The commission assembled two groups of volunteers. One group spent twenty difficult, anxious days wearing the filthy clothing of yellow fever patients, sleeping in their soiled sheets, and eating from plates they had used. During this time, however, they were completely screened in and thereby protected from mosquitoes. Not one of these soldiers contracted yellow fever.

The second group of volunteers used only fresh clothing and linens and remained totally isolated from yellow fever patients. These volunteers, however, allowed themselves to be bitten by mosquitoes that had previously bitten yellow fever patients. Because members of the commission thought it unfair to ask others to take a risk they would not take themselves, three of them participated in this group. (Reed himself wanted to take part, but his associates would not let him.) Many of the volunteers in the second group, including all three doctors from the commission, developed yellow fever. One of them, Dr. Jesse Lazear, died.

Reed's experiment had risked human lives—and had cost one. But it had tested an idea and had proved that mosquitoes carried the infection. As a result, war was declared against the mosquito. In ninety days, Havana was completely free of yellow fever. This courageous example of the scientific method in action saved the lives of thousands of people who might have died from the disease.

Walter Reed's discovery of the way in which yellow fever was spread saved countless lives. But most scientists would not necessarily agree that humans should be used in such experiments. Are there diseases so dangerous that finding a cure or treatment is worth placing humans at risk? Or is no discovery worth the cost in human lives? What about only using volunteers, as Reed did? What about only using people with fatal diseases? These are difficult questions to consider. There may not be a right or wrong answer. What is your opinion on this issue?



PROBLEM

What is the proper procedure for using a compound microscope?

MATERIALS (per group)

compound microscope	light thread
glass slide	scissors
coverslip	medicine dropper
dark thread	

PROCEDURE

1. Study Figure 2-12 on page 34 and the Appendix on the use of a microscope at the back of this book until you know the names and functions of each part of the microscope.
2. The magnification of the eyepiece, or ocular lens, is written on the eyepiece. In general, the eyepiece magnifies 10 times.
3. Now find the low-power objective lens and the high-power objective lens. The magnification of each objective lens is written on the lens. In most microscopes, the low-power lens magnifies 10 times and the high-power lens magnifies 43 times. The total magnifying power of the microscope is found by multiplying the magnification of the eyepiece by the objective lens being used.
4. Cut a piece of dark thread about 1 cm long. Do the same with light thread. Place the threads on a clean glass slide so that the threads cross each other at right angles.
5. Use the medicine dropper to place a drop of water on the threads. Then touch one edge of a coverslip to the drop of water and lower the coverslip over the threads.
6. Place the slide on the stage, using the stage clips to hold the slide in position.
7. Position the low-power objective over the slide so that the objective is just above the top of the slide. **CAUTION:** *Never allow the objective to touch the slide.*
8. Look through the eyepiece. Adjust the mirror and the diaphragm so that the field is bright.
9. If the threads are out of focus, use the coarse adjustment knob to raise the objective lens until the threads are clearly seen. Then use the fine adjustment knob to sharpen the focus.
10. Adjust the slide so that the place where the threads cross is in the center of your field of vision.
11. After you have viewed the slide under low power, raise the body tube of the microscope so that the objective is well clear of the lens. Rotate the high-power objective into place above the slide, making sure the objective does not touch the slide. Lower the high-power objective until it is just above the slide.
12. Again, use the coarse adjustment knob to raise the objective until the threads are in focus. Then use the fine adjustment knob to sharpen the focus.
13. Move the slide to the left, to the right, forward, and back. Note the direction the threads appear to move each time you move the slide.

OBSERVATIONS

1. What happens to the brightness when the magnification is changed from low power to high power?
2. When you use the fine adjustment knob, how many threads are in focus at a time?
3. When you move the slide in any direction, how do the threads appear to move?

ANALYSIS AND CONCLUSIONS

1. Why is it important to raise the body tube before rotating the high-power lens into place?
2. Would you be able to see the threads if they were larger and thicker? Explain your answer.

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

2-1 Characteristics of Living Things

- All living things are made up of one or more cells.
- All living things reproduce, either sexually or asexually.
- Living things grow and develop, using energy and raw materials they obtain from the environment.
- Anabolism is any chemical process in a living thing in which complex substances are built up, or synthesized, from less complex substances.
- Catabolism refers to chemical reactions in living things in which complex substances are broken down into simpler ones.
- The sum total of anabolism and catabolism is called metabolism.
- Living things respond to stimuli from their environment. Stimuli include heat, light, water, sound, odor, and pressure.
- To survive, living things must keep conditions in their bodies relatively stable. Home-

ostasis refers to an organism's ability to maintain constant conditions within its body.

2-2 Biology: The Study of Life

- Different branches of biology deal with questions at the molecular level, cellular level, multicellular level, population level, and global level.
- Biologists use a wide variety of tools; in particular, various types of microscopes.
- The compound light microscope is used to examine living things. It uses light passing through an object to create a magnified image of that object.
- At some point, called the limit of resolution, the object being magnified loses clarity and becomes blurred.
- Electron microscopes use electrons, rather than light, to produce magnified images. To prepare a specimen for viewing under the electron microscope, the specimen must be killed.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

2-1 Characteristics of Living Things

unicellular
multicellular
sexual reproduction

asexual reproduction
anabolism
catabolism
metabolism
homeostasis

2-2 Biology: The Study of Life

compound light
microscope
limit of resolution

transmission electron
microscope
scanning electron
microscope

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- Single-celled organisms are also called
 - multicellular.
 - bacteria.
 - unicellular.
 - viruses.
- Reproduction that involves the union of cells from two parents is called
 - asexual reproduction.
 - irritability.
 - cell division.
 - sexual reproduction.
- Chemical reactions in an organism that build, or synthesize, complex molecules from less complex molecules are called
 - metabolism.
 - anabolism.
 - catabolism.
 - digestion.
- The ability of an organism to maintain constant conditions within the body is called
 - irritability.
 - homeostasis.
 - metabolism.
 - stimulus.
- The branch of biology concerned with animal behavior is
 - microbiology.
 - zoology.
 - botany.
 - ethology.
- To observe the surface features of a bacterium, you would use a
 - compound light microscope.
 - scanning electron microscope.
 - magnifying lens.
 - transmission electron microscope.
- To observe living organisms in a drop of water, you would use a
 - compound light microscope.
 - scanning electron microscope.
 - magnifying lens.
 - transmission electron microscope.
- To observe the internal features of a bacterium, you would use a
 - compound light microscope.
 - scanning electron microscope.
 - magnifying lens.
 - transmission electron microscope.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- Few cells can perform all the functions we associate with life.
- Plants obtain their energy from sunlight in a process called metabolism.
- Stimuli include heat, light, pressure, and temperature.
- Pipettes are used to transfer solids from one container to another.
- The lens at the top of a compound light microscope is called the objective lens.
- Compound light microscopes are used to observe living organisms.
- In a transmission electron microscope, the image is magnified onto a fluorescent screen at the bottom of the microscope.
- Surface features of very small organisms are best viewed using a dark field microscope.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

1. unicellular, multicellular, cell wall, single-celled
2. temperature, pressure, irritability, gravity
3. zoology, botany, chemistry, ecology
4. ocular lens, electron beam, objective lens, glass slide
5. SEM, compound light microscope, limit of resolution, TEM

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. List and describe the basic characteristics of living things.
2. Compare sexual reproduction with asexual reproduction.
3. What is irritability? Give three examples of a stimulus and a possible response in humans.
4. Discuss the importance of cell-staining techniques in the study of living things.
5. Describe the way a transmission electron microscope produces an image.
6. No one microscope is better than another. Each type has an important role to play in biological research. Do you agree or disagree with these statements? Explain your answer.

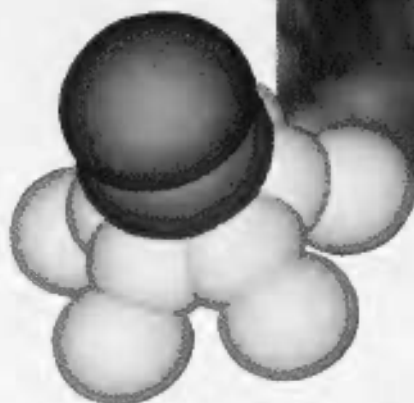
CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Relating concepts** Why is biology considered a science?
2. **Making generalizations** List the attributes you think scientists should possess in order to be successful in their work.
3. **Applying concepts** How would you decide if an object were living or not?
4. **Making inferences** Why might biologists consider metabolism to be the single most important characteristic of life?
5. **Relating cause and effect** An organism's response to a stimulus can be a method of protection. How do these 3 stimuli-response situations protect the organism?
 - a. Pulling a hand away from a hot iron
 - b. Squinting in a bright light
 - c. Producing tears if dirt gets in the eyes
6. **Making comparisons** Compare the growth of an icicle with the growth of a living thing.
7. **Identifying relationships** Which characteristic of living things is important to the survival of the species rather than to the organism itself? Explain your answer.
8. **Using the writing process** You are a biologist and have the opportunity to travel back in time to study an extinct species of your choice. You may take just one modern tool for your study. Which tool would you choose and why?
9. **Using the writing process** If microscopes could talk, what stories would they tell? Write a microscope story. (*Hint: First decide if you are a compound light microscope or an electron microscope.*)

CHAPTER 3

Introduction to Chemistry



An understanding of life—in all its glorious forms—depends upon an understanding of the atomic nature of matter.

For many years, biology was a science that respected a fundamental distinction between the living and the nonliving worlds. Biologists studied organisms; physicists and chemists studied materials. In the twentieth century, however, this distinction has begun to fade. Biologists have gradually realized that a complete description of life must begin at the atomic level and then work up through the complex chemistry of the living cell. Indeed, one of the great scientific stories of this century is the manner in which the boundaries between biology and the physical sciences have become blurred. Biologists now appreciate that the starting point for an understanding of the nature of life is an understanding of the atom. In this chapter, you will do exactly as biologists have done—you will learn about the atomic structure of living and nonliving matter.

CHAPTER OUTLINE

3-1 Nature of Matter

- Properties of Matter
- Phases of Matter

3-2 Composition of Matter

- The Atom
- Chemical Elements
- Chemical Compounds

3-3 Interactions of Matter

- Ionic Bonds
- Covalent Bonds

3-4 Chemical Reactions

3-1 Nature of Matter

Section Objectives

- Identify several important properties of matter.
- Compare physical and chemical properties.

What are living things made of? Are there special substances that are found in living things but not in nonliving material? Is there a special "spirit" or "essence" that living things possess? Does life have a physical and chemical basis that we can hope to understand and describe in the same way we do something that is not alive, like an automobile engine or a calculator? To answer these questions, we must first examine the world around us . . . a world made up of matter and energy.

Properties of Matter

Matter is all around us. Almost everything we see, touch, taste, or smell is matter. And all forms of matter have properties, or characteristics, by which they are identified.

Certain properties of matter are **physical properties**. Two very important physical properties are used by scientists to define matter: Matter is anything that has mass and volume. Mass is the quantity of matter in an object. Volume is the amount of space matter takes up.

Mass is related to another important property of matter: weight. An object has weight because it has mass, but mass and weight are not the same thing. Weight is a measure of the force of gravity on an object. The greater the mass of an object, the greater the force of gravity on it, and the greater its weight. Thus we can say that the weight of an object is directly proportional to its mass.

Figure 3-1 The physical properties of matter are often all you need to observe in order to tell substances apart. Because of their physical properties, the rose and the cactus are easily distinguishable.





Figure 3-2 What physical properties would you use to distinguish coal from sugar? Do these two substances have any physical properties in common?

Matter has other physical properties. These include color, odor, shape, texture, taste, and hardness. You know from experience that a lump of coal has a certain color, texture, and hardness. A lump of sugar has a different color, texture, and hardness. It even has a special taste. Two other important physical properties are melting point and boiling point. **Physical properties of matter can be observed and measured without permanently changing the identity of the matter.**

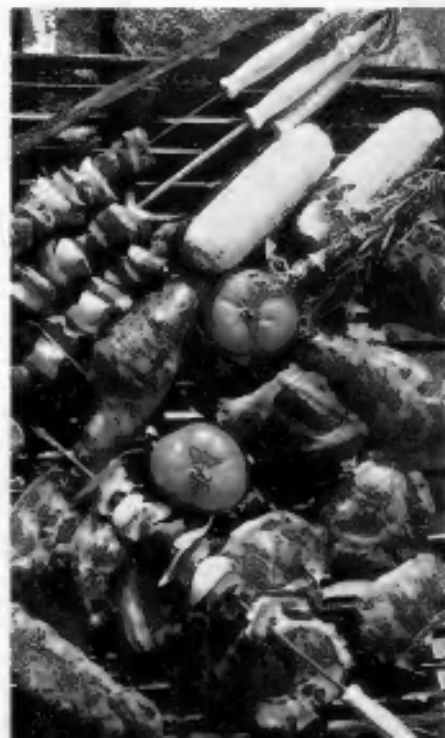
Matter has chemical properties also. Chemical properties describe a substance's ability to change into another new substance as a result of a chemical change. A chemical change is a process in which a substance is permanently altered. When a chemical change is completed, it is difficult, if not impossible, to reverse the process and get the starting material back. When coal burns, it undergoes a chemical change with oxygen to form other gases. Once a lump of coal has burned, it is no longer coal. And the gases produced cannot be converted back to coal. The chemical properties of a substance are determined by learning what sorts of chemical reactions the substance can undergo.

Phases of Matter

Ice, liquid water, and water vapor may seem very different to you. Certainly they have different appearances and uses. But actually they are all made of exactly the same substance in different states. These states are called **phases**. Phase is an important physical property of matter. Ice is the solid phase of water. Liquid water is the liquid phase. And water vapor is the gas phase.

The change from one phase of matter to another is a physical change because the substance is not altered. Water, regardless of its phase, is still water. Physical and chemical changes

Figure 3-3 Chemical properties describe how a substance changes into other new substances as a result of a chemical change. What chemical changes can you identify in these photographs of a rusty nut and bolt (left), a fireworks display (center), and a delicious meal grilling on the barbecue (right)?



are common in the world around us. And because living things, including ourselves, are made of matter, an understanding of these physical and chemical changes is important to biology.

3-1 SECTION REVIEW

1. Define the following terms: mass, weight, volume.
2. Compare a physical property and a chemical property. A physical change and a chemical change.
3. Using a piece of paper as an example, distinguish between the physical and chemical properties of matter.

3-2 Composition of Matter

Nearly 3000 years ago, the Greek philosopher Democritus challenged his students with a series of questions regarding the nature of matter. He picked up a small piece of salt, divided it into two fragments, and asked his students if each half was still salt. They said it was, and Democritus agreed. Could each half, he then asked, be divided into smaller and smaller pieces forever? Or was there a limit to the number of times a piece of matter could be divided? Democritus surprised his students with this novel idea by further arguing that there must be a tiny elementary particle that one could no longer divide and still call salt. He believed that all forms of matter were made up of basic, indivisible particles. He called these elementary particles **atoms**. The word atom comes from the Greek word *atomos*, meaning unable to be cut.

The approach of Democritus was philosophical rather than experimental. In part, this means that he was content to think about the problem but go no further. Scientists, however, must go further. They will speculate much as Democritus did, but then they will think of a way to test their ideas in an experiment. In the last 200 years, scientists have carefully studied Democritus' concept of the atomic nature of matter and have concluded that he was basically right. We now know that matter is indeed made up of small particles—not because it makes philosophical sense but because the evidence proves it. But we also now know that the atom itself is divisible and that particles smaller than the atom do exist!

The Atom

The basic unit of matter is the atom. Atoms are very, very small. Indeed, 100 million atoms placed side by side would form a row only 1 centimeter long—about the width of your pinky! Despite its extremely small size, the atom contains many

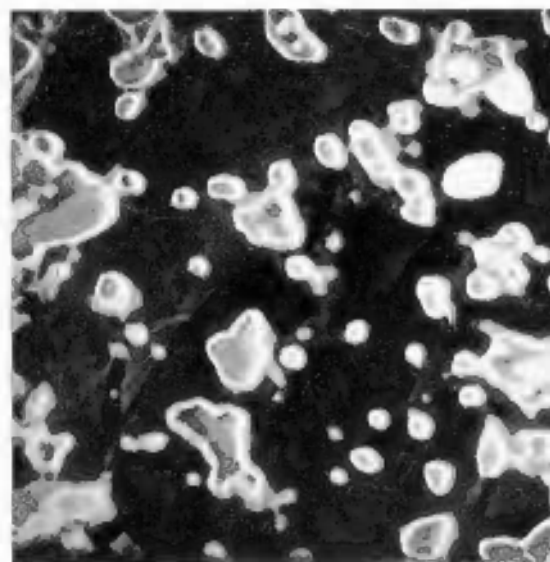


Figure 3-4 Phase is an important physical property of matter. Here you see water in its three phases: solid, liquid, and gas.

Section Objectives

- Describe the structure of an atom.
- Compare elements and compounds.
- Discuss the uses of radioactive isotopes.

Figure 3-5 This photograph of uranium atoms was taken with a scanning transmission electron microscope (STEM). The small dots are individual atoms. The larger patches are clusters of 2 to 20 atoms.



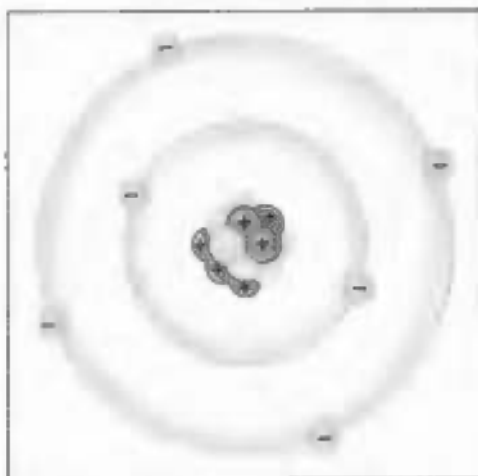


Figure 3-6 This artist's conception of an atom shows the nucleus, with its protons and neutrons, and the series of energy levels, with their electrons, that surround it (top). The illustration shows an atom of the element carbon (bottom).

smaller particles, known as subatomic particles. Scientists know about the existence of at least 200 different kinds of subatomic particles. The three principal subatomic particles are the proton, neutron, and electron.

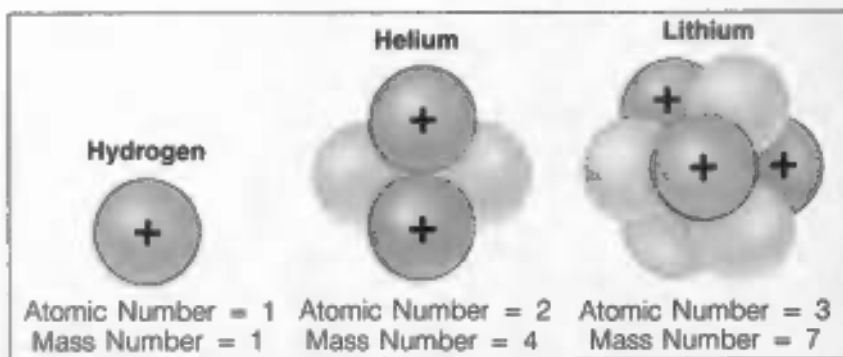
ATOMIC STRUCTURE The center of the atom is called the **nucleus**. Although the nucleus is about a hundred thousand times smaller than the entire atom, it makes up 99.9 percent of the mass of the atom. The nucleus contains two different kinds of subatomic particles held together by special atomic forces. One of these particles is the **proton**. The proton is a positively charged particle. The other particle found in the nucleus is the **neutron**. The neutron is an electrically neutral particle. It has no charge at all. The proton and neutron are nearly equal in mass (1 atomic mass unit, or amu).

In addition to protons and neutrons, the atom contains another kind of subatomic particle called the **electron**. The electron is a negatively charged particle with a mass about 2000 times less than that of either the proton or neutron (1/1836 amu). Under normal circumstances, the number of negatively charged electrons in an atom is equal to the number of positively charged protons. Therefore, the atom as a whole is neutral; it is neither negatively nor positively charged.

Electrons are not found in the nucleus. They travel at high speeds throughout the atom in a series of distinct **energy levels**, or orbits, that surround the nucleus. The existence of electrons in distinct energy levels is very important in determining the chemical properties of an atom, as you will learn shortly.

ATOMIC NUMBER AND MASS NUMBER The number of protons in the nucleus of an atom is called the **atomic number**. The atomic number identifies an atom. Atoms of the same substance have the same atomic number. But atoms of different substances have different atomic numbers. Thus the atomic number of an atom of a substance is a unique quantity. An atom of hydrogen, which has only 1 proton, has an atomic number of 1. All hydrogen atoms—but only hydrogen atoms—have an atomic number of 1. Helium, with 2 protons in the nucleus of

Figure 3-7 The nuclei of hydrogen, helium, and lithium atoms all contain protons. Those of helium and lithium atoms also contain neutrons. Yet hydrogen, helium, and lithium are very different elements. Why?



every atom, has an atomic number of 2. Uranium has an atomic number of 92. How many protons are in a uranium atom?

Although all subatomic particles contribute to the mass of an atom, protons and neutrons are much more massive than electrons. This explains why most of the mass of an atom is concentrated in the nucleus. Scientists often refer to the total number of protons and neutrons in the nucleus as the **mass number**. Hydrogen has a mass number of 1 because the only particle in the nucleus of a hydrogen atom is a proton. A helium atom has 2 protons and 2 neutrons in the nucleus. So the mass number of helium is 4.

Chemical Elements

As you read before, every substance in the world is made up of atoms. **Some substances, known as elements, consist entirely of one type of atom.** At present, scientists have identified 109 different **elements**. Of these 109 elements, 90 types are found in nature. The remaining 19 have been artificially produced by physicists using very special laboratory equipment. Each element can be represented by a chemical symbol. A chemical symbol is a shorthand way of representing an element. Each symbol consists of one or two letters, usually taken from the element's name. For example, the symbol for the element iodine is I. The symbol for hydrogen is H; for carbon, C. Scientists often use the Latin name of an element to create its symbol. For example, the symbol for lead is Pb, from the Latin word *plumbus*. You may recognize that word as the source for the English word plumbing, reflecting the fact that water pipes were once made of lead. Figure 3-8 lists some common elements and their symbols.

Most of the chemical elements are solids. Common examples include carbon, sulfur, phosphorus, sodium, calcium, and potassium. Some elements—such as oxygen, nitrogen, and chlorine—are gases. Only a few elements are liquids. Mercury and bromine are the most common examples.

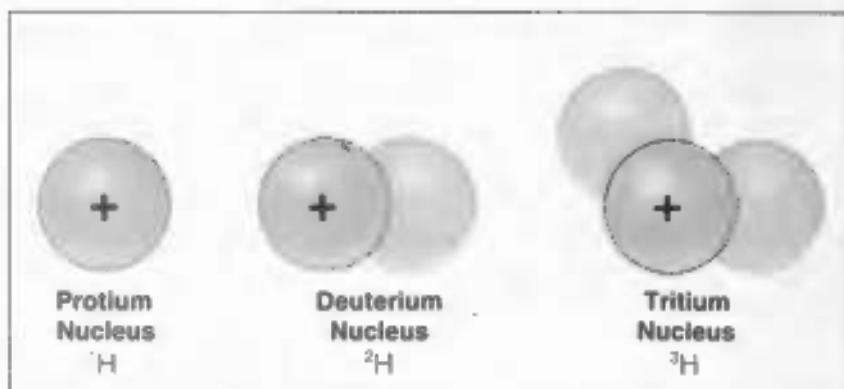
ISOTOPES As you read, each element has an atomic number that is determined by the number of protons in the nucleus of its atoms. The atomic number of an element never changes. This means that the number of protons in the nucleus of every atom of the element is always the same. However, the number of neutrons can vary from one atom of the element to the next. For example, the most common form of hydrogen has 1 proton and no neutrons in its nucleus. Another form of hydrogen, sometimes known as deuterium, has 1 proton and 1 neutron in its nucleus. And a third form, tritium, has 1 proton and 2 neutrons in its nucleus. Although they have different mass numbers, each form of hydrogen has an atomic number of 1, a single proton in the nucleus, and a single electron. Each form is hydrogen. Atoms of the same element that have the

ELEMENTS IN THE HUMAN BODY

Element	Symbol	Mass (%)
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.3
Phosphorus	P	1.0
Sulfur	S	0.3
Sodium	Na	0.2
Magnesium	Mg	0.1
Silicon	Si	trace
Fluorine	F	trace

Figure 3-8 This chart shows some of the elements in the human body, their symbol, and their percentage by mass. Which element makes up the greatest percentage? Which elements are found in only trace quantities?

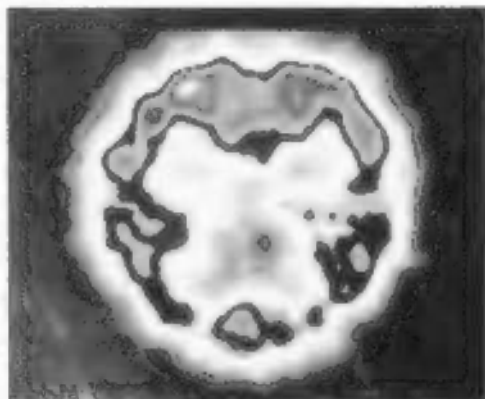
Figure 3-9 The three isotopes of hydrogen are protium, deuterium, and tritium. Which isotope contains 2 neutrons? What is the atomic number of each isotope?



same number of protons but different numbers of neutrons are known as **isotopes** of that element.

Isotopes of an element are represented by adding the number that indicates the mass number of that isotope to the atomic symbol. Thus, ordinary hydrogen is ^1H , deuterium is ^2H , and tritium is ^3H .

Figure 3-10 Radioactive isotopes can be used as tracer elements to produce images such as this axial section through a normal brain (top) and this image of the heart (bottom).



RADIOACTIVE ISOTOPES The nuclei of some atoms are unstable and will from time to time break down, releasing matter and/or energy that we call radiation. Atoms that emit radiation are said to be radioactive. Many elements have at least one radioactive isotope. All the isotopes of elements with atomic numbers greater than 83 are radioactive.

Radioactive isotopes have many practical uses. They are used to study living organisms, to diagnose and treat diseases, to sterilize foods, and to measure the ages of certain rocks.

Radioactive isotopes are frequently used as tracers. A tracer is a radioactive element whose pathway through the steps of a chemical reaction can be followed. An example of a tracer is phosphorus-32.

The nonradioactive element phosphorus is used in small amounts by both plants and animals. If phosphorus-32 is given to an organism, the organism will use the radioactive phosphorus just as it does the nonradioactive phosphorus. However, the path of the radioactive element can be traced, allowing scientists to learn how plants and animals use phosphorus.

Tracers are extremely valuable in diagnosing diseases. Radioactive iodine, iodine-131, can be used to study the function of the thyroid gland, which absorbs iodine. Sodium-24 can be used to detect diseases of the circulatory system. Iron-59 can be used to study blood circulation.

Radioactive isotopes are also used to treat certain diseases. When administered carefully and in the proper amounts, radiation can kill cancer cells with minimal damage to healthy tissue. Cobalt-60 is used extensively in cancer radiation treatments. Carbon-14 has been used to treat brain tumors.

Radioactive isotopes can also be used to kill bacteria that cause food to spoil. Radiation is used to preserve the food that astronauts eat while on the moon and in orbit.

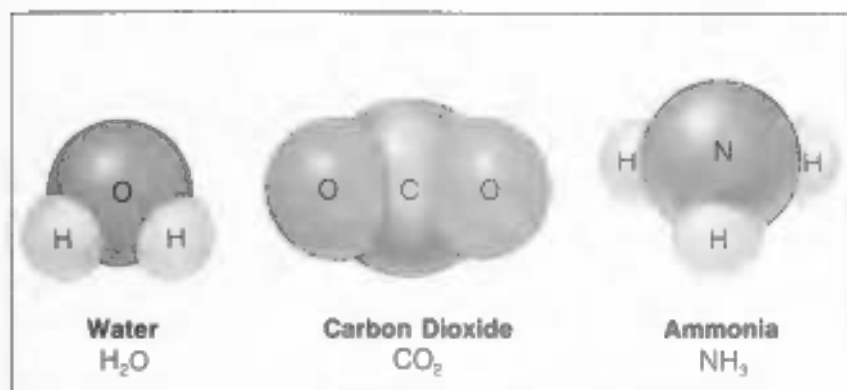


Figure 3-11 As you can see from this diagram, compounds are made of two or more different atoms combined in definite proportions. The chemical formula for each compound indicates the elements that make up the compound and the number of atoms of each element.

Another use of radioactive isotopes is in measuring the ages of certain rocks and the fossils they may contain. This use has increased our understanding of the evolution of life on Earth.

One of the difficulties in using radioactive materials is that these substances must be handled with great care. Radiation can damage or kill living things. So it is important that proper safety precautions be taken whenever radioactive isotopes are used. And it is also important that you be aware of and concerned about radioactive materials in the environment.

Chemical Compounds

When elements combine to form substances consisting of two or more different atoms, chemical compounds are produced. A chemical compound involves the combination of two or more different atoms in definite proportions. Most materials in the living world are compounds.

Just as elements are represented by chemical symbols, so too are compounds represented by a kind of shorthand. A chemical compound is represented by a chemical formula. A chemical formula consists of the chemical symbols for the elements that make up the compound. Water, which contains 2 atoms of hydrogen and 1 atom of oxygen, has the chemical formula H_2O . Table salt, made of sodium and chlorine, has the formula $NaCl$. What elements are present in the compound sulfuric acid, whose chemical formula is H_2SO_4 ?

3-2 SECTION REVIEW

1. Describe the structure of an atom. What is meant by atomic number? Mass number?
2. What is an element? How are elements represented?
3. What is an isotope? What are some uses of radioactive isotopes?
4. How is a compound different from an element?

Section Objectives

- Explain how electron arrangement determines an atom's reactivity.
- Describe the two types of chemical bonds.

3-3 Interactions of Matter

Chemical compounds are formed by the interactions of individual atoms. These interactions involve the combining of atoms of elements in a process known as **chemical bonding**. Chemical bonds are formed in very definite ways. The atoms combine according to certain rules. Such rules are determined by the number of electrons that surround the atomic nucleus—more specifically, the electrons found in the outermost energy level.

Each energy level in an atom can hold only a certain number of electrons. The first, or innermost, energy level can hold only 2 electrons. The second energy level can hold 8 electrons, as can the third when it is an outermost energy level. Figure 3-12 illustrates the arrangement of electrons in the first three energy levels.

When the outermost energy level of an atom contains the maximum number of electrons, the level is full, or complete. Atoms that have filled outermost energy levels are very stable, or unreactive. Such atoms usually do not combine with other atoms to form compounds. They do not form chemical bonds.

In order to achieve stability, an atom will either gain, lose, or share electrons. In other words, an atom will bond with another atom if the bonding gives both atoms complete outermost energy levels.

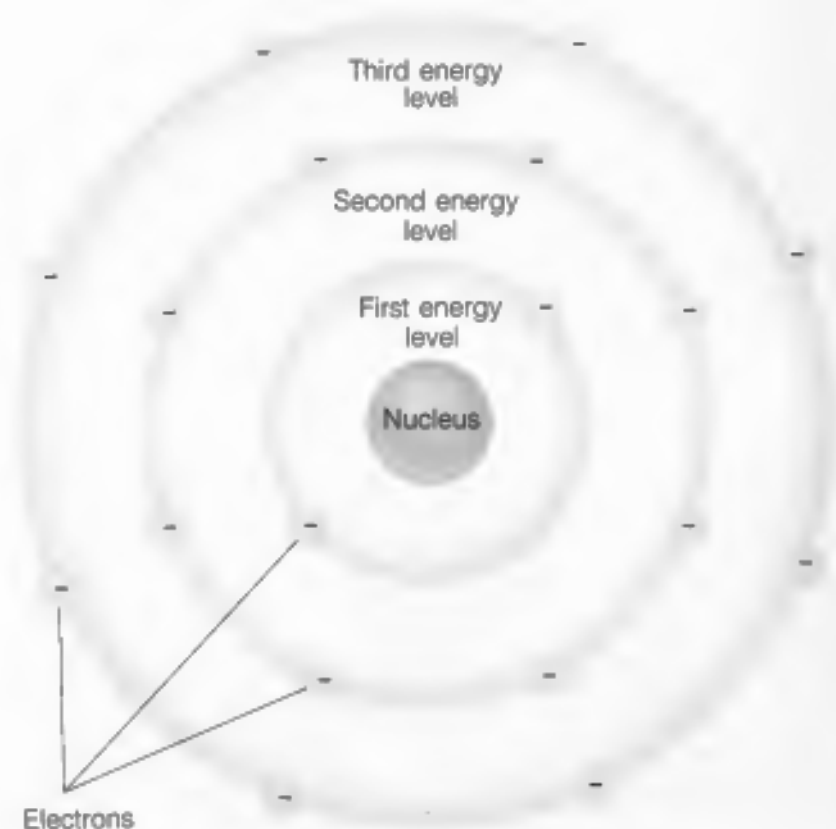


Figure 3-12 Each energy level in an atom can hold only a certain number of electrons. When the outermost energy level is holding its maximum number of electrons, it is complete, and the atom is stable.

Ionic Bonds

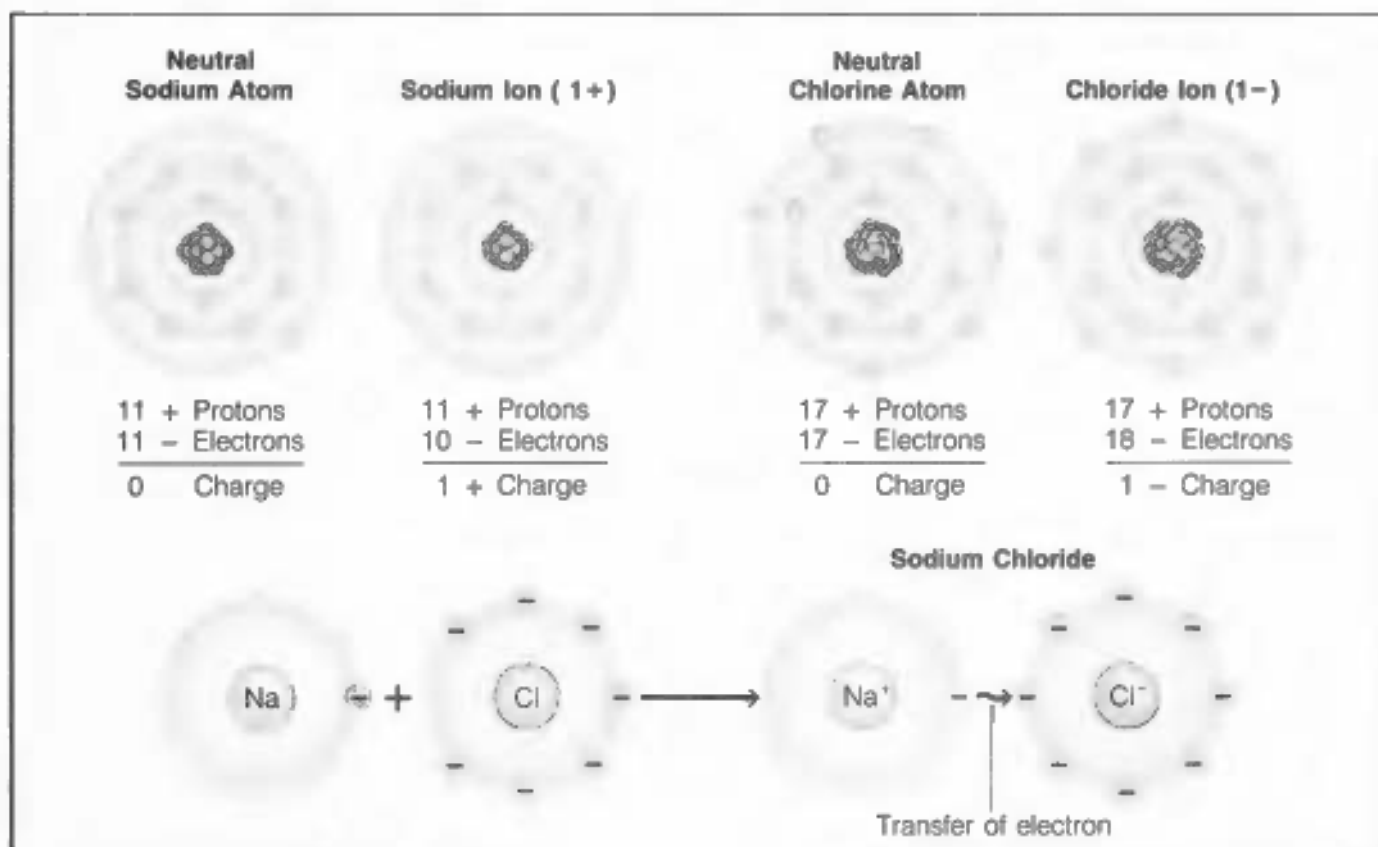
One way a complete outermost energy level can be achieved is by the transfer of electrons from one atom to another. A bond that involves a transfer of electrons is called an **ionic bond**. An ionic bond, or electron-transfer bond, gets its name from the word **ion**, which means charged particle. Ions are formed when an ionic bond occurs.

A sodium atom has only 1 electron in its outermost energy level, so it can lose that electron very easily. The loss of an electron from a sodium atom produces a sodium ion (Na^+), which has a positive charge. Similarly, chlorine needs only 1 electron to fill its outermost energy level, so it grabs an extra electron easily—possibly from a nearby sodium atom. The addition of an electron to a chlorine atom produces a negatively charged chloride ion (Cl^-). These two ions, now oppositely charged, have a strong attraction for each other—much like opposite poles of a magnet. The strong attraction between oppositely charged ions that have been formed by the transfer of electrons holds the ions together in an ionic bond.

Figure 3-13 The formation of a positive sodium ion involves the loss of an electron by a sodium atom. The formation of a negative chloride ion involves the gain of an electron by a chlorine atom. The transfer of an electron produces oppositely charged ions that are strongly attracted and held together in an ionic bond. Because only the electrons in the outermost energy level are involved in bonding, only this level has been shown in the bottom diagram.

Covalent Bonds

A chemical bond formed by the sharing of electrons is known as a **covalent bond**. By sharing electrons, each atom



fills up its outermost energy level. So the shared electrons are in the outermost energy level of both atoms at the same time. This produces a strong bond that is characteristic of most of the chemicals found in living organisms.

Covalent bonds can be single, double, or triple, depending on the number of electrons that are shared in the bond. The covalent bond between hydrogen and oxygen in water (H_2O) is a single bond. A single pair of electrons is shared between the oxygen atom and each of the 2 hydrogen atoms. In the compound carbon dioxide (CO_2), the carbon atom shares two pairs of electrons, or a total of 4 electrons, with each of the oxygen atoms in the compound. The carbon-oxygen bond in carbon dioxide is a double bond.

Figure 3-14 The bonding in molecules can be represented by electron-dot formulas and by structural formulas. An electron-dot formula shows the electron pairs involved in the bonding. A single bond involves one pair of electrons; a double bond involves two. In a structural formula, a dash (–) is used to represent a pair of shared electrons, or a single bond. How is a double bond represented?

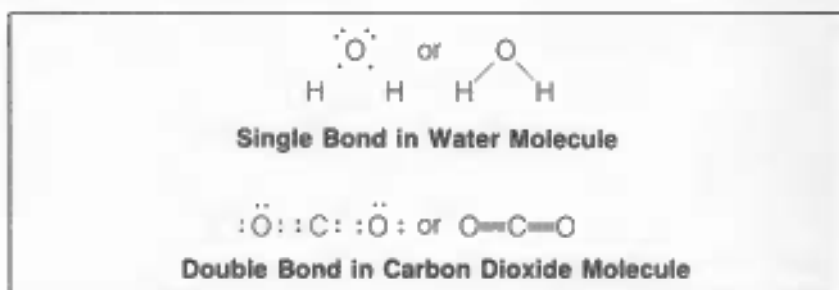
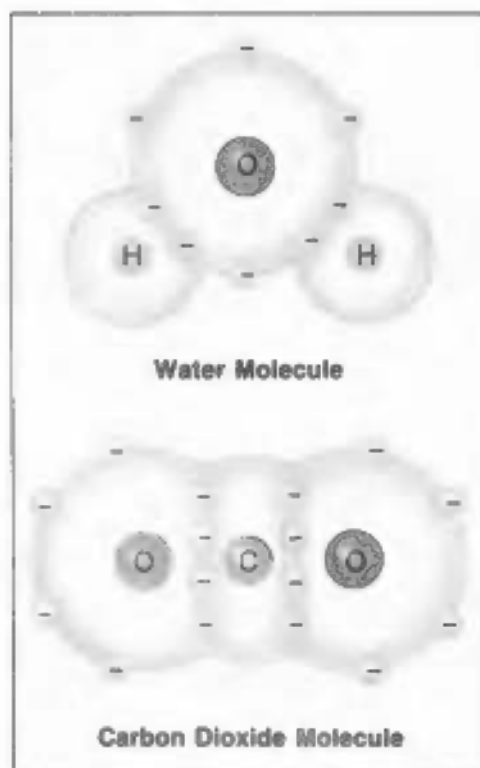


Figure 3-15 A covalent bond involves the sharing of electrons. How many double bonds are there in a molecule of carbon dioxide?



In a covalent bond, a relatively small number of atoms are involved in the sharing of electrons. The combination of atoms that results forms a separate unit called a **molecule**. A molecule is the smallest particle of a covalently bonded compound. In addition to water and carbon dioxide, some other common covalent compounds are sugar ($\text{C}_6\text{H}_{12}\text{O}_6$) and ammonia (NH_3).

Regardless of the type of bond formed, atoms change their physical and chemical properties when they form a compound. For example, sodium is a silvery metal that reacts explosively with water. Chlorine is a poisonous greenish gas, which was responsible for the deaths of many soldiers in World War I. Neither element in its pure form can be used by your body. Yet they combine to form sodium chloride (NaCl), or table salt, a solid that dissolves easily in water, is not poisonous, and is essential to most living things. It also tastes great on a pretzel!

3-3 SECTION REVIEW

1. Describe the arrangement of electrons in the first three energy levels.
2. Compare an ionic bond to a covalent bond.
3. An oxygen atom has 6 electrons in its outermost energy level. A hydrogen atom has 1. Describe how the covalent bonds in the water molecule enable each atom to achieve a complete outermost energy level and, therefore, stability.

A Do-It-Yourself Poison

Each year they cause more than \$5 billion in damage to crops and livestock. They are a threat to human health because they can transmit certain diseases. And in order to eliminate them, poisonous substances that may endanger our health as well as the health of our environment must be used. What are these pests who have created economic, environmental, and safety problems? Insects!

Farmers and gardeners use insecticides to protect their plants and animals against insects. Insecticides are compounds that kill insects in a variety of ways. Some kill insects that eat the chemical compounds. Others kill insects upon contact. Certain insecticides produce lethal vapors and gases. Still others kill by infecting insects with deadly diseases.

Although many insecticides are effective in the battles against insect infestation, they often have profound effects on the environment and other living things. Until recently, people had to balance the benefits of insecticide use against possible damage to planet Earth. Now a new class of insecticides that af-

fect only their target and pose little danger to us has been developed.

Scientists working at the State University of New York at Stony Brook combined polyesters—special compounds manufactured by plants—with the element fluorine to produce a new group of compounds called 29-fluorophytosterols. These compounds are harmless to most organisms—ourselves included! But inside an insect's body, special chemicals called enzymes can act on the fluorophytosterols and break them down to produce fluoroacetate, a deadly poison. For insects unfortunate enough to have the special enzymes, this new class of insecticide spells doom!

In and of themselves, 29-fluorophytosterols are harmless, presenting little danger to most living things. But the chemical composition and bodily processes of insects render these compounds deadly! By applying a knowledge of basic chemistry to the workings of living systems, scientists were able to develop exactly the compound they sought: a safe and effective insecticide.

3-4 Chemical Reactions

You have learned that two types of bonds can exist between atoms and that compounds with different chemical and physical properties can be formed by the transfer or sharing of electrons. Whenever a chemical bond is formed, a chemical change takes place. Any process in which a chemical change occurs is known as a **chemical reaction**.

Chemical reactions occur all the time and are very much a part of your daily life. Some chemical reactions occur slowly, such as the combination of iron and oxygen to form rust. Others occur quickly. When hydrogen gas is ignited in the presence of oxygen, the reaction is rapid and explosive.

In any chemical reaction there are always two kinds of substances: the substances that are present before the change and the substances that are formed by the change. The elements or

Section Objectives

- Identify the substances involved in a chemical reaction.
- Describe the role of energy in chemical reactions.

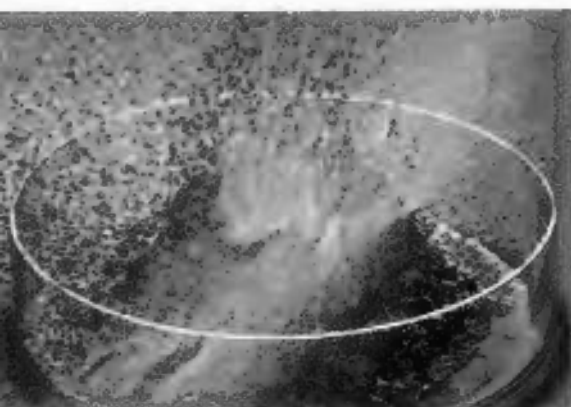
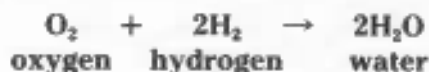


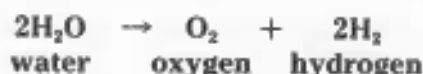
Figure 3-16 Chemical reactions are many and varied. Here you see two examples: the heating of ammonium dichromate (top) and the decaying of apples (bottom). A chemical reaction always involves a change in the properties and in the energy of the substances involved.

compounds that enter into a chemical reaction are known as reactants. The elements or compounds produced by a chemical reaction are known as products.

A chemical reaction can be described by using a shorthand method known as a chemical equation. In a chemical equation, symbols and formulas are used to represent reactants and products. And an arrow, which is read “yields,” shows the direction of the reaction. Let us use the chemical reaction involving the combination of hydrogen and oxygen to form water to illustrate a chemical equation.



Chemical reactions are reversible. In principle, any chemical reaction can run in either direction. For example, it is possible for the reaction we have just described to run in reverse.



This generally does not occur however. Why? Because there is an important difference between the two chemical reactions. When oxygen gas and hydrogen gas burn to form water vapor, an enormous amount of energy is released in the form of heat, light, and sound. But water, on the other hand, does not spontaneously decompose to form hydrogen gas and oxygen gas. In fact, the only convenient way to drive the reaction in this direction is to run an electric current through the water to decompose it. Thus, in one direction the reaction produces energy; in the other direction, it requires energy.

Chemists have learned that the most important factor in determining whether a reaction will occur is the flow of energy. Chemical reactions that release energy will occur spontaneously. Chemical reactions that require energy will not occur without a source of energy.

What significance does this have for you and the other living things that share your world? All living things carry on both kinds of reactions in order to stay alive. The energy needed to grow tall, to read, to think, and even to dream comes from chemical reactions that occur in your body when you digest the food you eat. In the following chapters, you will explore these reactions and the flow of energy necessary for life.

3-4 SECTION REVIEW

1. What is a chemical reaction? A chemical equation?
2. What is a reactant? A product?
3. Describe the role of energy in chemical reactions.
4. Why is it important that energy-absorbing and energy-releasing reactions take place in living things?

PROBLEM SOLVING

IN BIOLOGY

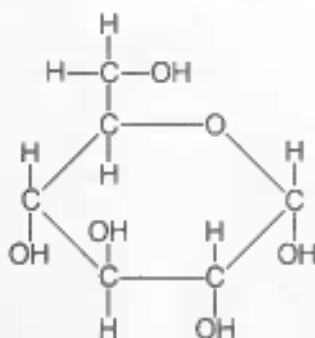
STRUCTURAL FORMULAS

Molecules are too small to be seen, yet we draw their pictures anyway. The reason for doing this is simple: In living things, a great many important things happen at the molecular level, and we need a way of representing these events. How shall we draw these pictures of molecules? And once drawn, what do they mean? Let's begin by considering glucose, a simple sugar.

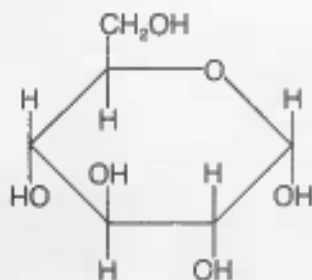
One way to represent glucose is to write its molecular formula:



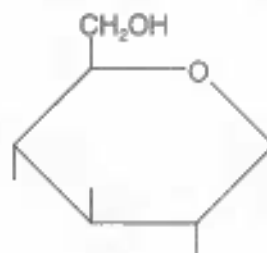
This formula tells us how many atoms of each element are in a molecule of glucose. But it does not indicate how the atoms are arranged. To do that, we need to draw a structural formula for the glucose molecule:



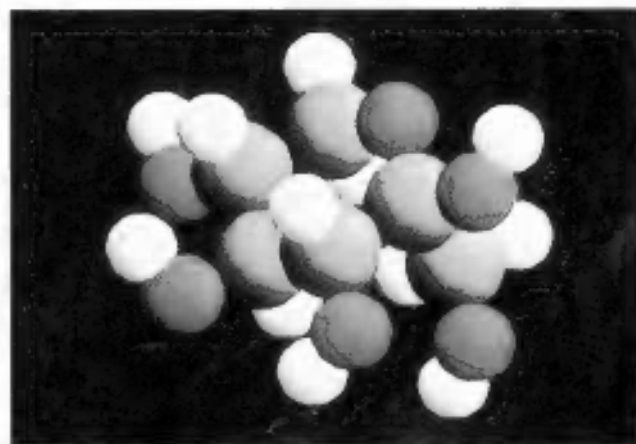
Chemists often try to simplify structural formulas. One way of doing this is to leave nearly all of the carbons out of the picture. However, everybody knows they're still there! Now the molecule looks like this:



Sometimes chemists draw the same molecule in an even simpler fashion, like this:



Each drawing is useful because it provides important information. For example, we can see that the glucose molecule is folded to form a ring and that the -OH groups (hydroxyl groups) project from one side or the other of that ring into space. None of the structural formulas, however, actually looks like a real molecule of glucose:



The key idea to remember about chemical formulas and structural formulas is that they are representations. Representations are useful and informative. They help us to visualize things that are hard to explain.

Now try your hand at drawing structural formulas for the following compounds: CH_4 methane; CCl_2F_2 Freon; $\text{C}_2\text{H}_4(\text{OH})_2$ ethylene glycol or antifreeze; C_2H_6 ethane.

LABORATORY INVESTIGATION

IDENTIFYING ELEMENTS BY DENSITY

PROBLEM

How do the densities of different elements compare?

MATERIALS (per group)

aluminum metal
zinc metal
unknown metal sample
graduated cylinder
balance

PROCEDURE



1. Density is mass per unit volume. In this laboratory investigation, you will measure the density of two elements, zinc and aluminum. Copy the data table shown below onto a separate sheet of paper to record your observations.
2. Using a balance, measure the mass of a small sample of aluminum metal (about 40 g). Record the mass in the data table.
3. Measure the volume of the aluminum metal using the following procedure: Fill a 100-mL graduated cylinder halfway with water and record the initial volume in your data table. Put the aluminum metal into the graduated cylinder. This will cause the water level to rise. Record the final volume of water. Find the volume of the aluminum by subtracting the ini-

tial volume of the water from the final volume of the water. Record the result.

4. Calculate the density of the aluminum by dividing the aluminum's mass by its volume: $D = M/V$. Record the result.
5. Find the density of a small sample of zinc metal by measuring its mass and volume according to the same procedure you used for aluminum.
6. Measure the density of an unknown sample of metal. Use your results to determine whether the unknown metal is aluminum or zinc.

OBSERVATIONS

1. How do the densities of aluminum and zinc compare?
2. What are some observable properties of aluminum and zinc?

ANALYSIS AND CONCLUSIONS

1. Is the unknown metal aluminum or zinc? How do you know?
2. Is density a physical or a chemical property? How can you tell?
3. Can density be used to help identify elements? Explain your answer.

Element	Mass (g)	Volume (mL)			Density (g/mL)
		Initial	Final	Metal	
Aluminum					
Zinc					
Unknown					

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

3-1 Nature of Matter

- Two important properties—mass and volume—are used to define matter.
- Physical properties of matter can be observed and measured without permanently changing the identity of the matter. Chemical properties describe a substance's ability to change into another new substance as a result of a chemical change.

3-2 Composition of Matter

- The basic unit of matter is the atom. The nucleus of the atom contains positively charged protons and electrically neutral neutrons. Energy levels outside the nucleus contain negatively charged electrons.
- The number of protons in the nucleus of an atom is called the atomic number.
- Substances that consist entirely of one type of atom are called elements. Atoms of the

same element that have the same number of protons but different numbers of neutrons are called isotopes.

- A chemical compound consists of two or more different atoms chemically combined in definite proportions.

3-3 Interactions of Matter

- The combining of atoms of elements is known as chemical bonding. An ionic bond involves a transfer of electrons between atoms. A covalent bond involves the sharing of electrons.

3-4 Chemical Reactions

- In any chemical reaction, reactants combine to yield products.
- Although chemical reactions are reversible in principle, they occur spontaneously only in the direction that produces energy.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review the definition.

3-1 Nature of Matter

physical property
chemical property
phase

nucleus

proton

neutron

electron

energy-level

atomic number

mass number

element

isotope

compound

ion

covalent bond

molecule

3-2 Composition of Matter

atom

3-3 Interactions of Matter

chemical bonding

ionic bond

3-4 Chemical Reactions

chemical reaction

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. Substances that enter into a chemical reaction are known as
 - a. reactants.
 - b. catalysts.
 - c. products.
 - d. isotopes.
2. Two important physical properties used to define matter are
 - a. taste and smell.
 - b. mass and volume.
 - c. weight and boiling point.
 - d. mass and freezing point.
3. The nucleus of an atom contains
 - a. electrons and protons.
 - b. electrons and neutrons.
 - c. protons, electrons, and neutrons.
 - d. protons and neutrons.
4. A substance consisting of two or more different elements chemically combined is a(an)
 - a. molecule.
 - b. crystal.
 - c. compound.
 - d. isotope.
5. An atom with an atomic number of 8 has
 - a. 8 protons.
 - b. 4 protons plus 4 neutrons.
 - c. 4 protons plus 4 electrons.
 - d. 4 neutrons plus 4 electrons.
6. Which is true of carbon-12 and carbon-14?
 - a. They have the same number of neutrons.
 - b. They have the same number of protons.
 - c. They have the same mass number.
 - d. They are isotopes of different elements.
7. A shorthand way of representing an element is a chemical
 - a. formula.
 - b. reaction.
 - c. property.
 - d. symbol.
8. Radioactive isotopes are used
 - a. as tracers.
 - b. to diagnose disease.
 - c. to treat disease.
 - d. to do all of these.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. Chemical properties describe a substance's ability to undergo a chemical change.
2. The sharing of electrons is characteristic of ionic bonds.
3. Any process in which a chemical change occurs is known as a chemical formula.
4. The number of protons in the nucleus of an atom is called the mass number.
5. Chemical reactions that absorb energy will occur spontaneously.
6. The amount of space an object takes up is known as weight.
7. Atoms that have complete outermost energy levels are said to be very stable.
8. The positively charged subatomic particle is the electron.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

1. energy level, proton, nucleus, neutron
2. oxygen, sodium, carbon dioxide, mercury
3. solid, mass, liquid, gas
4. 2, second energy level, 8, third energy level
5. molecule, electron transfer, covalent bond, water
6. color, phase, ability to burn, texture
7. products, physical change, reactants, yields
8. Democritus, atom, divisible particle, Greek philosopher

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Describe two important differences between physical and chemical properties.
2. Identify each of the following changes as either a physical change or a chemical change:
 - a. melting butter
 - b. boiling water
 - c. digesting food
 - d. baking brownies
 - e. exploding TNT
 - f. dissolving sugar
 - g. burning fuel oil
3. Describe the subatomic particles found in the atom. Be sure to include their charge, mass, and location in your description.
4. What is the atomic number of an element? What is its significance?
5. Nitrogen-14 and nitrogen-15 are isotopes of the element nitrogen. Describe how atoms of these isotopes differ from each other.
6. What is a radioactive isotope? Describe three uses of radioactive isotopes.

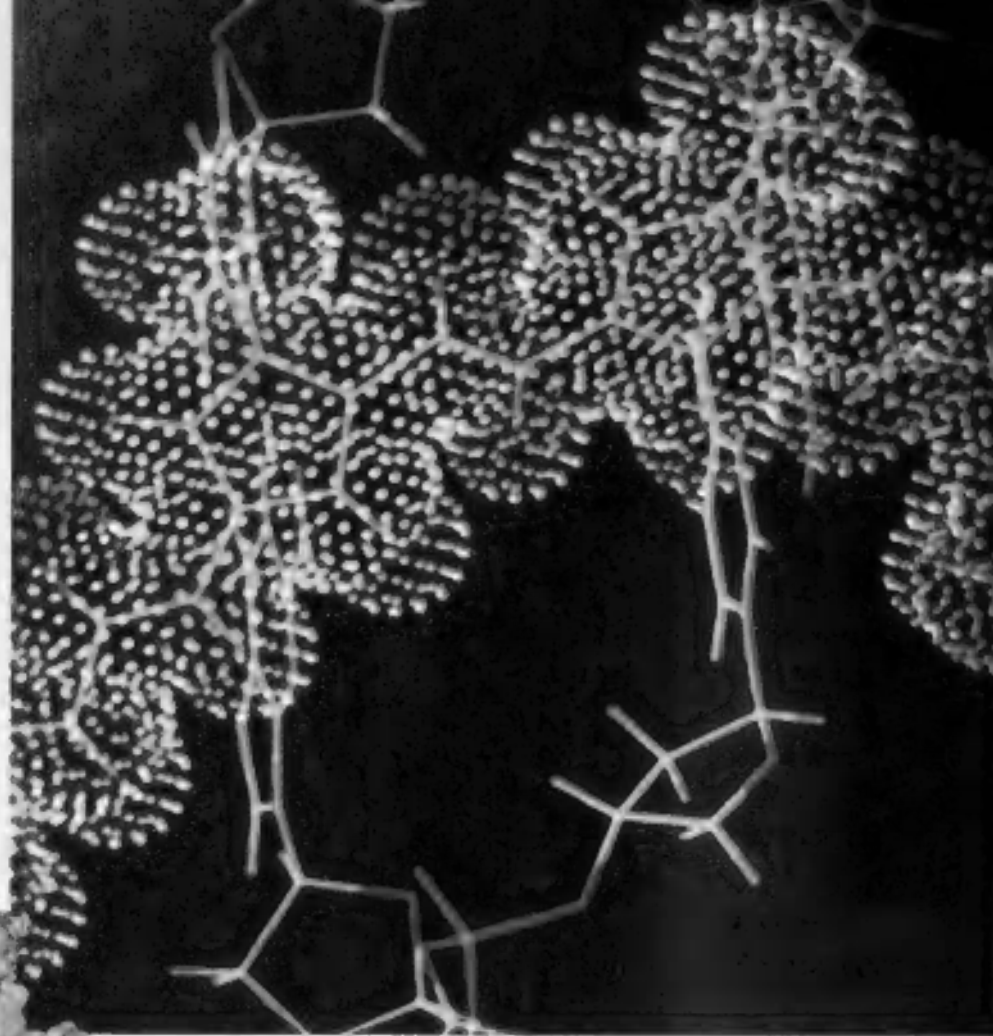
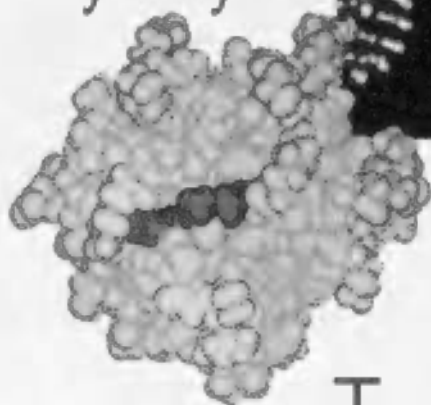
CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Relating facts** Explain why the use of radioactive isotopes has both advantages and disadvantages.
2. **Developing a model** Draw a diagram of the electron arrangement for the following elements based on their atomic number: lithium (3), carbon (6), fluorine (9), magnesium (12), phosphorus (15), argon (18).
3. **Identifying patterns** Explain why the element neon, with an atomic number of 10, is unreactive.
4. **Synthesizing concepts** Explain the role of energy in chemical reactions.
5. **Applying concepts** A basic principle of electricity is "like charges repel and opposite charges attract." How does the organization of particles in an atom illustrate this principle? How does it refute it?
6. **Using the writing process** The time is 3000 years ago. The Greek philosopher Democritus has proposed that all matter is made up of atoms. Write a brief speech supporting or refuting the concept of indivisible atoms.

CHAPTER 4

The Chemical Basis of Life



A variety of important chemical substances are combined in specific ways to produce protein molecules, which are among the basic compounds of life.

There are no special elements found in living things. In fact, the molecules that make up a living cell do not, in and of themselves, have the property of life. Yet there can be no doubt that certain elements organized into a variety of molecules do indeed account for life. How, you might ask, is this possible? In a way, we will spend the rest of this book searching for an answer, an answer that will remain incomplete in the end. For life itself is not completely understood. But we can begin. And one way to start is by understanding life not as the property of one particular molecule but as something made possible by a large group of molecules. In this chapter you will learn about the molecules that give life to you and to all other organisms on Earth.

CHAPTER OUTLINE

4-1 Water

- Mixtures
- Solutions
- Suspensions

4-2 Chemical Compounds in Living Things

- Inorganic Compounds
- Organic Compounds
- Polymerization

4-3 Compounds of Life

- Carbohydrates
- Lipids
- Proteins
- Enzymes
- Nucleic Acids

4-1 Water

Section Objectives

- List some important properties of water.
- Describe the nature of mixtures, solutions, and suspensions.
- Define acids, bases, neutralization, and pH scale.

Someone once said that if there is magic on this planet, then it is to be found in water. Water? To most of us, water is so ordinary that it is of little interest and certainly does not seem magical. Yet how wrong we are!

Water is one of the few naturally occurring compounds that is liquid at the temperatures found on much of the Earth's surface. Unlike most other materials, water expands slightly as it makes the phase change from liquid to solid. This explains why ice floats at the surfaces of lakes and rivers rather than sinking to the bottom—a situation that might be disastrous for fish and plant life, to say nothing of the sport of skating!

Water is a most unusual molecule, with physical and chemical properties found in no other material. Water covers more than 75 percent of the Earth's surface and is the most abundant compound in nearly all living organisms.

The most important property of the water molecule is that due to an uneven distribution of electrons, it is slightly

Figure 4-1 The importance of water to all living things cannot be denied—whether it's as a vital body fluid or as home to penguins in Antarctica. The Earth and its inhabitants cannot survive without water. Every attempt must be made to preserve this resource necessary to life.



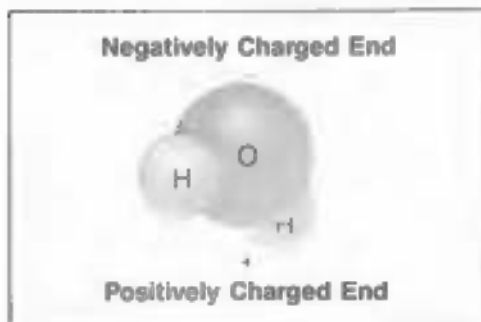


Figure 4-2 The polarity of a water molecule explains why water is able to dissolve thousands of substances—whether they be ionically or covalently bonded. Which end of a water molecule is positive? Negative?

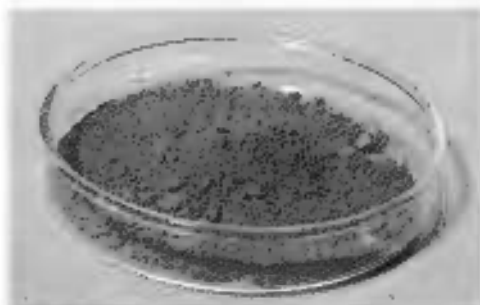
charged on each end. See Figure 4-2. In this way, each water molecule is like a little magnet, with one pole near the nucleus of the oxygen atom and the other pole near the nuclei of the two hydrogen atoms. This polarity produces a strong attraction between individual water molecules and between water molecules and other charged molecules.

Mixtures

The slight charges of water molecules make them especially good at forming **mixtures**. A mixture is a substance composed of two or more elements or compounds that are mixed together but not chemically combined. Salt and pepper stirred together constitute a mixture. So do sugar and sand. Unlike chemical compounds, the substances that make up mixtures can be added in varying amounts and are not linked by chemical bonds.

Earth's atmosphere is a mixture of gases; soil is a mixture of individual solid particles; and living things are in part com-

Figure 4-3 By combining powdered iron (top) with powdered sulfur (center), an iron-sulfur mixture is formed. But because the substances making up this mixture are not linked by chemical bonds, they can be separated easily by a magnet (bottom). The gold miner can separate heavy pieces of gold from rock, sand, and dirt by shaking the mixture in a pan of water and letting the gold settle to the bottom (right).



posed of mixtures involving water. The mixtures that are made with water can be of two important types: solutions and suspensions.

Solutions

If a cube of sugar is placed in a glass of warm water, the movement of the water molecules gradually breaks off single molecules from the sugar cube. These sugar molecules then become dispersed in the water and the sugar dissolves. See Figure 4-4. Before long, the sugar cube has completely disappeared and the sugar molecules are uniformly spread throughout the water, forming a **solution**. The sweet taste of the solution tells us that the sugar is still there. The sugar has undergone a physical but not a chemical change in forming a solution with water.

You have probably made solutions of water and many other materials, such as sugar, salt, tea, and cocoa. In these solutions, water is the **solvent**, or substance that does the dissolving. The substance that is dissolved—salt or tea, for example—is the **solute**. All solutions consist of a solvent and a solute. Without exaggeration, water is the greatest solvent in the world. This distinction is due largely to the charges at either end of the water molecule, which attract water molecules to other molecules whether they are positively or negatively charged.

ACIDS When ionically bonded compounds dissolve in water, they often dissociate, or break apart, into individual ions. Common table salt (sodium chloride) is a good example.



The dissociation of sodium chloride produces the positive sodium ion (Na^+) and the negative chloride ion (Cl^-). Many other compounds follow this general pattern when they dissolve in water. One group of compounds, however, deserves special attention. Consider the following dissociation reaction:



At first glance this compound dissociates in the same way that salt does. Just like salt, it produces a chloride ion (Cl^-). But the hydrogen ion (H^+) that is produced is very different from the sodium ion (Na^+). The H^+ is the most chemically reactive ion known. It is a single proton, lacking any electrons. This absence of electrons enables the hydrogen ion to attack the chemical bonds in a wide variety of molecules.

Compounds that release hydrogen ions into solution are known as **acids**, and we know HCl as hydrochloric acid. Can you name some other examples of acids?

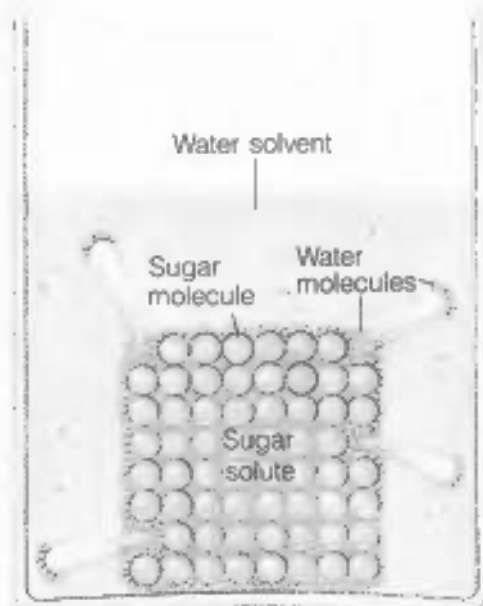
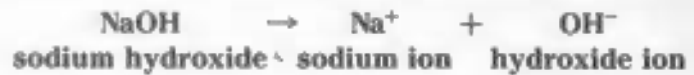


Figure 4-4 The solution process first involves the separation of solute particles from the surface of the solid solute. Then the solute molecules enter the solution. Finally, the solute molecules are attracted to the solvent molecules.

Figure 4-5 Hydrochloric acid, HCl, is a strong acid present in the stomach that aids in the process of digestion. Here you see a fiber optic endoscopic image of the stomach lining.

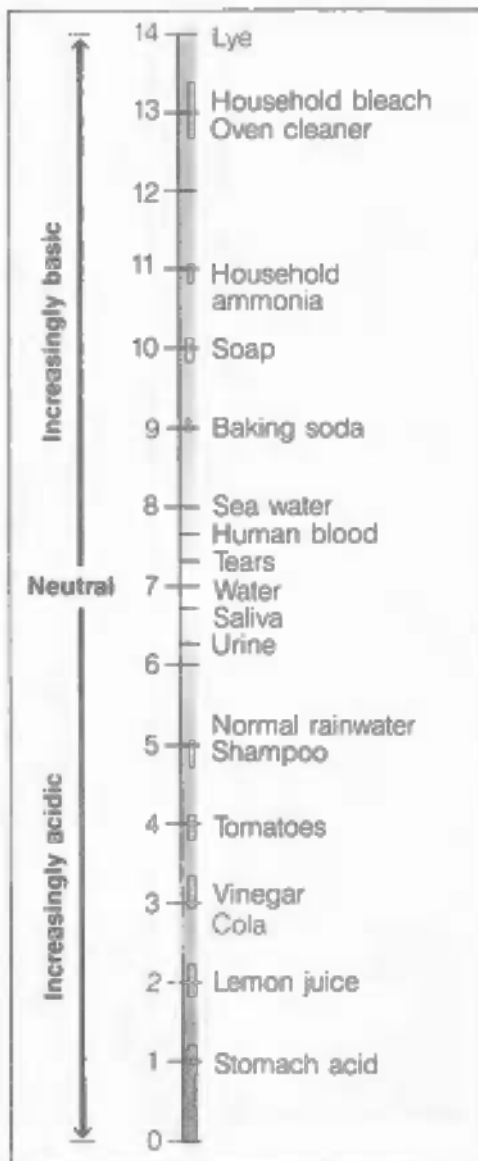


BASES Bases are compounds that release hydroxide ions (OH^-) into solution. Sodium hydroxide is an example of a base.

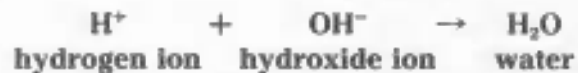


Strong acids and bases are highly reactive chemical compounds. They can attack and break a variety of chemical bonds, thus making them potentially dangerous to living tissue.

Figure 4-6 On the pH scale, 7 is neutral, acids are between 0 and 7, and bases are between 7 and 14. A difference of 1 between consecutive numbers on the scale is actually a difference of 10 times the relative strengths of the acids or bases. What cleaner is more basic? What body fluid is most acidic?



NEUTRALIZATION AND pH Mixing a strong acid and a strong base results in a reaction in which hydrogen ions and hydroxide ions react to form water. This type of reaction is called a **neutralization reaction**. Can you guess the reason for this name?



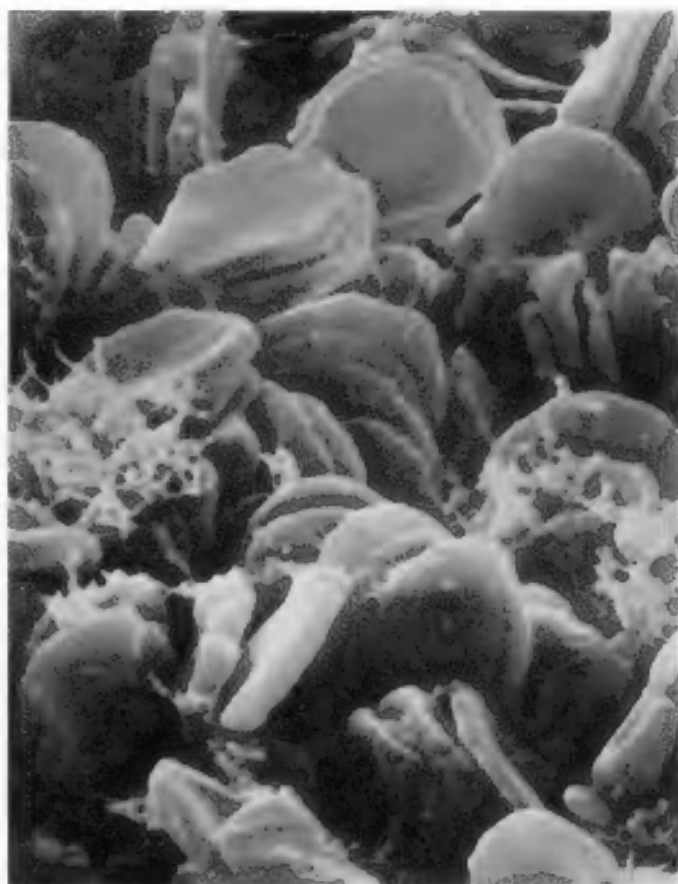
If the quantities of acid and base being mixed are in perfect balance, the neutralized solution that results is neither acid nor base. The concentrations of hydrogen ions and hydroxide ions are equal. The relative concentrations of hydrogen ions and hydroxide ions in a solution is an important indicator of the properties of the solution. A measurement system known as the **pH scale** indicates the relative concentrations of these two ions. See Figure 4-6.

The pH scale ranges from 0 to 14. Pure water, in which the concentrations of H^+ and OH^- ions are equal, has a pH value of 7.0. Acids have pH values of less than 7. Strong acids, such as those that help digest food in the stomach, have pH values of 1 to 3. Bases have pH values greater than 7. Strong bases, like ammonia or lye, have high pH values, ranging from 11 to 13. The pH values within most cells range from 6.5 to 7.5. These near-neutral values are maintained by dissolved compounds that help prevent sharp, sudden swings of pH, which might cause damaging chemical changes within living tissues.

Suspensions

Some materials do not break into individual molecules when placed in water but still form pieces so small that they will not settle to the bottom of a container. The movement of water molecules keeps these small particles suspended. Such mixtures of water and nondissolved material are known as **suspensions**.

In living things, both solutions and suspensions are very important. A perfect example is the blood that circulates through your body. Blood, as you might have guessed, is mostly water. In that water are many dissolved compounds, including salt. So blood is a solution. But blood is also a suspen-



sion. It contains tiny structures that aid in clotting, as well as living cells and other suspended particles. See Figure 4-7. These components do not dissolve in blood. Instead, they form a suspension that circulates through the body—an extremely vital suspension made possible by the most important molecule found in living things: water.

Figure 4-7 Mixtures of water and nondissolved material are called suspensions. Oil and water (left) is a common suspension. Perhaps less familiar to you is the suspension circulating through your body—blood! Blood contains clotting structures, living cells, and other particles, all suspended in a solution of water and other dissolved compounds (right).

4-1 SECTION REVIEW

1. What are some important properties of water? What property accounts for its being the best solvent?
2. What is a mixture? What are two important types of mixtures? How do these two types differ?
3. What is a solution? A solvent? A solute?
4. Describe two important differences between acids and bases.
5. What is a neutralization reaction? Give an example.
6. Hydrogen fluoride (HF) is dissolved in pure water. Predict whether the pH of the solution will be greater than or less than 7.0.

Section Objectives

- Identify the four most abundant elements in living things.
- Compare inorganic compounds and organic compounds.
- Describe the properties that make carbon unique.
- Explain the importance of polymerization.

4-2 Chemical Compounds in Living Things

Although the Earth's crust contains 90 naturally occurring chemical elements, only 11 of these elements are common in living organisms. Another 20 are found in trace amounts. Just four elements—carbon, nitrogen, oxygen, and hydrogen—make up 96.3 percent of the total weight of the human body. **In varying combinations, the elements carbon, hydrogen, oxygen, and nitrogen make up practically all the chemical compounds in living things.** To make the study of these and all other chemical compounds easier, scientists have divided them into two groups: **organic compounds**, which contain carbon, and **inorganic compounds**, which do not.

Inorganic Compounds

Inorganic compounds are primarily those compounds that do not contain carbon. One exception to this definition is carbon dioxide, which although it does contain carbon is an inorganic compound. The natural world is dominated by such compounds. Water is inorganic, as are the minerals that make up most of the sand, soil, and stone of the Earth's landmasses.

Living things contain a great many inorganic compounds, ranging from water to carbon dioxide to calcium phosphate, a mineral from which bones are formed. The group of compounds known as salts that help to balance the pH of the blood are largely inorganic.

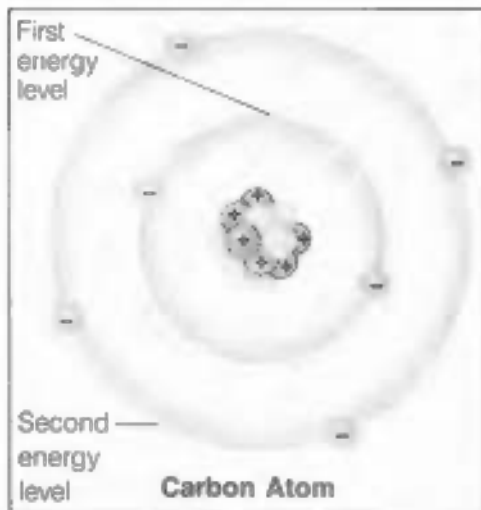
Organic Compounds

Organic compounds are carbon-containing compounds. A special branch of chemistry called organic chemistry deals with the chemistry of carbon and its more than 2 million compounds. Why is carbon so special?

Carbon is a unique element because of its remarkable ability to form covalent bonds that are strong and stable. You will recall that covalent bonds involve the sharing of electrons. Carbon has 6 electrons, 2 in the first energy level and 4 in the second. So only 4 of the 8 positions in its outermost energy level are filled. This means that carbon can form four single covalent bonds. The simplest compound that can be formed from carbon is methane, CH_4 . Carbon can also form covalent bonds with oxygen, nitrogen, phosphorus, and sulfur atoms. The ability to bond easily and form compounds with these common elements would be enough to make carbon an interesting element. But there's more!

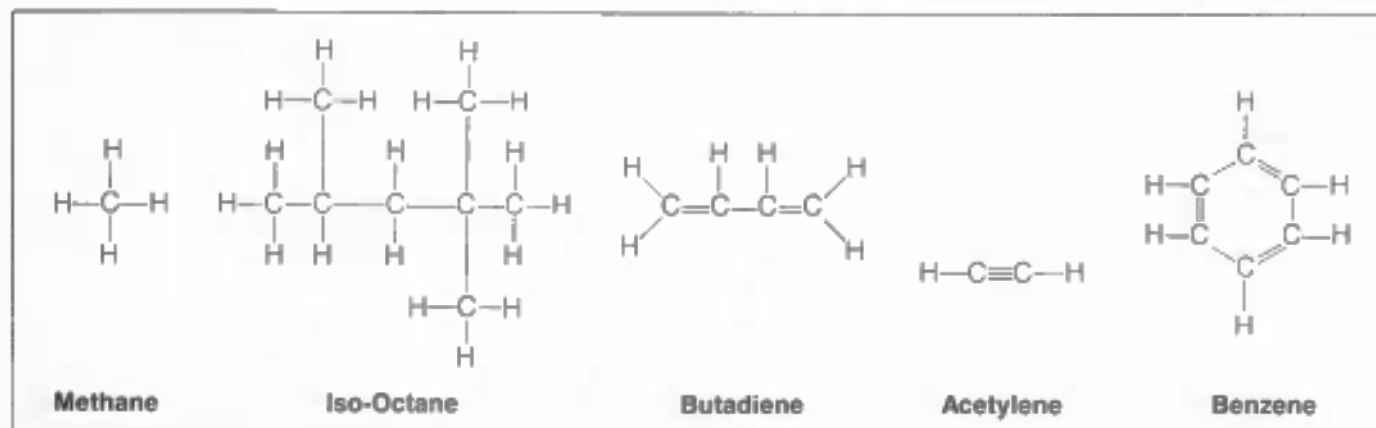
Carbon can form chains of almost unlimited length by bonding to other carbon atoms. The bonds between carbon atoms in these straight chains can be single, double, or triple

Figure 4-8 A carbon atom contains 6 protons, 6 neutrons, and 6 electrons. What is the arrangement of these 6 electrons?



covalent bonds—or combinations of these bonds. No other element can equal carbon in this respect. These chains can be closed on themselves to form rings. The ring structures may include single or double bonds, or a mixture of both. This gives even more variety to the kinds of molecules that carbon can form. See Figure 4-9.

Figure 4-9 Because of its remarkable ability to form a variety of covalent bonds, carbon is an unparalleled element. Here you see some of the different types and arrangements of carbon bonds.

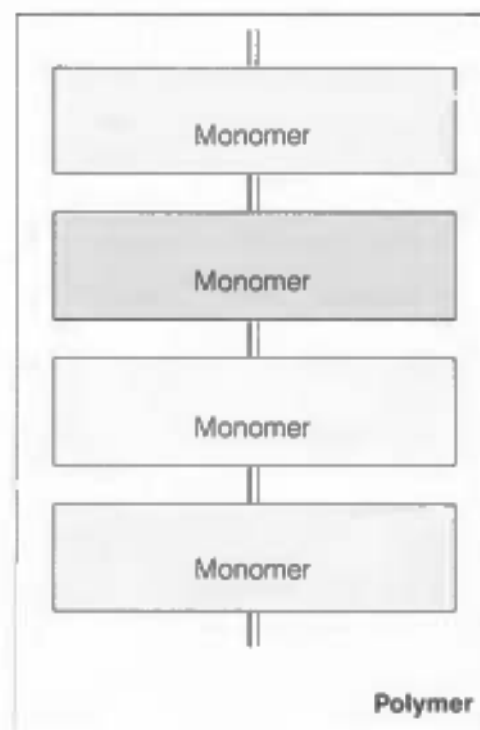


Polymerization

Many carbon-based compounds are formed by a chemical process known as **polymerization**, in which large compounds are constructed by joining together smaller compounds. The smaller compounds, or **monomers**, are joined together by chemical bonds to form **polymers**. Many polymers are so large that they are called **macromolecules**. As used here, the prefix *macro-* means giant.

Polymerization provides a way to form complex molecules by joining monomers together. The chemical diversity that polymerization allows living things is similar to the diversity that our alphabet allows us. Although there are only 26 letters in the alphabet, our ability to join them together (polymerize them) to form words gives us an almost infinite variety of possible words (molecules).

Figure 4-10 A polymer is made up of a series of monomers.



4-2 SECTION REVIEW

1. What is an inorganic compound? An organic compound?
2. Is the chemical composition of the human body similar to the composition of the Earth's crust? Explain your answer.
3. What special properties of carbon make it such an important compound in living things?
4. Describe the process of polymerization.

Section Objectives

- Identify the four groups of organic compounds found in living things.
- Describe the structure and function of each group of compounds of life.
- Explain how enzymes work and why they are important to living things.

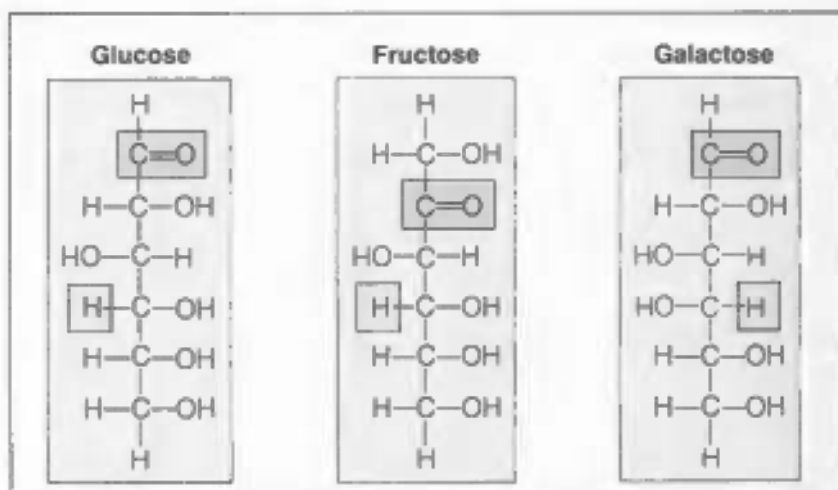
4-3 Compounds of Life

The number of possible organic compounds is almost limitless. Fortunately, however, it is possible to classify many important organic compounds found in living things into four groups. **The four groups of organic compounds found in living things are carbohydrates, lipids, proteins, and nucleic acids.** By knowing the characteristics of just these groups, you will know a great deal about the chemistry of living things.

Carbohydrates

Although you may not realize it, you are probably quite familiar with the group of organic compounds known as **carbohydrates**. Carbohydrates, you see, are the molecules that we often call sugars. Carbohydrates contain carbon, hydrogen, and oxygen atoms in an approximate ratio of 1:2:1 (C:H:O). The simplest carbohydrates are called **monosaccharides**, meaning single sugars. Examples of monosaccharides include glucose, galactose, and fructose. Glucose is the sugar green plants produce during the food-making process. Galactose is found in milk. And fructose, the sweetest of these simple sugars, is found in fruits. The formula for all three of these simple sugars is $C_6H_{12}O_6$. What makes them different from one another is the arrangement of the individual atoms. See Figure 4-11.

Figure 4-11 Glucose, fructose, and galactose are single sugars, or monosaccharides. Sugars form a group of organic compounds known as carbohydrates. The formula for all three of these single sugars is $C_6H_{12}O_6$. What makes them different from one another?



Sugars are important to living things because they contain a great deal of energy. This energy is stored in the chemical bonds that make up the carbohydrate molecules. When the chemical bonds are broken, the energy is released. Nearly all organisms use glucose as one of their basic energy sources. In Chapter 6, you will learn how the energy from sugar molecules is used by living things.

DEHYDRATION SYNTHESIS Complex carbohydrates are made by a process of polymerization in which two or more

DEHYDRATION SYNTHESIS

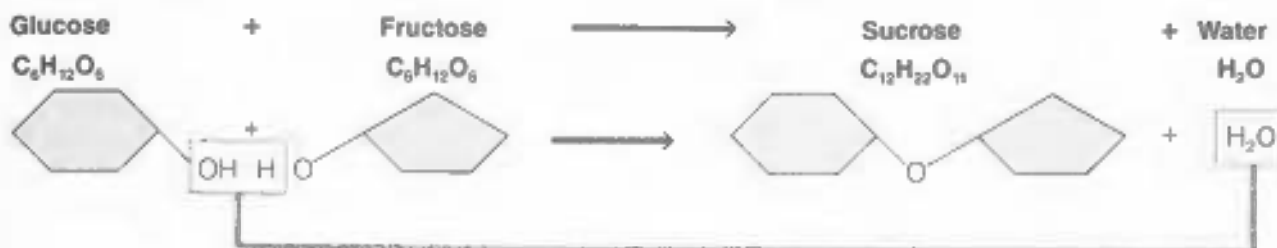


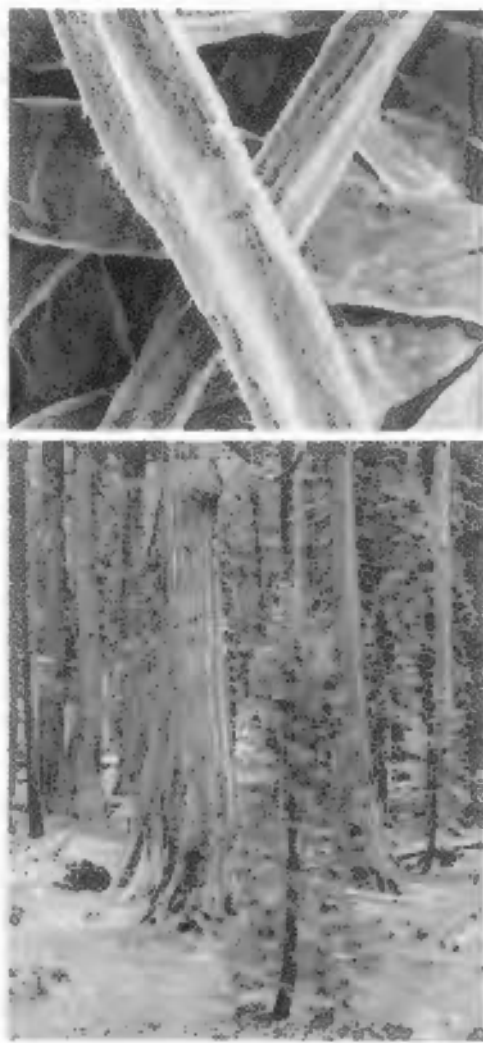
Figure 4-12 The dehydration synthesis of a molecule of glucose and a molecule of fructose produces a molecule of sucrose and a molecule of water. What type of sugar is sucrose?

monosaccharides are combined to form larger molecules. The chemical bond that links two simple sugars is formed between the $-OH$ groups present in each molecule. As you can see from Figure 4-12, one OH from one molecule combines with the H of the OH from the other molecule. When the bond is complete, a molecule of water is removed from the two monosaccharides. Because of the loss of water, the joining of two sugars is known as **dehydration synthesis**. Dehydration means loss of water, and synthesis means putting together.

The compound formed from the joining of two single sugars in dehydration synthesis is called a **disaccharide**, or double sugar. Ordinary table sugar, or sucrose ($C_{12}H_{22}O_{11}$), is a disaccharide. Other disaccharides include maltose (malt sugar) and lactose (milk sugar).

POLYSACCHARIDES Very large molecules can be formed by joining together many monosaccharide units. Such compounds are known as **polysaccharides**. Polysaccharides are the form in which living things store excess sugar. One important polysaccharide is starch. Plants store excess sugar in the form of starch, which is present in potatoes and bread. Starch is a very large molecule formed by joining together hundreds of glucose molecules. Animals store their excess sugar in the form of glycogen in the liver and muscles. Glycogen is an even larger molecule consisting of hundreds or even thousands of glucose molecules. Glycogen is sometimes called animal starch. Do you see why? Because they are polymers of single sugars, both starch and glycogen help store energy in living things. Another polysaccharide is cellulose, which is found only in plants. Cellulose helps to support a plant by giving it strength and rigidity. Cellulose is the major component of wood. As such, it is often used as a building material or a printing material. The page upon which these words are printed is made principally of cellulose.

Figure 4-13 Cellulose fibers (top) are extremely strong and thus able to support the enormous mass of these giant sequoia trees (bottom).



HYDROLYSIS

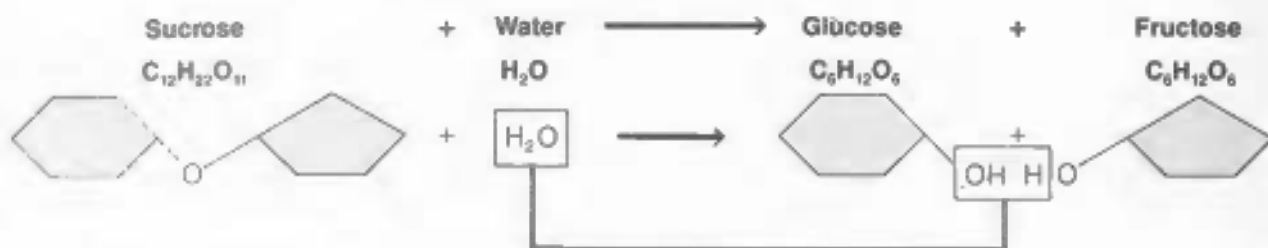


Figure 4-14 The hydrolysis of a molecule of sucrose produces a molecule of glucose and a molecule of fructose.

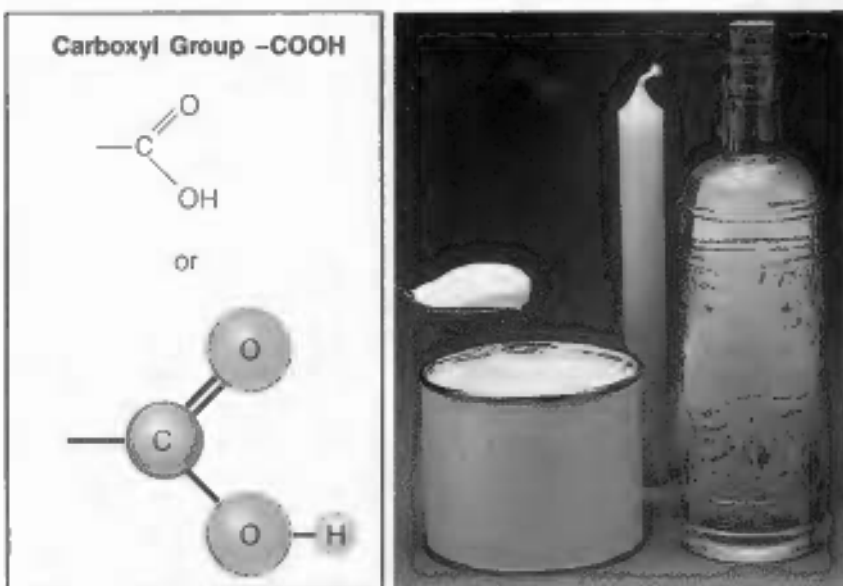
HYDROLYSIS When polysaccharides are split apart to again form monosaccharides, the dehydration synthesis reaction is reversed. This reverse reaction is known as **hydrolysis**. Hydrolysis, which means water splitting, is an appropriate name because a molecule of water is consumed by the chemical reaction that splits the bond between adjacent monosaccharides. Figure 4-14 illustrates the hydrolysis reaction.

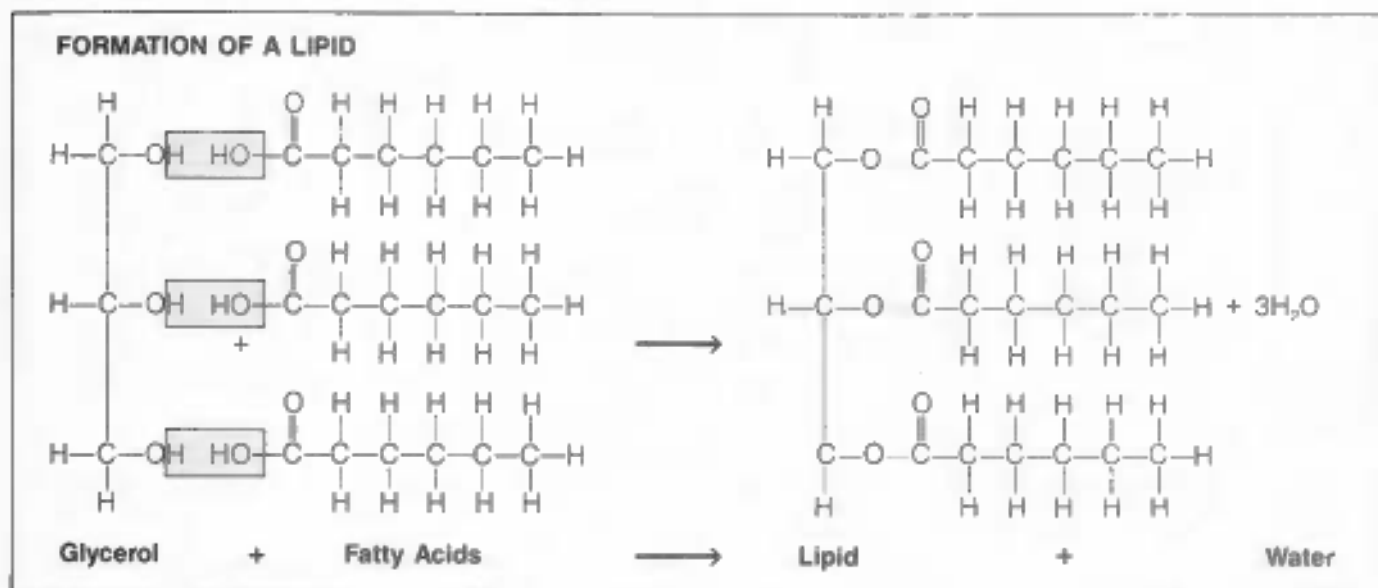
Lipids

Lipids are organic compounds that are waxy or oily. Lipids have three major roles in living organisms. Like carbohydrates, lipids can be used to store energy. Lipids are used to form biological membranes. And certain lipids are used as chemical messengers. The common names by which we know lipids are fats, oils, and waxes. Generally, fats and waxes are solid at room temperature, whereas oils are liquid.

Many important lipids are formed from combinations of fatty acids and glycerol. Fatty acids are long chains of hydrogen and carbon atoms that have a carboxyl group attached at one

Figure 4-15 Lipids are organic compounds that are most familiar as fats, oils, and waxes (right). Many lipids are formed from fatty acids and glycerol. All fatty acids contain long chains of carbon and hydrogen atoms to which a carboxyl group is attached. A carboxyl group consists of 1 carbon atom, 1 hydrogen atom, and 2 oxygen atoms (left).





end. A carboxyl group is a chemical group consisting of one carbon atom, one hydrogen atom, and two oxygen atoms ($-\text{COOH}$). See Figure 4-15. Glycerol, which is an organic alcohol, contains three carbon atoms, each of which is attached to a hydroxyl ($-\text{OH}$) group. Many lipids are formed by the attachment of two or three fatty acids to glycerol. Figure 4-16 shows how fatty acids combine with glycerol to form a lipid. Can you recognize the chemical reaction that is responsible for the formation of the lipid?

SATURATED AND UNSATURATED LIPIDS If every carbon atom in a fatty acid chain is joined to another carbon atom by a single bond, the fatty acid is said to be saturated because it contains the maximum number of hydrogen atoms. If a pair of carbon atoms is joined by a double bond, the fatty acid is said to be unsaturated. Because of the double bond, it does not contain the maximum number of hydrogen atoms. If a fatty acid contains several double bonds, it is said to be polyunsaturated. Figure 4-18 on page 74 shows an example of each of these types of fatty acids.

Lipids made from saturated fatty acids are called saturated fats. Such fats are commonly found in meats and most dairy products. Lipids made from polyunsaturated fatty acids are called polyunsaturated fats. If that term seems familiar, it should. Polyunsaturated fats tend to be liquid at room temperature and are used in many cooking oils, such as sesame, peanut, and corn oil. Including polyunsaturated fats in the diet may help to prevent heart disease, a connection we will explore more completely in Chapter 41.

Both plants and animals use lipids as a means of storing energy. Because lipids contain far fewer oxygen atoms than carbohydrates do, they have less mass per unit of chemical energy than carbohydrates. In other words, when lipids are

Figure 4-16 The formation of a lipid involves the combination of three fatty-acid molecules with one glycerol molecule. What type of chemical reaction is taking place here?

Figure 4-17 Animals use lipids as a means of storing energy. When black bears retreat to their dens in late autumn, they lie down and often cease to move, eat, drink, and eliminate wastes for about 5 months. Burning up nearly 4000 calories per day, a bear's metabolism operates at 50 to 80 percent its normal rate. The energy the bear needs comes primarily from its stored lipids.



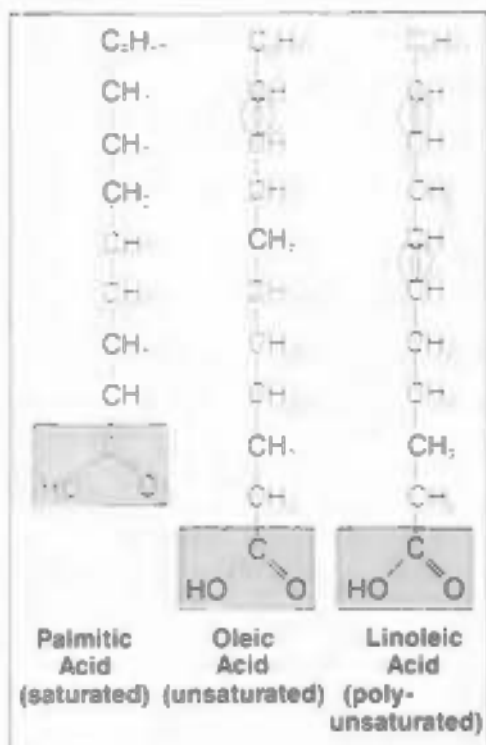
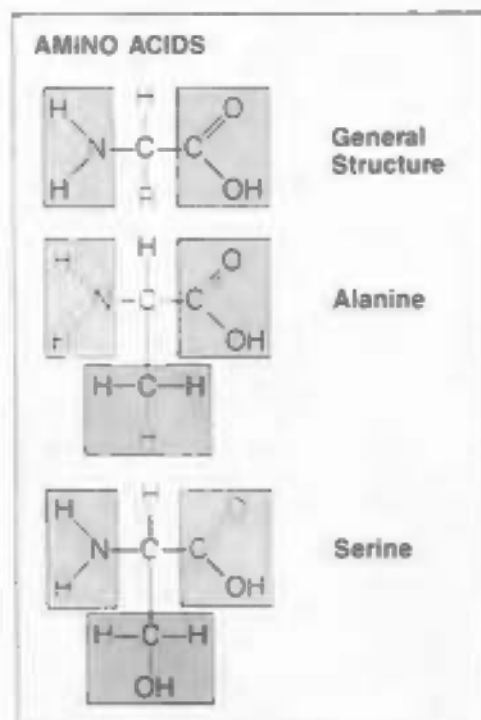


Figure 4-18 Palmitic acid is a saturated fatty acid. Why do we say that oleic acid is unsaturated? Why is linoleic acid polyunsaturated?

Figure 4-19 All amino acids have an amino group ($-\text{NH}_2$) on one end and a carboxyl group ($-\text{COOH}$) on the other. They differ in a region of the molecule known as an R group.



broken down, they produce more energy gram for gram than carbohydrates do.

STEROLS AND PHOSPHOLIPIDS Two other kinds of lipids are particularly important in living organisms. They are sterols and phospholipids. One of the most common sterols is a molecule called **cholesterol**. Cholesterol is an important part of many cells, but excessive cholesterol in the diet is a risk factor in heart disease. Sterol lipids play a number of important roles in building cells and carrying messages from one part of the body to another. We will learn more about sterols later in this textbook.

Phospholipids are molecules consisting of parts that dissolve well in water and parts that do not dissolve well in water. The portions of a phospholipid molecule that do not dissolve in water are oily. What happens to a molecule made of two very different parts? When phospholipid molecules are mixed with water, they may form small balloonlike structures known as liposomes. Each liposome is formed from a double layer, or bilayer, of lipid molecules. A liposome forms spontaneously, or without any outside help. It forms merely by the attraction of the oily parts of the lipid molecules for each other and by the attraction of the other parts of the lipid molecules for the surrounding water. The ability to form bilayers spontaneously is an important property of lipids that enables them to play a key role in forming cell membranes.

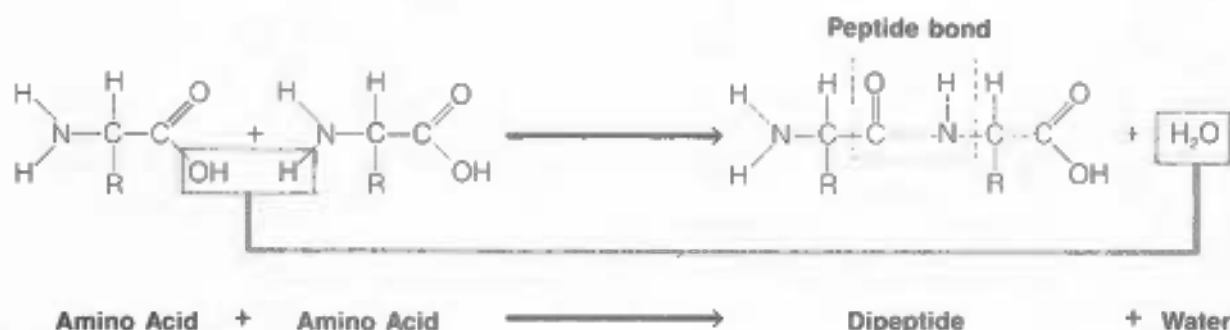
Proteins

Proteins are organic compounds that contain nitrogen in addition to carbon, hydrogen, and oxygen. Proteins are polymers of **amino acids**. An amino acid has an amino group ($-\text{NH}_2$) on one end and a carboxyl group ($-\text{COOH}$) on the other. These groups can form covalent bonds with each other. As a result of these bonds, very long chains of amino acids can be put together. All amino acids have a similar chemical structure, but they differ in a region of the molecule known as an R group. See Figure 4-19. There are more than 20 different amino acids, each of which contains a different R group.

PEPTIDES The covalent bond that joins two amino acids is known as a **peptide bond**. A molecule of water is lost when a peptide bond is formed between two amino acids. This reaction is another example of dehydration synthesis. A dipeptide is two amino acids joined by a peptide bond. A tripeptide contains three amino acids. And, as you might expect, a polypeptide is a long chain of amino acids.

PROTEIN STRUCTURE A complete protein contains one or more polypeptide chains and may contain a few other chemical groups that are important to its proper function. Proteins

FORMATION OF A DIPEPTIDE



have numerous roles: They help to carry out chemical reactions; they pump small molecules in and out of cells; and they are even responsible for the ability of cells to move. The functions of proteins are at the very center of life itself.

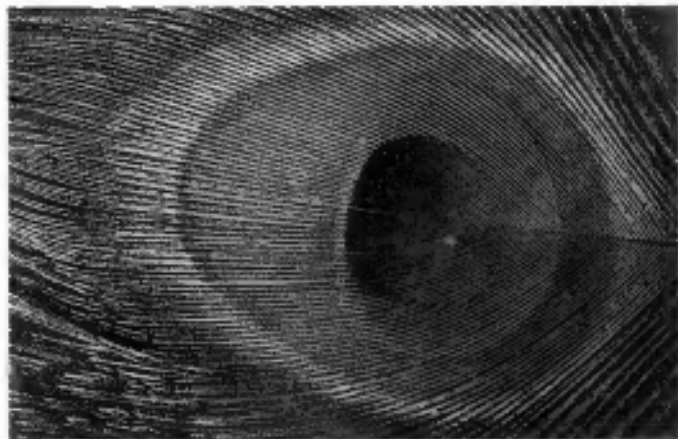
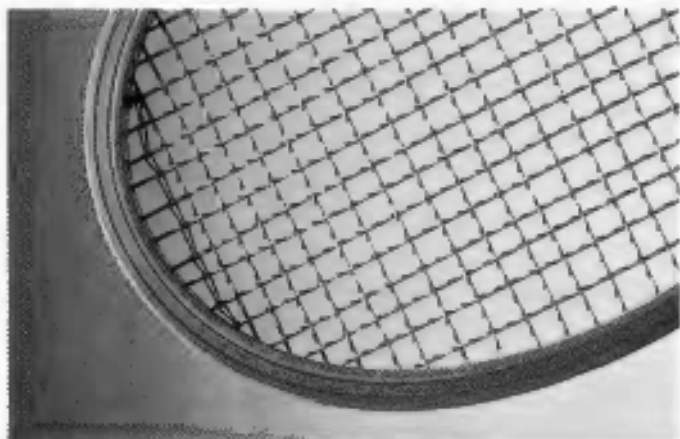
Figure 4-20 Peptide bonds—which result in the formation of dipeptides, tripeptides, and polypeptides—form during the dehydration synthesis of amino acids.

Enzymes

Chemical reactions make life possible. Hundreds of chemical reactions are involved in a process as simple as digesting a chocolate bar. If these chemical reactions proceeded too slowly, not only would the chocolate bar remain in the stomach for a long time, but the ordinary activities of life would come to a halt as well. Since this is not the case, some substances in the body must be responsible for speeding up the process.

A substance that speeds up the rate of a chemical reaction is called a **catalyst**. Catalysts are not changed by the reactions

Figure 4-21 Proteins are found in a variety of substances. These photographs show some of the more common proteins: collagen used in tennis racket strings (top, left), keratin in a peacock feather (top, right), silk from a spider's web (bottom, left), and human hair (bottom, right).



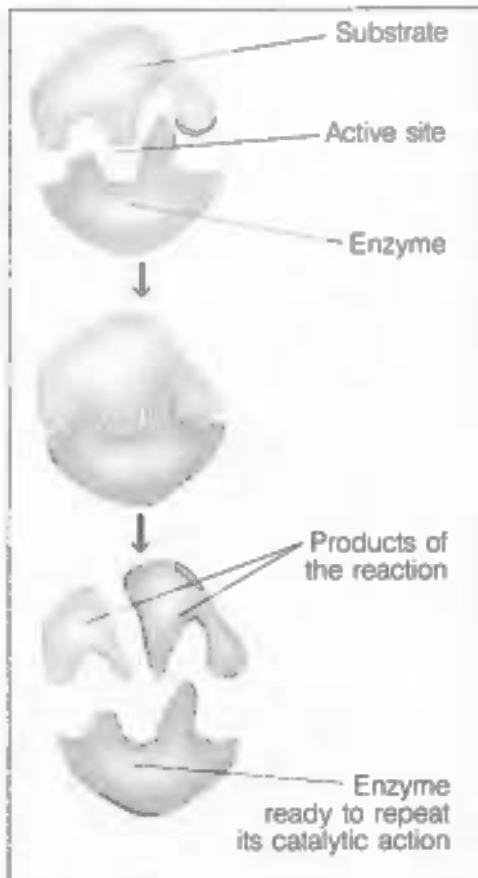
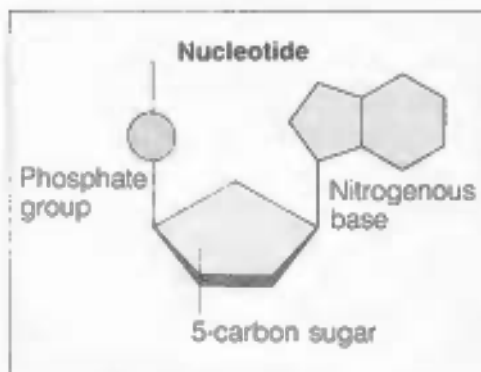


Figure 4-22 In the lock-and-key hypothesis of enzyme action, an enzyme and its substrate bind at a region known as the active site in a manner similar to the way in which two pieces of a jigsaw puzzle fit together. What is the role of an enzyme?

Figure 4-23 Nucleic acids are polymers of nucleotides, which are molecules built up from three basic parts: a special 5-carbon sugar, a phosphate group, and a nitrogenous base.



they promote, and therefore they are not used up during the reaction. Catalysts work by lowering the “start-up” energy of a reaction. Chemists often seek catalysts that will speed up reactions important to industry. Living organisms have gone the industrial chemist one better—they contain their own special catalysts, which are known as **enzymes**.

With a few exceptions, enzymes are proteins. Understanding their function is an important part of the study of proteins. Simple cells may have as many as 2000 different enzymes, each one catalyzing a different reaction. An enzyme may accelerate a reaction by a factor of 10^{10} —that is, making it happen 10,000,000,000 times faster! Thus a reaction that might take as long as 1500 years without an enzyme can be completed in just 5 seconds!

Enzymes speed up a reaction by binding to the reactants, which, as you may recall, are the substances that enter into a chemical reaction. The reactants that are affected by an enzyme are known as **substrates**. Substrates bind to enzymes at a region known as the **active site**.

The way in which a chemical reaction is catalyzed varies from one enzyme to another. An enzyme can catalyze a reaction by holding two substrates in positions in which they can react with each other. Or an enzyme can catalyze a reaction by twisting a substrate molecule slightly so that a chemical bond is weakened and broken.

Enzymes are very specific. A particular enzyme can catalyze only one particular chemical reaction involving specific substrates. Scientists theorize that this has something to do with the shape of the enzyme’s active site. In fact, the fit between an enzyme’s active site and its substrate is often compared to that of a lock and key.

Enzymes are important in regulating chemical pathways, synthesizing materials needed by cells, releasing energy, and transferring information. You will discover that enzymes are involved in digestion, respiration, reproduction, vision, movement, thought, and even in the making of other enzymes.

Nucleic Acids

Nucleic acids are large complex organic molecules composed of carbon, oxygen, hydrogen, nitrogen, and phosphorus atoms. Nucleic acids are polymers of individual monomers known as **nucleotides**. Nucleotides are molecules built up from three basic parts: a special 5-carbon sugar, a phosphate group, and a molecule generally known as a nitrogenous base. See Figure 4-23. Individual nucleotides can be linked together by covalent bonds to form a polynucleotide. There are two basic kinds of nucleic acids: **ribonucleic acid (RNA)**, which contains the sugar ribose, and **deoxyribonucleic acid (DNA)**, which contains the sugar deoxyribose. Despite their name, nucleic acids are not strongly acidic.

Nucleic acids store and transmit the genetic information that is responsible for life itself. How they do this, and how that information is decoded and transferred, is a fascinating story that we will leave for Chapter 7.

4-3 SECTION REVIEW

1. What are the four groups of organic compounds found in living things? Give an example of each.
2. Distinguish between monosaccharides, disaccharides, and polysaccharides.
3. What are lipids? How are they important to living things?
4. Describe the structure of a protein.
5. What is an enzyme? What is its function in living things?
6. Describe the structure and function of nucleic acids. What are two important nucleic acids?

SCIENCE, TECHNOLOGY, AND SOCIETY

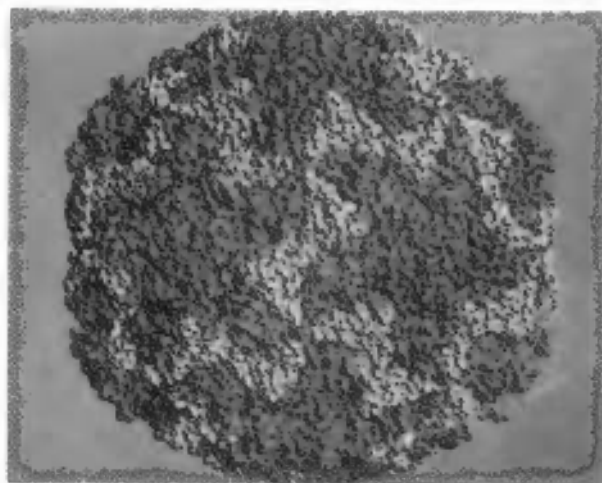
BREAKTHROUGH

The Structure of Proteins

Although proteins are among the largest of all macromolecules, it is sometimes possible to determine their detailed structure, including the position of every atom. This is done with the aid of a technique called X-ray crystallography.

The first, and often the trickiest, step in the procedure is to grow small crystals of a protein—often no larger than a grain of salt (0.1 mm). These protein crystals are then placed in a finely tuned beam of X-rays. As the X-rays pass through the crystal, they are scattered in a pattern that is recorded on film and then analyzed by computers. These X-ray scattering patterns contain enough information to allow scientists to build a complete model of the protein. The accompanying photograph, showing the arrangement of proteins on the surface of a common cold virus, was obtained

by this technique. X-ray crystallography is a powerful scientific tool that enables us to visualize protein structure and understand the biological activities of complex molecules.



PROBLEM

How does pH influence the activity of the enzyme catalase?

MATERIALS (per group)

5 125-mL flasks	0.1 M hydrochloric acid
graduated cylinder	3% hydrogen peroxide
petri dish	liver puree (catalase)
3 medicine droppers	small piece of raw beef liver
stirring rod	glass-marking pencil
hydrion (pH) papers	safety goggles
0.1 M sodium hydroxide	

PROCEDURE

1. Prepare an appropriate data table on a separate sheet of paper.
2. Put on safety goggles. Put a small piece of raw liver in an open petri dish. Using a medicine dropper, put a drop of hydrogen peroxide on the liver. **CAUTION:** *Hydrogen peroxide can be irritating to skin and eyes. If you spill any on yourself or your clothes, wash it off immediately.* Observe what happens. Liver contains the enzyme catalase, which breaks down hydrogen peroxide formed in cells. When hydrogen peroxide is broken down by catalase, bubbles of oxygen gas are released.
3. Using the glass-marking pencil, number the flasks from 1 through 5. With a clean medicine dropper, put 10 drops of water in flask 1. Using a graduated cylinder, measure out 5 mL of hydrochloric acid and add it to the water in the flask. **CAUTION:** *When diluting an acid, always pour the acid into the water.* Rinse the dropper and the cylinder.
4. Prepare the following solutions for the remaining flasks. Use procedures similar to those used in step 3. Flask 2: 10 drops of hydrochloric acid added to 5 mL of water. Flask 3: 5.5 mL of water only. Flask 4: 10 drops of sodium hydroxide added to 5 mL of water. Flask 5: 5 mL of sodium hydroxide added to 10 drops of water.

5. Using the stirring rod, put a drop of the solution from flask 1 on a piece of hydrion paper to measure the solution's pH. Record the results in the data table. Repeat the procedure for the solutions in flasks 2, 3, 4, and 5.
6. Using the clean graduated cylinder, add 5 mL of hydrogen peroxide to each flask. Look for bubbles. Identify the amount of activity in each flask by assigning it a number from 0 to 3, when 0 means no bubbles, 1 means few bubbles, and 3 means many bubbles.
7. Rinse out the five flasks thoroughly. Repeat steps 3 through 5.
8. Using a clean medicine dropper, add 5 drops of liver puree to each solution and mix well by swirling the flask.
9. Using the clean graduated cylinder, add 5 mL of hydrogen peroxide to each flask. Identify the amount of activity in each flask from 0 to 3, as you did in step 6.

OBSERVATIONS

1. What happened when hydrogen peroxide was added to each flask without liver puree?
2. What happened when hydrogen peroxide was added to each flask with liver puree?
3. In which flask(s) was the bubble activity greatest? What was the pH of the solution(s)?

ANALYSIS AND CONCLUSIONS

1. What is the purpose of the flasks without liver puree?
2. At what pH does catalase function best? How do you know?
3. If a strong acid has a pH of 1, a strong base, 14, and water, 7, does catalase work best in an acid, base, or neutral environment? Explain.
4. What conclusions can you draw about the pH in body cells?
5. Predict ways in which pH affects the chemical reactions in living cells.

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

4-1 Water

- Water is the most abundant compound in the majority of living organisms.
- A mixture is a substance composed of two or more compounds mixed together but not chemically combined.
- A solution consists of a solvent and solute.
- Compounds that release hydrogen ions (H^+) in solution are acids. Those that release hydroxide ions (OH^-) are bases.

4-2 Chemical Compounds in Living Things

- The four most abundant elements in living things are carbon, hydrogen, oxygen, and nitrogen.
- Inorganic compounds are primarily those that do not contain carbon. Organic compounds contain carbon.

- Polymerization is the process in which polymers are made by joining monomers.

4-3 Compounds of Life

- The four groups of organic compounds found in living things are carbohydrates, lipids, proteins, and nucleic acids.
- The polymerization of two monosaccharides to form a disaccharide occurs as a result of dehydration synthesis. Hydrolysis is the reverse reaction.
- Lipids are important sources of energy and compounds of biological membranes.
- Proteins are polymers of amino acids.
- Enzymes are, with a few exceptions, proteins. Enzymes are catalysts.
- Nucleic acids are polymers of nucleotides.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

4-1 Water

mixture
solution
solvent
solute
acid
base
neutralization
reaction
pH scale
suspension

4-2 Chemical Compounds in Living Things

organic compound
inorganic compound
polymerization
monomer
polymer
macromolecule

4-3 Compounds of Life

carbohydrate
monosaccharide
dehydration
synthesis
disaccharide
polysaccharide
hydrolysis
lipid
cholesterol
protein

amino acid
peptide bond
catalyst
enzyme
substrate
active site
nucleic acid
nucleotide
ribonucleic acid (RNA)
deoxyribonucleic acid (DNA)

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- The most abundant compound in most living things is
 - carbon dioxide.
 - water.
 - sodium chloride.
 - hydrochloric acid.
- A strong acid has a pH of
 - 14.
 - 7.
 - 5.
 - 2.
- Which group of elements combine to form practically all the chemical compounds in living things?
 - carbon, hydrogen, oxygen, nitrogen
 - carbon, hydrogen, phosphorus, nitrogen
 - carbon, sodium, chlorine, oxygen
 - sulfur, phosphorus, carbon, oxygen
- Proteins are polymers of
 - fatty acids.
 - amino acids.
 - sterols.
 - nucleic acids.
- The region on an enzyme to which a substrate binds is called the
 - catalyst.
 - activated complex.
 - active site.
 - carboxyl group.
- The function of nucleic acids is related to
 - energy release.
 - enzyme formation.
 - transmission of genetic information.
 - catalyzing chemical reactions.
- When phospholipid molecules are mixed with water, they form small balloonlike structures called
 - liposomes.
 - vacuoles.
 - lysosomes.
 - dipeptides.
- The polysaccharide found only in plants is
 - glucose.
 - glycogen.
 - cholesterol.
 - cellulose.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- A mixture of oil and vinegar is an example of a solution.
- Compounds that release hydrogen ions into solution are known as bases.
- Compounds that contain carbon are called organic compounds.
- The simplest carbohydrates are called disaccharides.
- A common sterol whose excessive intake is related to heart disease is cholesterol.
- Individual monomers of nucleic acids are known as nucleotides.
- Including saturated fats in the diet may help to prevent heart disease.
- Polysaccharides are split apart to form monosaccharides in a reaction called hydrolysis.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

- solution, suspension, solute, solvent
- monosaccharide, starch, glycogen, cellulose
- fats, oils, waxes, proteins
- substrate, enzyme, active site, nucleic acid

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Explain how the polarity of water molecules makes water the best solvent.
2. Compare solutions and suspensions.
3. Describe the properties of carbon that make carbon compounds so numerous.
4. Explain why the formation of a lipid molecule is a dehydration synthesis reaction. Use a diagram to help explain your answer.
5. Distinguish between a saturated, unsaturated, and polyunsaturated fatty acid.
6. Explain the importance of enzymes to living things. Be sure to include the following terms in your answer: catalyst, substrate, active site, "start-up energy," lock and key.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** One of the digestive juices in the human stomach is hydrochloric acid (HCl). Sometimes an excess of the acid causes stomach discomfort. In such a case, a person might take an antacid such as magnesium hydroxide ($\text{Mg}(\text{OH})_2$). Explain why this substance works to relieve the discomfort. What reaction is taking place?
2. **Identifying patterns** Explain why the name carbohydrate is an indication of the chemical composition of any sugar.
3. **Relating facts** Give two reasons why dehydration synthesis and hydrolysis are opposite chemical reactions.
4. **Applying concepts** Relate the structure of a phospholipid to the property that makes it so important in forming cell membranes.
5. **Developing a model** Materials generally dissolve more quickly in a solvent if its temperature is increased. Why do you think this is so?
6. **Identifying relationships** Describe the role that polymerization plays in the formation of carbohydrates, proteins, and nucleic acids.
7. **Applying concepts** The chemical process by which a saturated fat is converted to an unsaturated fat is called dehydrogenation. Explain why this is an appropriate name.
8. **Relating concepts** Despite their name, many amino acids actually raise the pH of a solution in which they are dissolved. How could this be true?
9. **Using the writing process** At the yearly convention of chemical compounds, a great debate is raging. The organic compounds, represented by the carbohydrates, claim they are the most important compounds in living things. The inorganic compounds, championed by water molecules, claim that life could not exist without them. Write a 5-minute speech in which you take the side of the organic or the inorganic compounds. Or, as an alternative, you may file a minority report in which you argue both sides are incorrect.
10. **Using the writing process** Write a short story entitled, "The Day Ice Stopped Floating."

Textbook Illustrator

Textbook illustrators create the artwork that accompanies the information in a textbook. Their illustrations serve to express ideas and clarify explanations contained in the text.

To become a textbook illustrator, a person needs only general art classes and artistic ability, but many artists obtain preparation beyond high school at specialized art schools. Furthermore, some illustrators choose areas such as medical or scientific art that require training in biology or the physical sciences.

To receive additional information write to the Association of Medical Illustrators, 2692 Huguenot Springs Rd., Midlothian, VA 23113.

Biology Teacher

Biology teachers help students explore the complex world of living things. By presenting topics through lectures, demonstrations, laboratory work, and field trips, they help students learn the importance of the scientific method and the value of research. Biology teachers also monitor the progress of individual students by evaluating assignments and exams.

To become a biology teacher, a Bachelor's degree with courses in biology and education is required. In addition, experience as a student teacher is necessary to obtain a state teaching license.

For more information write to the National Association of Biology Teachers, 11250 Roger Bacon Dr., Reston, VA 22090.

Biochemist

Biochemists study chemical processes within living things. They use highly complex equipment to better understand life processes such as growth, reproduction, and metabolism. Some biochemists study the effects of different chemicals on the human body, whereas others develop methods to help doctors diagnose and treat disease.

Biochemists must have a Bachelor's degree in chemistry or biochemistry and an advanced degree in a particular area of biochemistry.

For information about this career write to the American Society of Biological Chemists, 9650 Rockville Pike, Bethesda, MD 20014.

HOW TO
FIND OUT
ABOUT CAREERS

School and community libraries are a good source of information about different types of jobs and careers. There you will find a number of sources that not only define specific job titles but also describe the nature of the work, educational and training requirements, the employment outlook for that field, working conditions, and other necessary information. Two such publications are the Occupational Outlook Handbook, published by the United States government, and The Encyclopedia of Careers and Vocational Guidance.

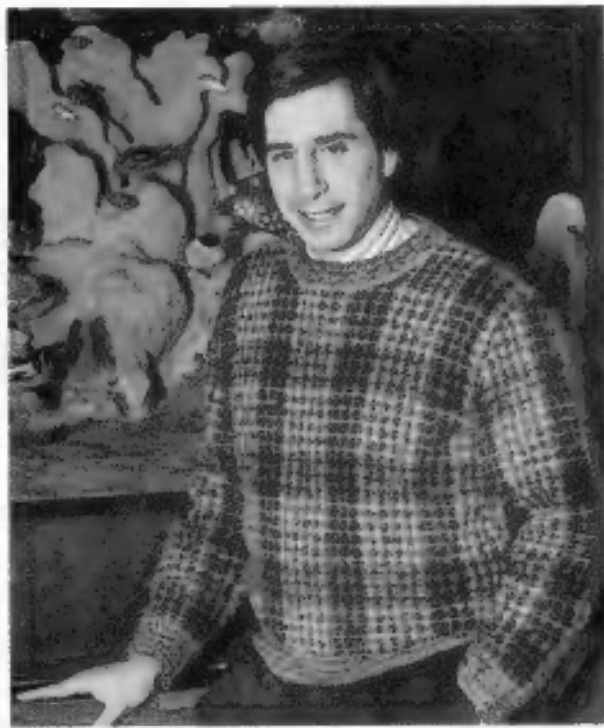
In addition, many corporations provide career information to interested students. Your school counseling office may have information about some of these companies.

Both of us agree that the first two chapters in this unit were among the hardest to write. Why? Because they have a big job to do. They must teach you not about a specific series of facts, but about an entire way of looking at the world. For biology is much more alive, much more challenging, and much more important than a list of facts could ever be.

Both of us are young as scientists go, but we have seen many changes in biology from the time we studied it in high school. As far as we're concerned, that's just as well. Anything that stays the same long enough can become boring. But biology is always changing fast enough that we never get a chance to get bored—or even to catch our breath. Every year or two, we have to throw out our lecture notes and many of our old ideas. New discoveries regularly force us to completely change the way we think about part of our field. It's a lot of work but also a lot of fun. Because by studying biology, we learn not only about the living world around us, but about the workings of one of the most fascinating parts of that world—the human mind.



Kenneth R. Miller



Joe Levine

Cells: The Basic Unit of Life

Don't be fooled by the inactivity of these polar bears. Even at rest, their bodies are alive with action. Millions of tiny internal factories are busily taking in raw materials, distributing them to specialized departments, shipping the products where they are needed, and disposing of wastes. What are these wondrous little factories? They are the fundamental units of all living organisms—cells.

Every cell is a highly organized structure that is responsible for the form and function of an organism. Some organisms consist of only one cell. Others consist of trillions of cells organized into complex organ systems. But regardless of size or shape, all organisms begin as just a single cell.

Only by understanding the complexity of life at the cellular level can we begin to understand the marvels of living things: why organisms behave as they do, how they develop and reproduce, and how they are affected by environmental factors.



CHAPTERS

5

Cell Structure and Function

6

*Cell Energy:
Photosynthesis and Respiration*

7

*Nucleic Acids and
Protein Synthesis*

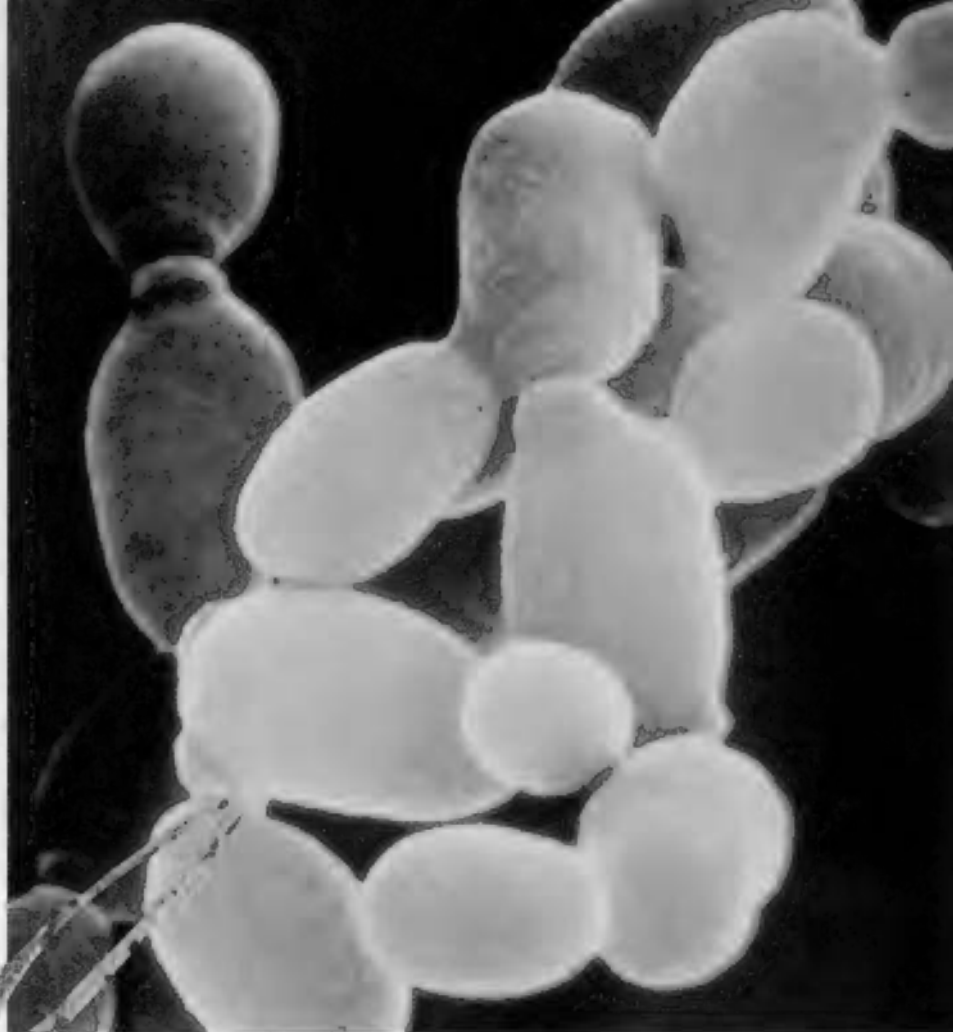
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Cell Growth and Division



CHAPTER 5

Cell Structure and Function



The microscope enabled scientists to discover that all living things are made up of cells. The spherical objects in the large photograph are single-celled yeasts; the branched object in the small photograph is a human nerve cell.

More than 100,000,000,000,000 cells are found in an adult human! We have about 155,000 cells in every square centimeter of our skin, about 30 billion cells in our brain, and about 20 trillion red blood cells in our blood. Many microscopic organisms, including bacteria, consist of just a single cell. Despite our complexity, we begin our lives as single cells.

Cells are the "atoms" of biology, the fundamental units of living organisms. Just as the atom is the smallest unit of an element, the cell is the smallest unit of an organism that can reasonably be thought of as alive. Questions concerning life—from ecology to behavior, from evolution to reproduction—must be partly answered at the level of the cell. The cell is the key to biology because it is at this level that a collection of water, salts, macromolecules, and membranes truly springs to life. In this chapter we shall begin our study of cells by looking into the various parts of the cell.

CHAPTER OUTLINE

5-1 The Cell Theory

5-2 Cell Structure

- Cell Membrane
- Cell Wall
- Nucleus
- Cytoplasm

5-3 Cytoplasmic Organelles

- Mitochondria and Chloroplasts: Power Stations
- Ribosomes: Protein Factories
- Endoplasmic Reticulum and Golgi Apparatus: Manufacturers and Shippers
- Lysosomes: Cleanup Crews
- Vacuoles and Plastids: Storage Tanks
- Cytoskeleton: Framework

5-4 Movement of Materials Through the Cell Membrane

- Diffusion
- Osmosis
- Facilitated Diffusion
- Active Transport

5-5 Cell Specialization

- Factory in Miniature
- A Light-Sensitive Cell
- The Street Sweepers

5-6 Levels of Organization

- Tissues
- Organs
- Organ Systems

5-1 The Cell Theory

Section Objectives

- List the contributions of van Leeuwenhoek, Hooke, Schleiden, Schwann, and Virchow to the development of the cell theory.
- State the cell theory.

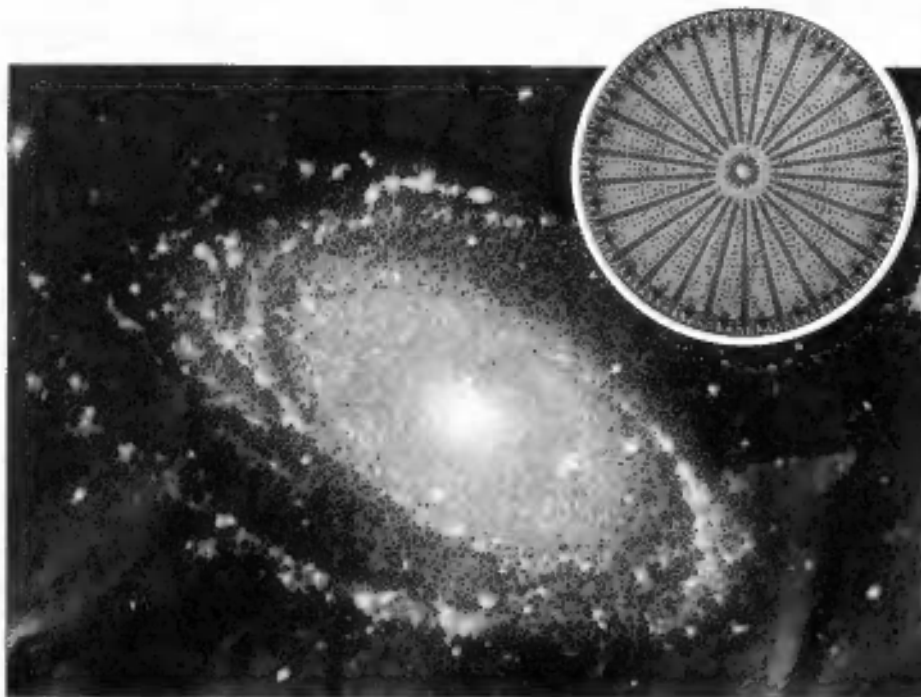
Each of us, at one time or another, has tried to look closely at something. You may have picked up a coin and tried to read the initials of its designer, cut closely into the coin's surface. You may have tried to read the details on the face of a stamp, or stared at a blade of grass until the tiniest detail was clear.

Such curiosity led early investigators to examine living things under lenses and microscopes in the hope of getting a better glimpse of their structure. Little by little, their findings led to the most fundamental of all discoveries about the nature of living things: All living things are made of **cells**. Cells are the basic units of structure and function in living things.

The first lenses were used in Europe hundreds of years ago by merchants who needed to determine the quality of cloth. They used their magnifying lenses to examine the quality of the thread and the precision of the weave in a bolt of cloth. From these simple glass lenses, combinations of lenses were put together. In Holland in the early 1600s, two useful instruments were constructed. One was the telescope, which enabled people to see objects at a distance. The telescope made the distant stars in the sky visible. The other instrument, the microscope, made the very small objects in nature visible.

The person who is given credit for developing the first microscope was Anton van Leeuwenhoek (LAY-vuhn-hook), a

Figure 5-1 The invention of the telescope enabled astronomers to study distant objects such as this spiral galaxy. The microscope, on the other hand, opened up the world of the very small to biologists. Before the invention of the microscope, a microscopic alga, such as this diatom, could not have been observed.



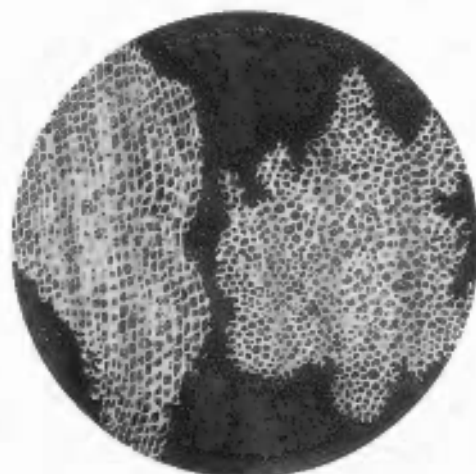
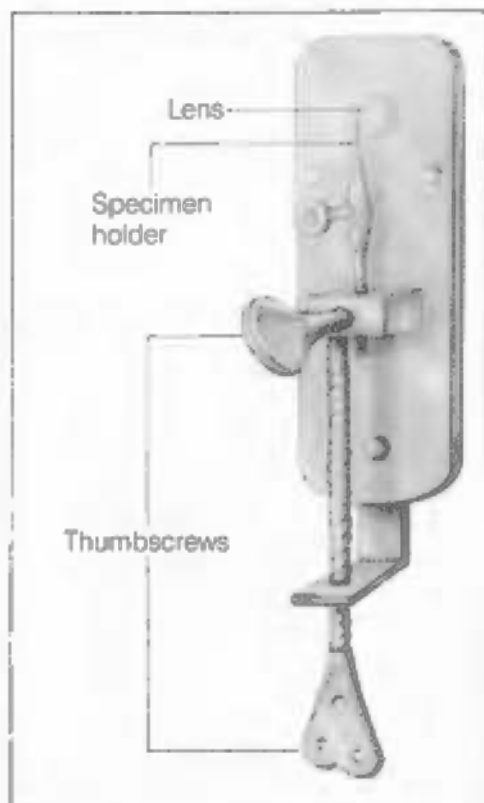


Figure 5-2 Van Leeuwenhoek's simple microscope (top) could magnify objects a few hundred times. Robert Hooke made this drawing of cork cells (bottom) using a microscope that he built. Hooke, however, was not looking at living cells; what he saw were the cell walls that surround living cork cells.

Dutch biologist. His invention enabled him to see things that no one had ever seen before. He could see tiny living organisms whose world consisted of a drop of water. Van Leeuwenhoek carefully observed the tiny living things in pond water and made detailed drawings of each kind of organism.

Van Leeuwenhoek's work interested other people in building microscopes. Before long, pioneers in several countries were experimenting with these new instruments. One such person was the Englishman Robert Hooke, who used one of his microscopes to look at thin slices of plant stems, wood, and pieces of cork. Looking at the cork, Hooke saw that it was composed of thousands of tiny chambers. He called these chambers cells because they reminded him of the small rooms called cells in a monastery.

Unfortunately, Hooke was not looking at living cells. He was looking at the nonliving outer walls of what had once been living plant cells. Nonetheless, Hooke's discovery was significant because it opened up the study of cells.

Gradually over the next 200 years, other scientists began to discover that cells were not only found in plants but in other living things too. In 1833, Robert Brown, a Scottish scientist, observed that many cells seemed to have a dark structure near the center of the cell. We now call this structure the nucleus. Five years later, German botanist Matthias Schleiden stated that all plants are made of cells. The next year, Theodor Schwann discovered that all animals are made of cells too. In 1855, Rudolf Virchow, a German physician, added one more element to the developing theory of cells. Based on research, he stated that all cells arise from the division of preexisting cells.

Today, the observations and conclusions of these scientists are summarized into the **cell theory**. The cell theory forms the basic framework in which biologists have tried to understand living things ever since. **The cell theory states:**

- All living things are composed of cells.
- Cells are the basic units of structure and function in living things.
- All cells come from preexisting cells.

5-1 SECTION REVIEW

1. When Hooke first used the term cell, did he intend it to apply to living material? Explain your answer.
2. What contributions did van Leeuwenhoek, Hooke, Schleiden, Schwann, and Virchow make to the development of the cell theory?
3. What role did the invention of the microscope play in the development of the cell theory?

5-2 Cell Structure

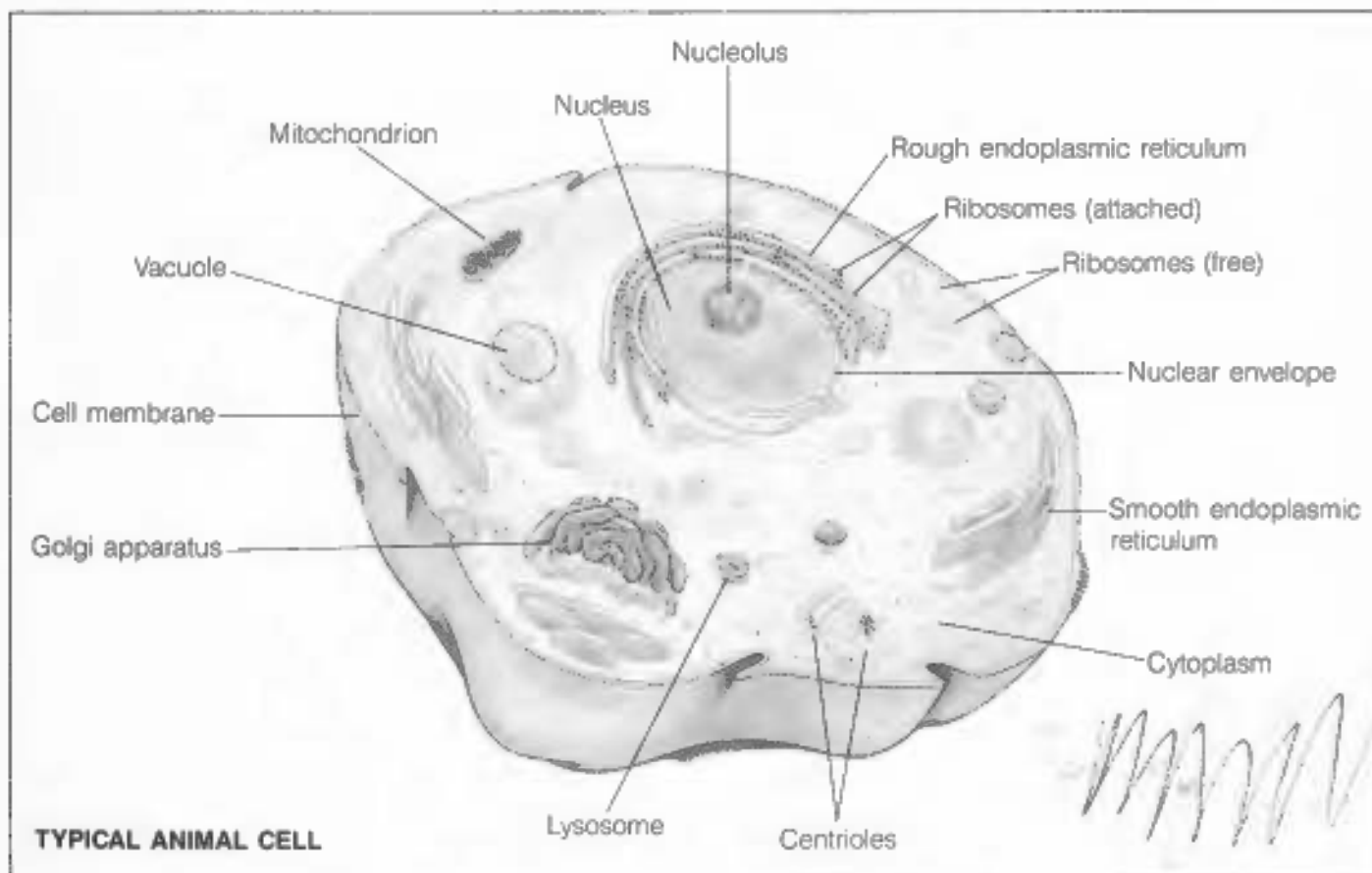
There is enormous variety in the size and shape of different cells. The smallest cells, belonging to a group of organisms known as *Mycoplasma* (migh-koh-PLAZ-muh), are only about 0.2 micrometers in diameter. A micrometer is equal to one millionth of a meter. *Mycoplasma* are so small that they often are beyond the resolving power of light microscopes. Larger cells include the giant amoeba *Chaos chaos*, which is about 1000 micrometers in diameter. Larger still are the yolks of bird eggs, which are actually single cells containing stored food for the developing bird. For the most part, cells are between 5 and 50 micrometers in diameter. Physical limits on the flow of information through the cell and on the flow of materials into and out of the cell prevent most cells from being much larger than this.

Despite differences in size and shape, there are certain structures that are common to most cells. **The cells of animals, plants, and related organisms have three basic structures: the cell membrane, or outer boundary of the cell; the nucleus, or control center; and the cytoplasm, or material between the cell membrane and the nucleus.** Let's examine a typical plant cell and an animal cell to learn about some of these basic structures.

Section Objectives

- Identify and give the function of the three basic structures of most cells.
- Compare the structure of the cell membrane and the cell wall.
- Distinguish between prokaryotes and eukaryotes.

Figure 5-3 This diagram shows a typical animal cell. Note that the structures shown are not to scale. (This is true of almost all cell diagrams.) Most structures have been enlarged so that they can be clearly seen. In addition, some structures are more extensive or more numerous in an actual cell than they are in this diagram.



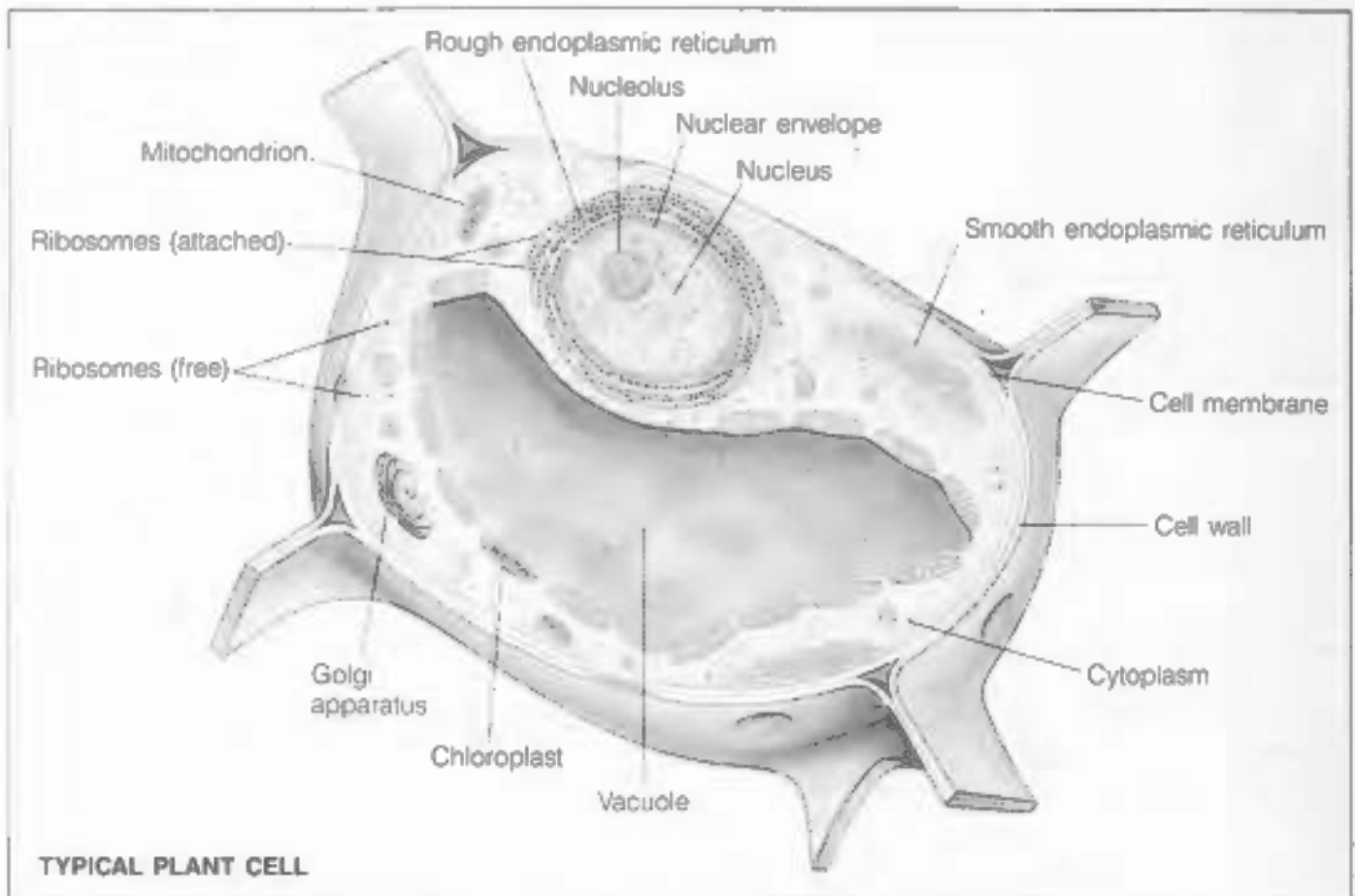


Figure 5-4 A typical plant cell is shown in this diagram. What is the outer boundary of a plant cell called?

Cell Membrane

All cells are separated from their surroundings by a **cell membrane**. The cell membrane regulates what enters and leaves the cell and also aids in the protection and support of the cell.

In a way, the cell membrane is similar to the walls that surround a house. As these walls help to protect the house from what is outside, so the cell membrane seals off the cell from its outside environment. But if you lived inside the house, you would still want to receive messages, fuel, and power from outside. So telephone, gas, and electric lines would have to be able to pass through the walls of the house. You would also want to bring in food and take out the trash. Thus doors would be needed. The needs of a cell are similar. It must communicate with other cells, take in food and water, and eliminate wastes. All of these processes take place through the cell membrane.

The cell membrane is composed of several kinds of molecules. The most important of these are the lipids. A double layer of lipid molecules, known as a bilayer, forms the basic unit from which cell membranes are constructed. You can see the structure of the cell membrane in Figure 5-5.

Proteins and carbohydrates are also associated with the cell membrane. Some proteins stick to the surface of the lipid

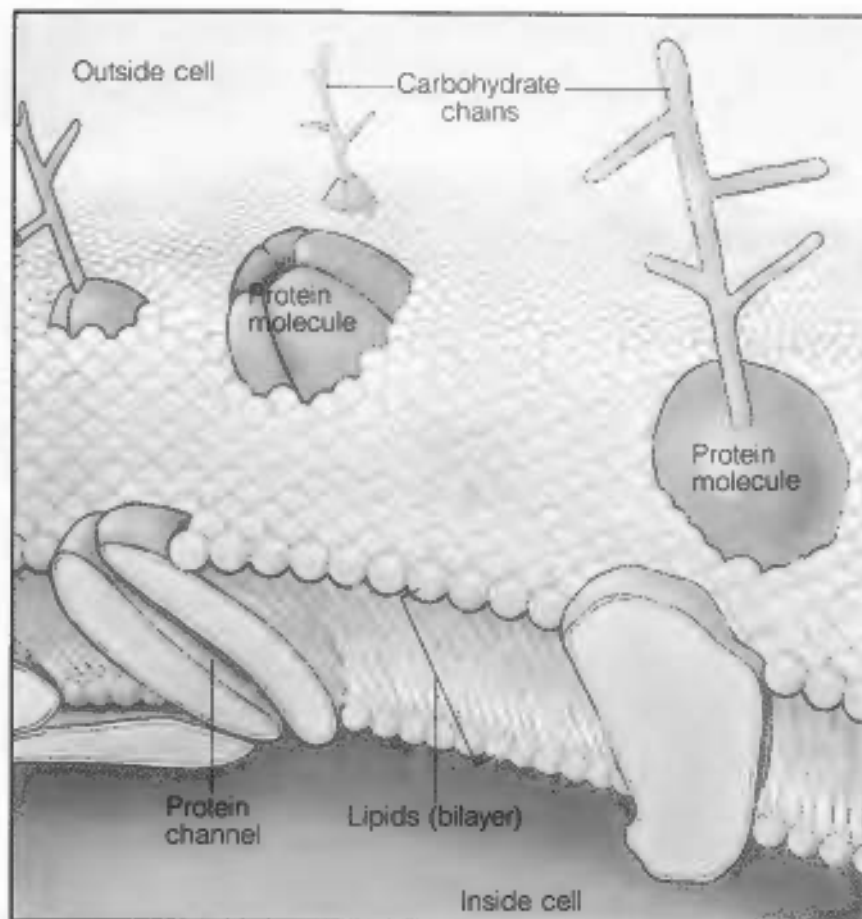


Figure 5-5 According to a widely accepted model of membrane structure called the fluid-mosaic model, cell membranes are formed from double layers of lipids (bilayers) in which proteins are embedded. Some of the proteins form channels that allow certain molecules to pass into and out of the cell. Others resemble small pumps that push molecules from one side of the membrane to the other.

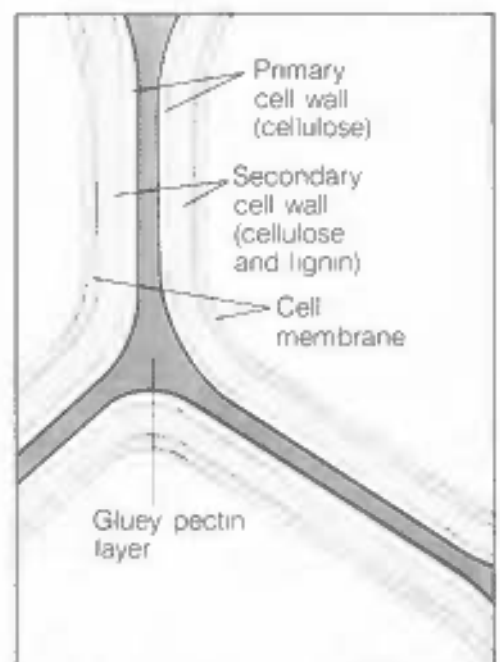
bilayer, whereas others are free to move around within the layer. Some of the free-moving proteins act as channels through which molecules can pass. Others act like small pumps, actively pushing molecules from one side of the membrane to the other. The carbohydrates are attached to proteins or lipids at the membrane surface. Many of these carbohydrates act like chemical identification cards, allowing cells to recognize and interact with each other.

Cell Wall

In organisms such as plants, algae, and some bacteria, the cell membrane is surrounded by a **cell wall**. In other words, the cell wall lies outside the cell membrane. The cell wall helps to protect and support the cell. Because the cell wall is very porous, water, oxygen, carbon dioxide, and other substances can pass through easily.

If we looked at an electron micrograph of a plant cell, we would discover that the cell wall is made up of two or more layers. These layers form in a series of steps. The first layer to form develops where two plant cells meet. See Figure 5-6. This layer contains a gluey substance, called pectin, that helps hold the cells together. Each of the cells then forms a primary cell

Figure 5-6 The primary cell wall forms the outer boundary of plants, algae, and some bacteria. The secondary cell wall, however, generally forms only in woody stems.



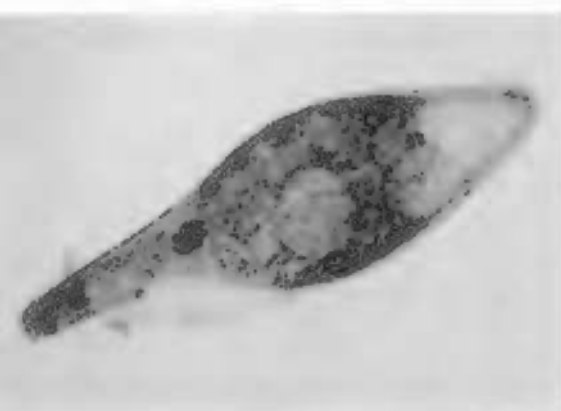


Figure 5-7 One way of classifying living things is by the presence or absence of a nucleus. Prokaryotes, such as bacteria, do not have a nucleus (top). Eukaryotes, such as a blepharisma, contain a nucleus surrounded by a nuclear envelope (bottom).

wall on its side of this gluey layer. The primary cell wall is made up of cellulose, a fibrous material. Cellulose fibers make the cell wall elastic, so that it can stretch as the cell grows.

In plants that have woody stems, another layer, called the secondary cell wall, develops. This wall is composed of cellulose and lignin (LIHG-nihn). Lignin makes cellulose more rigid. Wood consists mainly of secondary cell walls.

Nucleus

In many cells we can see a large dark structure, called the **nucleus**, which was first described by Robert Brown. Not all cells have nuclei. Small unicellular organisms known as bacteria, as well as several other kinds of organisms, do not have nuclei. The presence of a nucleus has been used by scientists to divide cells into two general categories: eukaryotic (yoo-kahr-ee-AHT-ihk) cells, those that have a nucleus, and prokaryotic (proh-kahr-ee-AHT-ihk) cells, those that do not have a nucleus.

Organisms made up of eukaryotic cells are commonly known as **eukaryotes** (yoo-KAHR-ee-ohts). The animals and plants that we see around us are eukaryotes. Those organisms, such as bacteria, that are made up of prokaryotic cells are known as **prokaryotes** (pro-KAHR-ee-ohts). The distinction between prokaryotes and eukaryotes is a basic one, and we will return to it many times as we consider the diversity of living things. In fact, scientists consider this distinction far more important than the distinction between plant and animal cells!

Many of the scientists who first examined cells under a microscope suspected that the nucleus was doing something important. What could it be? The nucleus has been found to be the information center of the cell and contains DNA (deoxyribonucleic acid). The instructions for making thousands of different molecules are found in the nucleus. These instructions are decoded and executed by a process that we will discuss in Chapter 7. The nucleus also directs all the activities that occur in a living cell.

NUCLEAR ENVELOPE The nucleus of a eukaryotic cell is generally 2 to 5 micrometers in diameter. Surrounding the nucleus are two membranes that form the **nuclear envelope**. These two membranes form the boundary around the nucleus. In the nuclear envelope are dozens of nuclear pores, or small openings. The molecules that move in and out of the nucleus pass through the nuclear pores.

NUCLEOLUS Most nuclei contain a small region called the **nucleolus** (noo-KLEE-uh-luhs) that is made up of RNA (ribonucleic acid) and proteins. The nucleolus is the structure in which ribosomes are made. Ribosomes, as you will soon learn, aid in the production of proteins within the cell.

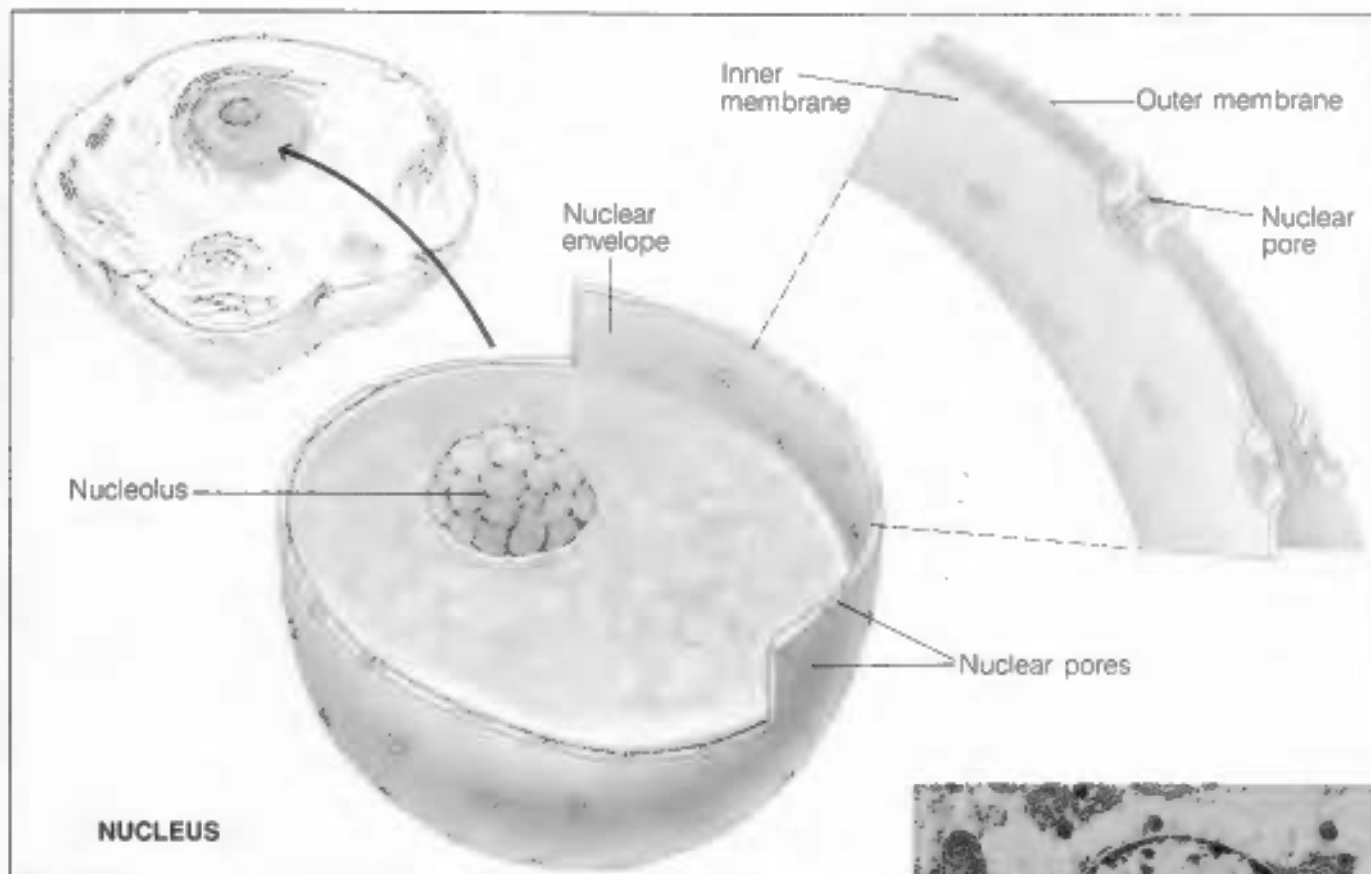


Figure 5-8 The nucleus directs all the activities of a cell. Notice the various structures that make up the nucleus and the appearance of the nucleus viewed through a transmission electron microscope.

CHROMOSOMES The DNA in the nucleus of eukaryotic cells is attached to special proteins and forms large structures called **chromosomes**. Chromosomes contain the genetic information that must be passed to each new generation of cells.

Cytoplasm

Because the nucleus sits in the center of many eukaryotic cells, we can divide the space within a cell into two compartments: the nucleus and the **cytoplasm**. The cytoplasm is the area between the nucleus and the cell membrane. The cytoplasm contains many important structures that we shall discuss in the next section.

5-2 SECTION REVIEW

1. What are the three basic structures found in most cells?
2. What is the function of the cell membrane?
3. Distinguish between a prokaryote and a eukaryote. Why is this distinction important to scientists?

Section Objectives

- Define organelle.
- Describe the functions of the cytoplasmic organelles.
- Compare a plant cell and an animal cell.

5-3 Cytoplasmic Organelles

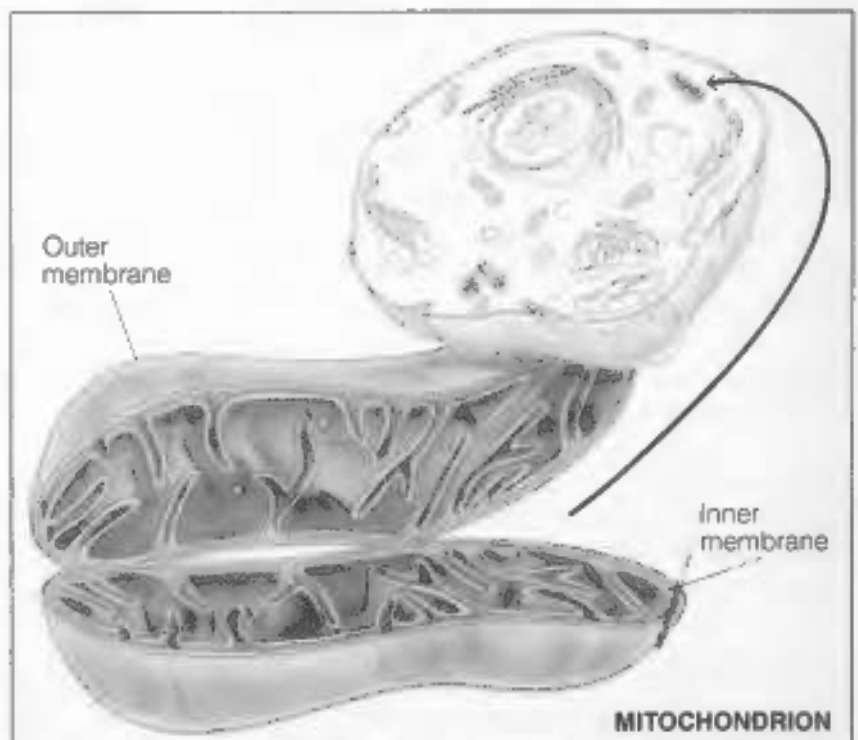
Even in the low-power images that we can produce with the light microscope, it is clear that there are structures inside the cytoplasm of the cell. The structures in the cytoplasm are generally called **organelles** (or-guh-NEHLZ). An **organelle** is a tiny structure that performs a specialized function in the cell. Each organelle (little organ) has a special job that helps maintain the cell's life. Let's look at some of the organelles that are found in plant and animal cells.

Mitochondria and Chloroplasts: Power Stations

All living things require a reliable source of energy. On the Earth that source is usually the sun or food substances. The **mitochondrion** (might-oh-KAHN-dree-uhn; plural: mitochondria) and the **chloroplast** are key organelles that change energy from one form to another. Mitochondria change the chemical energy stored in food into compounds that are more convenient for the cell to use. Chloroplasts trap the energy of sunlight and convert it into chemical energy. The reactions that take place in both of these organelles are closely related, and we will examine them in more detail in Chapter 6.

The mitochondrion contains two special membranes. The outer membrane surrounds the organelle, and the inner membrane has many folds that increase the surface area of the mitochondrion.

Figure 5-9 Mitochondria are the powerhouses of the cell. They provide the cell with the energy it needs to survive. Note the structure of a mitochondrion in the diagram and in the electron micrograph.



The structure of the chloroplast is similar. It is surrounded by two envelopelike membranes and contains a third kind of membrane, where the radiant energy of the sun is actually changed into chemical energy. Chloroplasts are found only in plant cells and algae. As we will see later, both mitochondria and chloroplasts have a degree of independence from the rest of the cell. This has led to some discussion that they may be descended from independent organisms.

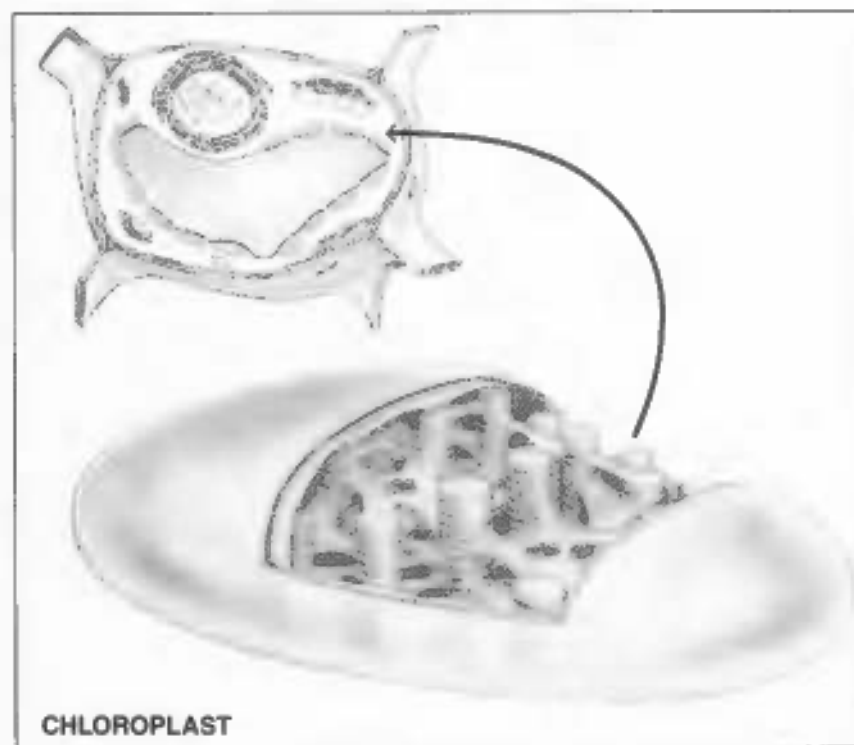
Ribosomes: Protein Factories

Ribosomes are the structures in which proteins are made. Cells that are active in protein synthesis are often crowded with ribosomes. Ribosomes are composed of RNA and protein. Some ribosomes are attached to membranes; some are found free in the cytoplasm. Ribosomes are among the smallest of organelles. They are no larger than 25 nanometers in diameter. A nanometer is equal to one billionth of a meter.

Endoplasmic Reticulum and Golgi Apparatus: Manufacturers and Shippers

Many cells are filled with a complex network of channels known as the **endoplasmic reticulum** (ehn-doh-PLAZ-mihk riH-TIHK-yuh-luhm), or ER. The endoplasmic reticulum transports materials through the inside of the cell. There are two types of endoplasmic reticulum. In the smooth endoplasmic reticulum (smooth ER), the walls of the channels look smooth

Figure 5-10 Chloroplasts are organelles that use the radiant energy of sunlight to produce the chemical energy organisms need to survive. Notice the envelopelike membranes within the chloroplasts.



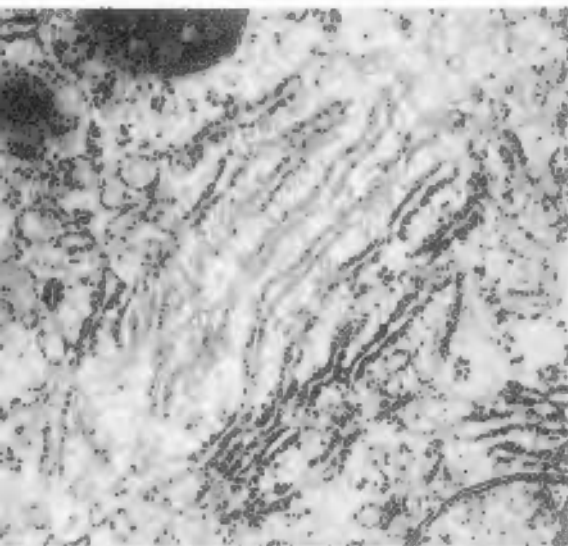


Figure 5-11 The endoplasmic reticulum is actually a series of channels that transport materials throughout the cell. Which type of endoplasmic reticulum has ribosomes attached to its surface?

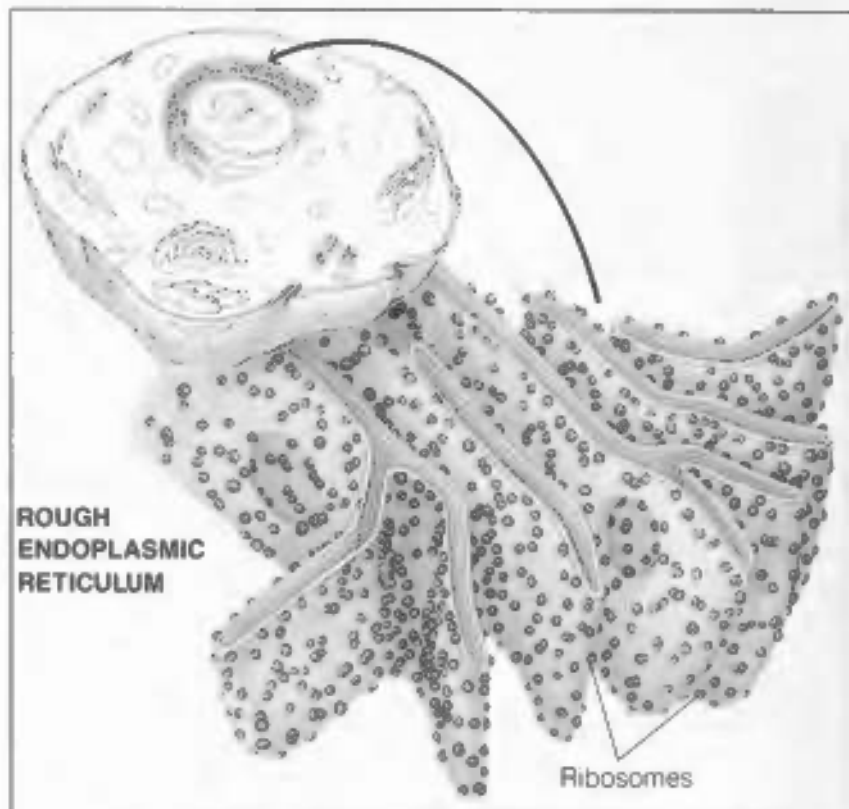
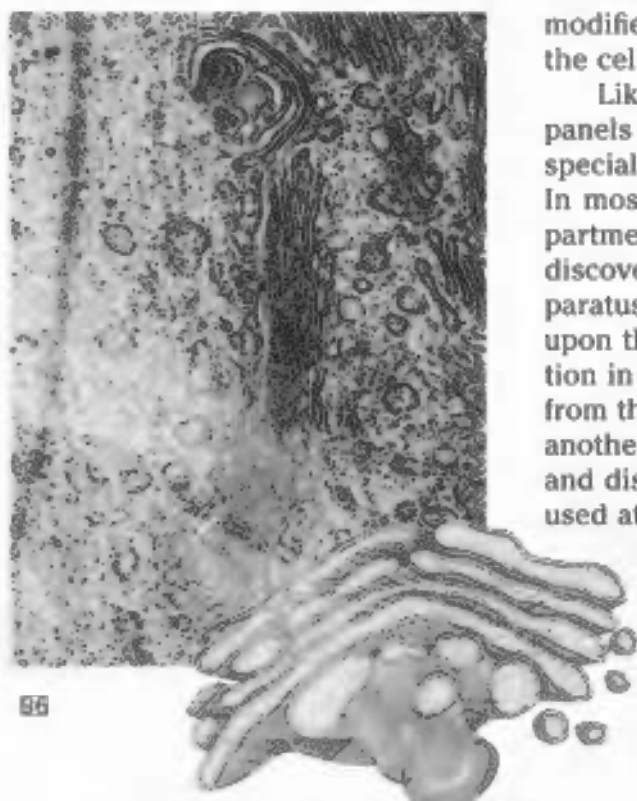


Figure 5-12 The Golgi apparatus modifies proteins by attaching carbohydrates or lipids to the proteins. The modified proteins can then be transported from one part of the cell to another.



and are not studded with particles or granules. In some cells, special enzymes and chemicals are stored in the smooth endoplasmic reticulum.

The other form of endoplasmic reticulum is involved in the synthesis of proteins. This form is called the rough endoplasmic reticulum (rough ER) because the ribosomes that are stuck to its surface give it a rough appearance. Newly made proteins are inserted into the rough ER, where they may be chemically modified. Many proteins that are released, or exported, from the cell are synthesized on the rough ER.

Like automobiles to which enthusiasts attach chrome panels and hood ornaments, proteins often are modified by special enzymes that attach carbohydrates and lipids to them. In most cases, the proteins are first moved into special compartments known as the **Golgi apparatus**, because they were discovered by the Italian scientist Camillo Golgi. The Golgi apparatus looks like a flattened stack of membranes piled one upon the other, not unlike a stack of pancakes. After modification in the Golgi apparatus, the proteins may then be released from the cell or take up positions in other parts of the cell. Put another way, the Golgi apparatus modifies, collects, packages, and distributes molecules made at one location of the cell and used at another.

Lysosomes: Cleanup Crews

Some white blood cells in your blood are capable of swallowing whole bacteria. Other cells, such as the single-celled ameba, are capable of engulfing clumps of yeast, sugar, and even tiny pieces of bread. Many cells will seem to engulf microscopic particles of food, foreign material, or even other cells. This process is called endocytosis (ehn-doh-sigh-TOH-sihs). Endocytosis is a way in which materials that are too large to pass through the cell membrane get into the cell.

When a cell encircles a particle, the cell membrane forms a pocket around the foreign material. The foreign material must now be digested, or broken down. That is the job of the **lysosomes** (LIGH-suh-sohmz). Lysosomes are small membrane-bordered structures that contain chemicals and enzymes necessary for digesting certain materials in the cell. Lysosomes are formed by the Golgi apparatus. Plant cells do not have lysosomes.

Lysosomes are also involved in breaking down organelles that have outlived their usefulness. In a way, lysosomes can be thought of as the cell's cleanup crews. As such, lysosomes perform vital functions. Why do you think human diseases that cause the lysosomes to work improperly, such as Tay-Sachs disease and possibly cystic fibrosis, can be serious and even fatal?

Vacuoles and Plastids: Storage Tanks

Many cells contain saclike structures, called **vacuoles** (VAK-yoo-ohlz), that store materials such as water, salts, proteins, and carbohydrates. In many plant cells there is a single large central vacuole filled with liquid. The pressure of the liquid-filled vacuole in these cells makes it possible for plants to grow quickly and to support heavy structures such as leaves and flowers. Why do you think a plant that has lost a large amount of water will begin to wilt?

Plastids are plant organelles that may take many forms, one of which is the chloroplast, an organelle we have already mentioned. Many plastids are involved in the storage of food and pigments. Some examples of plastids are leukoplasts (LOO-koh-plasts), which store starch granules, and chromoplasts (KROH-muh-plasts), which store pigment molecules. The red color in the skin of a ripe tomato comes from pigments produced in chromoplasts.

Cytoskeleton: Framework

Cells are found in a bewildering variety of shapes: some round, some cubical, some long and slender. In addition, most cells are capable of some type of movement. Even stationary cells can move the organelles around inside of them. How do they accomplish such motion? And what allows cells to keep their unusual shapes?

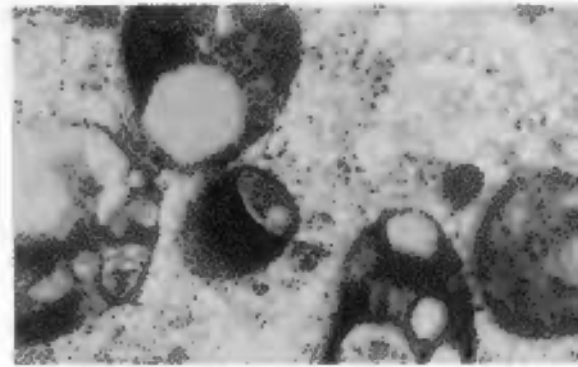


Figure 5-13 These spherical organelles are lysosomes that have been magnified approximately 95,000 times. Lysosomes contain enzymes that can digest other organelles that have outlived their usefulness. For this reason, lysosomes are thought of as the cell's cleanup crews.

Figure 5-14 The large saclike structure in this leaf cell is a vacuole, which has been magnified approximately 16,000 times. Vacuoles act as cellular storage tanks and may hold water, salts, proteins, and carbohydrates.

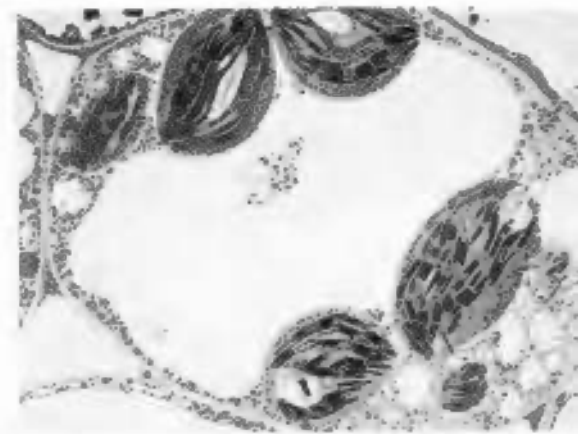
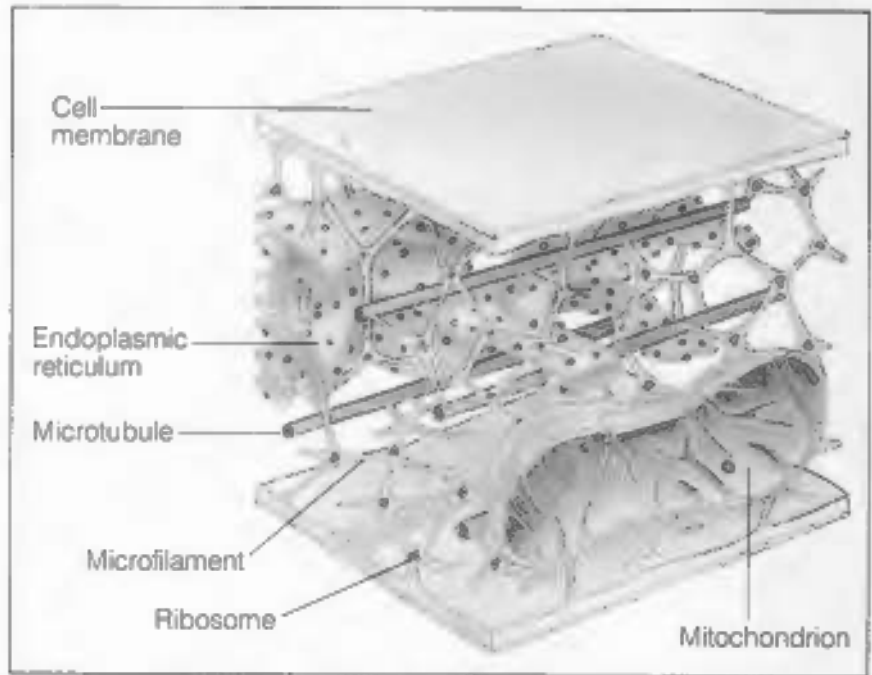




Figure 5-15 This diagram shows the cytoskeleton of the cell. Notice that the endoplasmic reticulum, mitochondria, and ribosomes are all held in place by the microfilaments and microtubules that form the cytoskeleton. The photograph shows the actual microtubules that make up the cytoskeleton.



Not too many years ago, scientists were content to suggest that the cytoplasm was filled with a material, called protoplasm, that gave the cell many unique properties. As we have learned more about the composition of the cell, the idea of "protoplasm" has lost acceptance. In its place, biologists have uncovered a framework known as the **cytoskeleton**. The cytoskeleton is composed of a variety of filaments and fibers that support cell structure and drive cell movement.

One of the main components of the cytoskeleton are microtubules, hollow tubules made out of proteins. Microtubules provide support for cell shape, help move organelles through the cell, and play a special role in cell division by forming centrioles (SEHN-tree-ohlz). Centrioles are found in animal cells and many other eukaryotic cells but not in plant cells.

In some cells, the microtubules support hairlike projections from the cell surface known as cilia (SIHL-ee-uh; singular: cilium) and flagella (fluh-JEHL-uh; singular: flagellum). Cilia are short threadlike structures that help unicellular organisms move. They also aid in the movement of substances along the cell's surface. Flagella are longer whiplike structures that help unicellular organisms move about. Cilia and flagella contain nine pairs of microtubules arranged around a pair in the center. These microtubules are linked to each other, and the bridges that connect them generate the force to produce motion.

Another principal component of the cytoskeleton are microfilaments—long, thin fibers that function in the movement and support of the cell. They also permit movement of the cytoplasm within the cell. This is called cytoplasmic streaming. The proteins that make up microfilaments are also found in muscle cells, which are specialized for contraction.



Figure 5-16 The microtubules of the cytoskeleton support hairlike projections called cilia and flagella. Cilia, such as those on this single-celled organism (left), are short threadlike structures that help the cell move about by beating back and forth. Flagella, such as the one on the single-celled *Euglena* (right), help the cell move by beating in a whiplike fashion.

5-3 SECTION REVIEW

1. What are organelles? Give two examples of organelles.
2. How do lysosomes function to digest particles?
3. How are mitochondria and chloroplasts similar? How are they different?
4. What components make up the cytoskeleton?

5-4 Movement of Materials Through the Cell Membrane

Each individual cell exists in a liquid environment. Even the cells of multicellular organisms such as a maple tree or a human are bathed in liquid. The cells of our bodies are bathed in a liquid that was once part of blood. The presence of a liquid environment makes it easier for materials such as food, oxygen, and water to move into and out of the cell. There are several ways in which materials enter and leave the cell.

Section Objectives

- Explain the processes of diffusion and osmosis.
- Compare active and passive transport.
- Describe endocytosis, phagocytosis, pinocytosis, and exocytosis.

Diffusion

Although the cell membrane is a barrier, it must not be too effective. Materials must pass into and out of the cell. How is this movement accomplished?

We know that molecules move constantly, colliding with one another and tending to spread out randomly through space. This random motion results in the tendency of molecules to move from a region where they are more numerous to a region where they are less numerous. In other words, molecules move from an area of higher concentration to an area of lower concentration.

The driving force behind the movement of many substances across the cell membrane is called **diffusion** (dih-FYOO-zhuhn). **Diffusion is the process by which molecules of a substance move from areas of higher concentration of that substance to areas of lower concentration.**

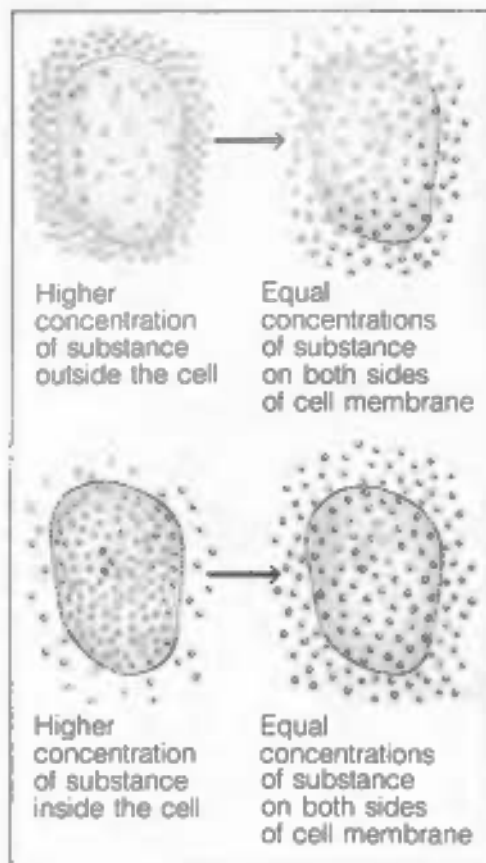


Figure 5-17 Diffusion is the movement of the molecules of a substance from areas where they are more concentrated to areas where they are less concentrated. What point has been reached when the concentration of a substance is equal on both sides of a cell membrane?

What factors determine whether diffusion occurs across a membrane? If two substances are present in unequal amounts on either side of a membrane, each substance will tend to move toward the area of lower concentration until equilibrium is reached. See Figure 5-17. Equilibrium occurs when the concentrations of the substances on both sides of the membrane are the same. At this point, we may say that an equilibrium point for each substance has been reached. Individual molecules continue to move rapidly between the two sides at equilibrium, but because roughly equal numbers of molecules move in each direction, there is no further change in concentration.

Another important factor that determines whether diffusion occurs across a membrane is permeability (per-mee-uh-BIHL-uh-tee). If a particular substance is able to diffuse across a membrane, then we say that the membrane is permeable to that substance. A membrane is said to be impermeable to those things that cannot pass across it. As you might expect, biological membranes are permeable to some things and impermeable to others. Therefore, we can describe most biological membranes as **selectively permeable**.

Osmosis

Although compounds that are able to dissolve in the lipid bilayer of the cell membrane pass through the membrane easily, most other molecules do not. There is, however, one important exception to that rule: water. Water molecules pass through most cell membranes very rapidly. The fact that water molecules can pass through membranes so easily has important consequences for the cell.

The diffusion of water molecules through a selectively permeable membrane is called **osmosis** (ahs-MOH-sihs). If a membrane separates two solutions, in which direction will the water molecules move? To answer this question, let us suppose that we place a concentrated sugar solution on one side of a selectively permeable membrane and a dilute sugar solution on the other. As you have just learned, water will pass through the membrane by diffusion from the area of high water concentration to the area of low water concentration. In which direction is that?

Look at Figure 5-18. On the side of the membrane with the concentrated sugar solution, fewer water molecules will strike the membrane because they will be crowded out by the sugar molecules. Thus, this side is the area of low water concentration. On the side of the membrane with the dilute sugar solution, more water molecules will strike the membrane. This side is the area of high water concentration. As a result, more water moves through the membrane from the side that has the low sugar concentration to the side that has the high sugar concentration than moves through in the opposite direction. This results in a net movement of water from the side with the dilute

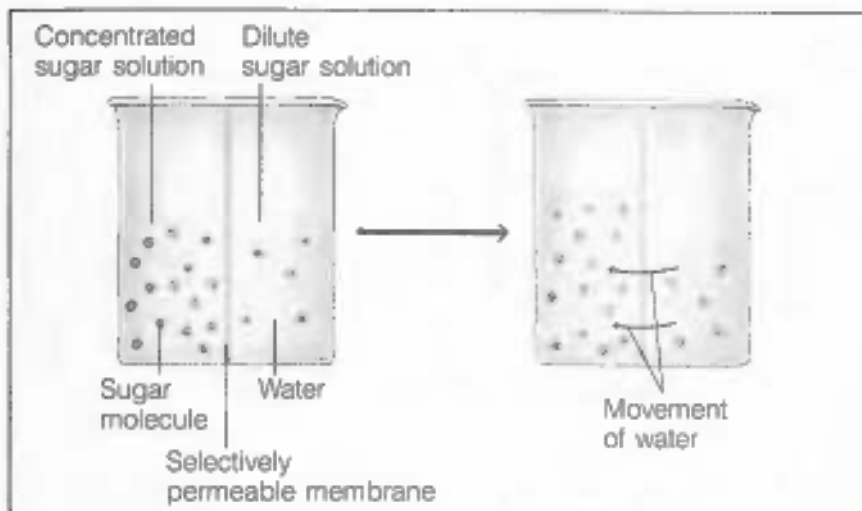


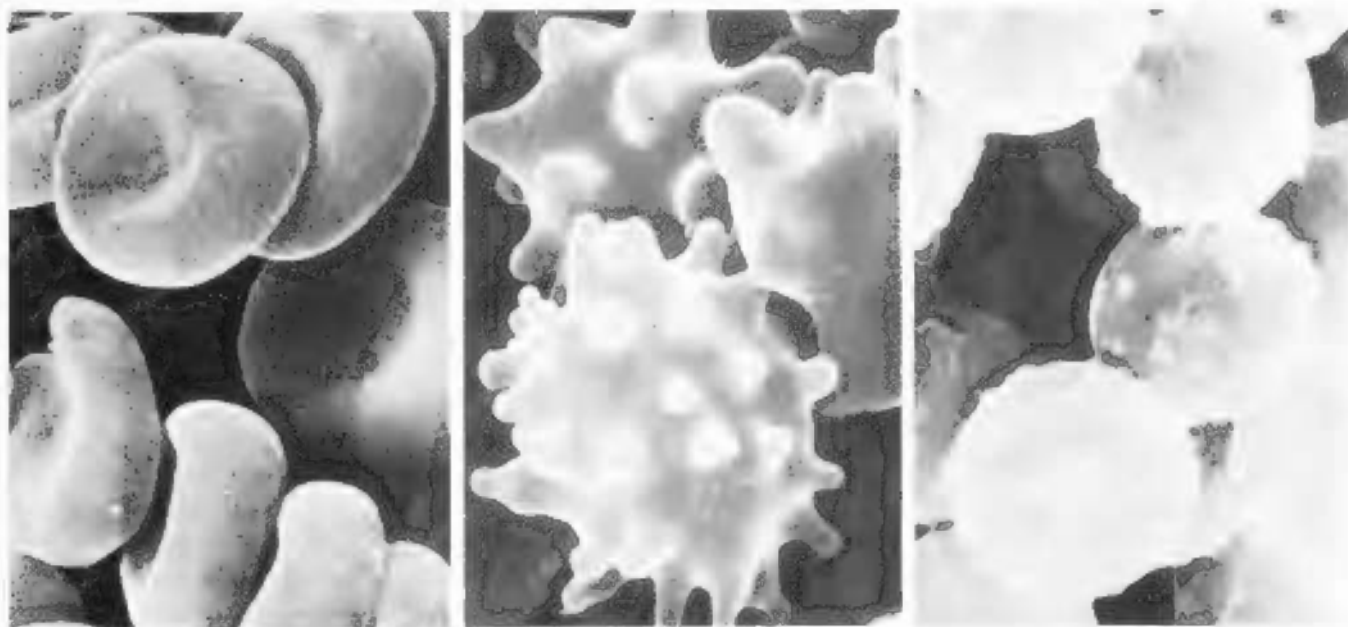
Figure 5-18 Osmosis is the diffusion of water molecules through a selectively permeable membrane from an area of greater concentration of water to an area of lesser concentration of water. In this diagram, there are more water molecules on the side containing the dilute sugar solution. As a result, the water molecules move to the side containing the concentrated sugar solution. Osmosis continues until equilibrium is reached.

sugar solution to the side with the concentrated sugar solution.

The force exerted by osmosis, or osmotic pressure, tends to move water across membranes from a more dilute solution into a more concentrated solution. If, however, two solutions contain exactly the same amount of dissolved material, there is no osmotic pressure across a membrane separating them because the concentrations of dissolved materials are in equilibrium.

Osmotic pressure can cause serious problems for a cell. Because the cytoplasm is filled with salts, sugars, proteins, and other molecules, it will almost always have a much lower concentration of water than is found in fresh water. Therefore, there should be a net movement of water into a typical cell if it is surrounded by fresh water. If water moves in freely, the volume of a cell will increase until the cell becomes swollen and bursts like an overinflated balloon.

Figure 5-19 Normal red blood cells (left) will shrink if too much water leaves the cells due to osmosis (center). If too much water enters the cells during osmosis, the red blood cells will swell (right).



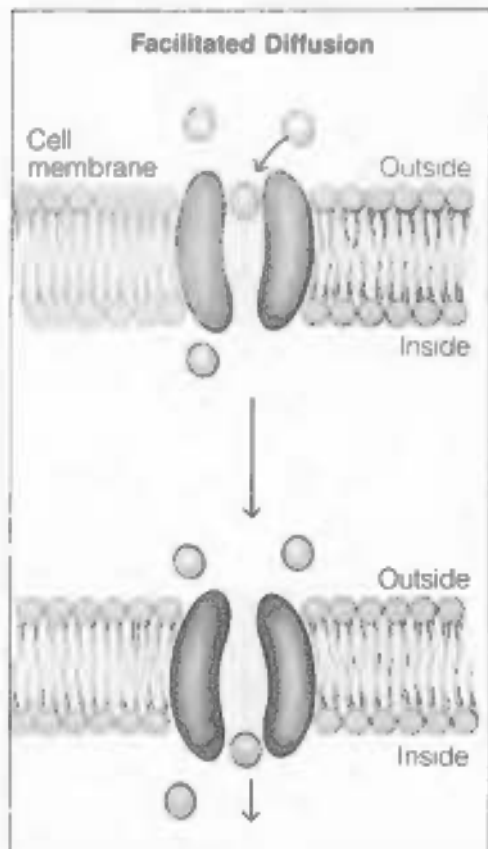


Figure 5-20 Most molecules that do not dissolve in the lipid bilayer of the cell membrane cannot pass through by diffusion. One way of getting such molecules into the cell is by facilitated diffusion. This process, which does not require any energy, uses a carrier molecule to transport a substance into the cell through the cell membrane.

The structure of the lipid bilayer makes cell membranes freely permeable to water. Cells deal with the problem of osmotic pressure in a variety of ways.

In some instances, the cells of many organisms do not come in contact with fresh water. Instead, the cells are bathed in fluids, such as blood, that have concentrations of dissolved materials roughly equal to the cells themselves.

Other cells, such as plant cells and bacteria, deal with osmotic pressure in another way. They are surrounded by cell walls that prevent the cells from expanding, even under tremendous osmotic pressure. However, the increased osmotic pressure makes the cells extremely vulnerable to injuries to the cell wall.

Still other cells employ a mechanism to pump out the water that is forced in by osmosis. For example, some unicellular organisms have a structure called a contractile (kuhn-TRAK-tihl) vacuole. By contracting rhythmically, the contractile vacuole pumps water out of the cell.

Facilitated Diffusion

Osmosis and diffusion are forms of passive transport across the cell membrane because energy is not needed for these processes. Some materials, including alcohols and small lipids, can pass directly through the membrane because they can dissolve in the lipid bilayer. But many molecules are transported across a membrane in the direction of lowest concentration by a carrier protein. This process is called **facilitated diffusion**. In red blood cells, for example, a carrier protein in the cell membrane transports glucose from one side of the membrane to the other. The glucose-transporter protein facilitates, or helps in, the diffusion of glucose.

Although facilitated diffusion is fast, specific, and does not require energy, it is still driven by diffusion. Therefore, a net movement of material across a cell membrane by facilitated diffusion can occur only if a concentration difference exists across that membrane.

Active Transport

Active transport is an energy-requiring process that enables material to move across a cell membrane against a concentration difference. There are two types of active transport.

In one type, individual molecules are carried through membrane-associated pumps. Special transport macromolecules that exist in the cell membrane move molecules across the membrane. Among the molecules that are transported are calcium, potassium, and sodium ions. Normally they are not able to diffuse across the membrane. The molecular pumps that carry out this transport require chemical energy, thus making this process a form of active transport. All cells that have been

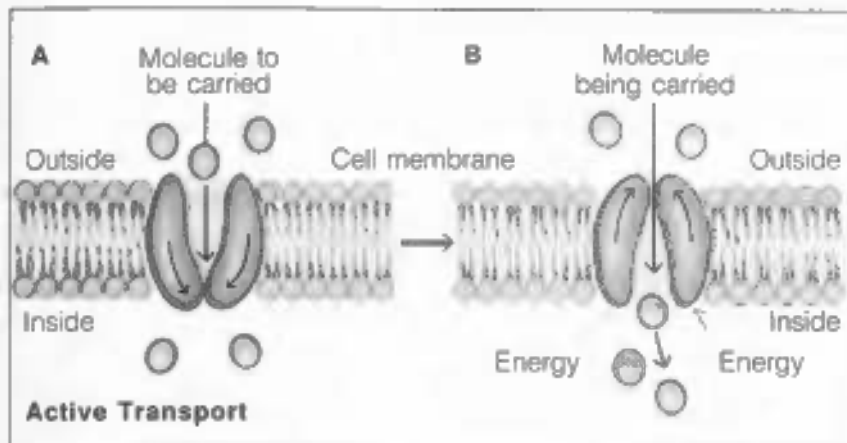


Figure 5-21 Very often a substance must pass through the cell membrane even if the concentration of that substance is greater inside the cell than it is outside the cell. In such cases, the cell must expend energy in a process called active transport. In one form of active transport, energy is used to change the shape of the cell membrane and to actively pull the substance through the membrane into the cell.

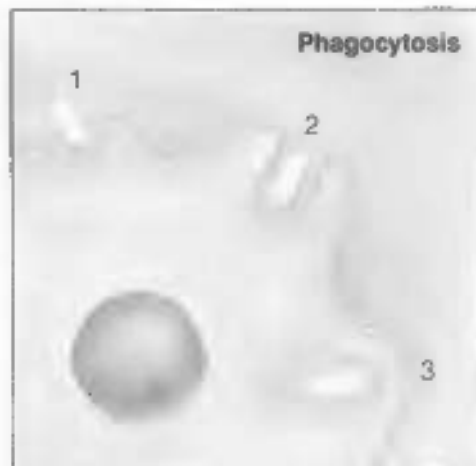
studied seem to transport at least a few molecules in this way. The use of energy in these systems enables cells to concentrate molecules, even when the normal forces of diffusion might tend to move those molecules in the opposite direction.

In the second type of active transport, large amounts of material are transported through movements of the cell membrane. One of these movements is called endocytosis. As you may remember, endocytosis is the process of taking material into the cell by means of infoldings, or pockets, of the cell membrane. The pocket that results breaks loose from the outer portion of the cell membrane and forms a vacuole within the cytoplasm. Large molecules, clumps of food, and even whole cells can be taken up in this way.

When large particles are taken into the cell by endocytosis, the process is called phagocytosis (fayg-oh-sigh-TOH-sihs). In phagocytosis, extensions of cytoplasm surround and engulf large particles. Amoebas use this method of taking in food.

In a process similar to endocytosis, many cells take up liquid from the surrounding environment in a similar way. Tiny pockets form along the cell membrane, fill with liquid, and pinch off to form vacuoles within the cell. This process is known as pinocytosis (pighn-oh-sigh-TOH-sihs).

Figure 5-22 Another form of active transport is called phagocytosis. During phagocytosis, a large particle is surrounded by pockets of the cell membrane (right). Once the particle is surrounded, the pocket breaks away from the cell membrane and forms a vacuole within the cell. Amoebas are one type of organism that takes in food and other materials through phagocytosis (left).



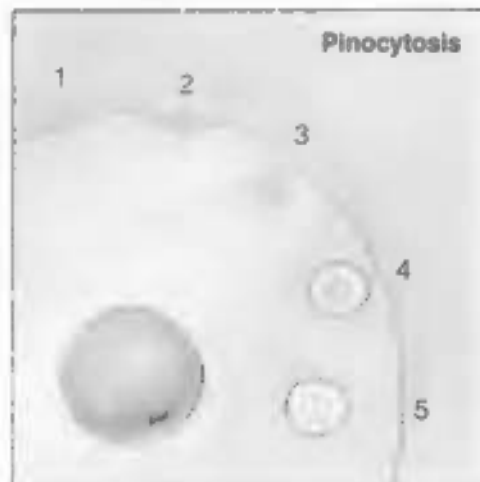


Figure 5-23 Like phagocytosis, pinocytosis is a form of active transport. In pinocytosis, however, cells take in liquids rather than solid particles.

Section Objective

- Relate cell specialization to cell structure.

As you might expect, cells are also capable of sending material out of the cell. The removal of water by means of a contractile vacuole is one example of this kind of active transport. When other large molecules are removed from the cell, the process is generally known as exocytosis (ehk-soh-sigh-TOH-sihs). As exocytosis occurs, the membrane surrounding the material fuses with the cell membrane, forcing the contents out of the cell.

5-4 SECTION REVIEW

1. What is diffusion?
2. Why is osmosis a form of diffusion?
3. Molecules that are soluble in lipids tend to move across cell membranes more quickly than those that are not. Based on this information, what could you conclude about the structure of the cell membrane?
4. The red blood cell contains a higher concentration of K^+ ions than does the liquid that surrounds it. Are K^+ ions most likely to be moved across the membrane by facilitated diffusion or active transport? Explain.

5-5 Cell Specialization

Cell specialization is one of the key characteristics of cells in a multicellular organism. By **cell specialization**, we mean that cells are often uniquely suited to perform a particular function within the organism. For example, some cells are specialized to move. Some cells are specialized to react to their environment—the world around them. Some cells are specialized to make certain products. We will now look briefly at three cells, each specialized for a different function.

Factory in Miniature

Located just below the stomach is a small structure called the pancreas. Portions of the pancreas contain cells that are specialized to produce digestive enzymes. Although these cells have most of the organelles found in other cells, they contain enormous amounts of the organelles involved in protein synthesis. In fact, one cell may contain 100 times the amount of rough endoplasmic reticulum found in other cell types. Each cell is filled with ribosomes as well as rough ER. These cells also contain large Golgi apparatus filled with vacuoles that are loaded with soon-to-be-released protein. Cells of the pancreas are dominated by organelles needed for protein synthesis.

Do Your Cells Belong to You?

In 1976, John Moore was diagnosed as having hairy cell leukemia. With this rare form of cancer, a person has too many B lymphocytes that develop tiny whiskerlike projections. B lymphocytes are white blood cells responsible for making antibodies, which are substances that help the body fight off certain diseases.

At the recommendation of his doctor, Moore had his enlarged spleen removed by physicians at the University of California at Los Angeles (UCLA) Medical Center. Normally, the spleen, an organ located near the stomach, filters out worn out or damaged blood cells. But in a person suffering from hairy cell leukemia, the spleen becomes filled with cancerous cells and can no longer perform its function. In addition, the healthy spleen cells are destroyed. Removal of the spleen is not a cure, but it helps return the number of blood cells to normal.

What Moore did not know until later, however, was that a portion of his spleen was saved and used by researchers to isolate and grow cells in culture—cells that produce a substance that may prove useful against cancer or AIDS. In 1984, UCLA obtained a patent for the cells and their products. One of these products was mass produced by a biotechnology company. The genetically engineered drug was then sold by a pharmaceutical firm. The development and sale of this new drug was proceeding well

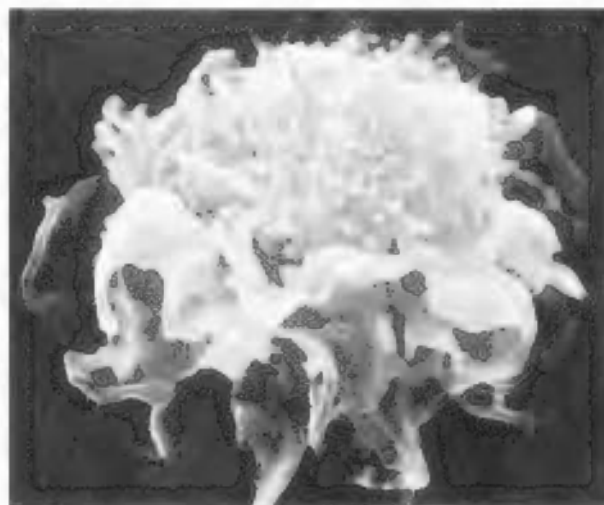
... that is, until Moore sued UCLA, his doctor, and others for patenting and profiting from parts of his body!

In response to the suit, UCLA and the doctor have claimed that Moore signed two consent forms. One form gave UCLA permission to remove Moore's spleen, a procedure that obviously saved his life. The other gave UCLA all rights to Moore's cells and any future product that might be developed from them. The doctor further stated that Moore gave up claims to

his spleen tissue—tissue that was worthless, even dangerous, to him. It was through the application of scientific knowledge that this poisoned tissue was turned into something of value.

In 1988, Moore's case went to trial in California. The court ruled that a person has all legal rights to cells and tissues removed during surgery and later used in scientific research. For now, the ruling stands.

But this is a very complicated issue whose impact may be far reaching. Many researchers believe that this ruling will interfere with new research and raise the cost of its progress. They are also convinced that it will discourage people from donating tissues and organs because of fear that researchers may profit from them. At the heart of the issue is this question: Do people have the right to control the use of their cells even though it might delay or prevent a medical breakthrough?



Whiskerlike projections on white blood cells are characteristic of a person who has hairy cell leukemia.

ORGAN SYSTEMS

System	Function
Skeletal	Protection and support
Muscular	Support and movement
Skin	Protection
Digestive	Breakdown and absorption of food
Circulatory	Transport of oxygen, wastes, and digested food
Respiratory	Gas exchange
Excretory	Removal of liquid and solid wastes
Endocrine	Regulation
Nervous	Regulation, conduction, and coordination
Reproductive	Production of sex cells

Figure 5-24 Which organ system breaks down food?

A Light-Sensitive Cell

You are able to see because your eyes are sensitive to light. But only a few cell types in the eye are actually sensitive to light. These light-sensitive cells are composed of two very different parts. The lower part of the cell is packed with mitochondria, perhaps four or five times as many as in a typical cell. This is an indication that the cell uses a lot of energy. The upper part contains small flattened membranes piled upon each other like a large stack of pancakes.

The membranes, which are known as disks, contain a pigment called rhodopsin (roh-DAH-p-sihn). Rhodopsin absorbs light and signals the rest of the cell that light has struck the disk. This action causes messages to be sent to other cells. These changes result in the sensation we call vision. The presence of many membranes ensures that even the smallest unit of light can be detected by this light-sensitive cell.

The Street Sweepers

The air we breathe is filled with dust, smoke, and even small bacteria. Why doesn't all this material collect in the lungs and clog its passageways? Lining these passageways are special cells that release a mixture of water, carbohydrates, and salts, called mucus. The particles of dust and dirt that are inhaled are trapped in this sticky mucus. Underneath this layer of mucus is another group of specialized cells that have cilia. As the cilia move, they create a sweeping action. This action keeps the most vital passageways in the body clean and open for business.

5-5 SECTION REVIEW

1. What is cell specialization?
2. What cell structures might the enzyme-producing cells in the pancreas contain? The cells in a muscle?

Section Objective

- 1. Describe the four levels of organization in a multicellular organism.

5-6 Levels of Organization

In order to describe a multicellular organism such as the human, biologists have developed levels of organization. These levels make it easier to classify and describe the cells within an organism. **The levels of organization in a multicellular organism include cells, tissues, organs, and organ systems that make up the organism.**

Tissues

In multicellular organisms, cells—the first level of organization—are organized in specialized groups called **tissues**. A

tissue is a group of similar cells that perform similar functions. Because they are organizations of cells, tissues are the second level of organization. The cells that produce digestive enzymes in the pancreas are one kind of tissue. So are the cells in the eye that respond to light and the cells that line your air passages. Most animals, which are multicellular organisms, have four main types of tissue. They include muscle, epithelial, nerve, and connective tissue.

Organs

Although hundreds or even thousands of cells may be involved in forming a tissue, many tasks within the body are too complicated to be carried out by just one type of tissue. In these cases, an **organ**, or a group of tissues that work together to perform a specific function, is needed. Organs make up the third level of organization. Many types of tissue may be used to form a particular organ. For example, each muscle in your body is an individual organ. However, within a muscle there is a lot more than muscle tissue. There is nerve tissue and connective tissue, a special tissue that connects different parts of the body. Each tissue performs an essential task to help the organ function successfully.

Organ Systems

In many cases, even a complex organ is not sufficient to complete a series of specialized tasks. As a result, an **organ system**, or a group of organs, works together to perform a certain function. Organ systems are the fourth level of organization. There are many organ systems in the body, including the muscular system, the skeletal system, the circulatory system, and the nervous system.

The organization of the cells of the body into tissues, organs, and organ systems makes possible a division of labor among those cells that makes multicellular life possible. Specialized cells such as nerve and muscle cells are able to exist precisely because other cells are specialized to obtain the food and oxygen that those cells need. This overall specialization and interdependence is one of the remarkable attributes of living things. Appreciating this is an important step in understanding the nature of living things.

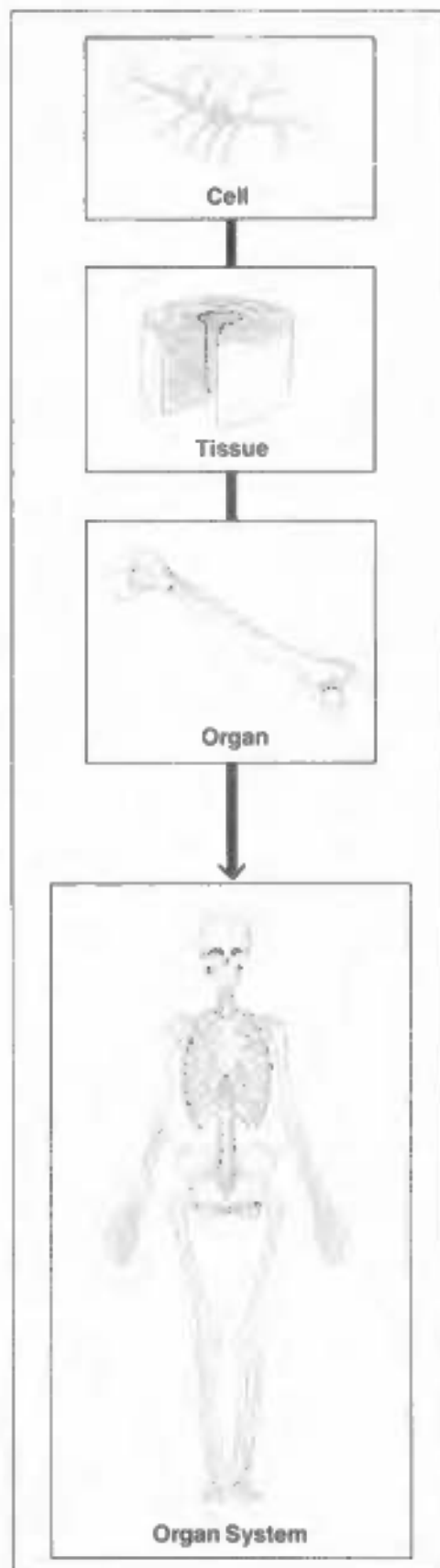


Figure 5-25 This diagram shows four levels of organization in the human body.

5-8 SECTION REVIEW

1. Describe the four levels of organization within most animals.
2. How do an organ and a tissue differ?
3. Why is human blood classified as connective tissue?

LABORATORY INVESTIGATION

OBSERVING OSMOSIS

PROBLEM

How can the process of osmosis be observed?

MATERIALS (per group)

glass-marking pencil	forceps
2 100-mL beakers	medicine
50 mL water	dropper
50 mL saturated sodium	2 glass slides
nitrate solution	teasing needle
scalpel	Lugol solution
small onion	2 coverslips
small potato	microscope

PROCEDURE

1. Using the glass-marking pencil, label one beaker "water" and the other "sodium nitrate." Add the water and sodium nitrate to the appropriately labeled beaker.
2. Using a scalpel, carefully cut the onion into quarters. **CAUTION:** *Be very careful when using a scalpel.* Each quarter will separate neatly into layers. Cut one layer into two pieces of equal size.
3. Again using the scalpel, carefully cut two slices from the potato. The slices should be about 2 to 3 mm in thickness. To determine the flexibility of the pieces of onion and potato, bend them back and forth a few times. Note their flexibility.
4. Place one piece of onion and one slice of potato in each beaker. Allow them to remain undisturbed in the beakers for 30 minutes.
5. After 30 minutes, remove the onion pieces and potato slices from the beakers with forceps. Note the degree of flexibility of each.
6. Return each onion piece and potato slice to its respective beaker.
7. Using a medicine dropper, place a drop of water in the center of a clean glass slide.
8. With the forceps, remove the onion piece from the beaker marked "sodium nitrate."

Remove the thin membrane from the inner surface of the onion by bending the onion inward and lifting the membrane with the forceps. Then place the thin onion membrane in the drop of water on the glass slide.

9. Using the teasing needle, try to flatten the onion membrane as much as you can. Add a drop of Lugol solution to the onion membrane and water. Cover with a coverslip.
10. Observe the onion membrane under the low power of the microscope. Then observe the membrane under high power. Note the appearance of cytoplasm. Draw a labeled diagram of a few onion cells.
11. Repeat steps 7 through 10 using the piece of onion from the beaker marked "water."

OBSERVATIONS

1. What was the degree of flexibility of the onion and potato before they were placed in water and in the sodium nitrate solution?
2. What was the degree of flexibility of the onion and potato after 30 minutes in water? After 30 minutes in the sodium nitrate solution?
3. Describe the differences between the cells of the onion membrane that were placed in water and the cells that were placed in the sodium nitrate solution.

ANALYSIS AND CONCLUSIONS

1. What is the purpose of the Lugol solution?
2. Which beaker contained the higher concentration of water?
3. Relate the degrees of flexibility of the potato and the onion dry, in water, and in the sodium nitrate solution to the process of osmosis.
4. Relate the differences in degrees of flexibility of the onion to the appearance of the cells observed under the microscope.

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

5-1 The Cell Theory

- The cell theory states: All living things are composed of cells; cells are the basic units of structure and function in living things; all cells come from preexisting cells.

5-2 Cell Structure

- Most cells have a cell membrane, nucleus, and cytoplasm.
- Scientists divide cells into eukaryotic cells and prokaryotic cells.

5-3 Cytoplasmic Organelles

- Within the cytoplasm are organelles, or tiny structures that perform specialized functions. They include mitochondria, chloroplasts, ribosomes, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, plastids, and cytoskeleton.

5-4 Movement of Materials Through the Cell Membrane

- Diffusion is the process by which molecules move from areas of higher concentration to areas of lower concentration.
- Active transport is an energy-requiring process that enables material to move across a cell membrane against a concentration difference.

5-5 Cell Specialization

- Cell specialization is the process by which cells are uniquely suited to perform a particular function within the organism.

5-6 Levels of Organization

- In multicellular organisms, such as most animals, cells are organized into tissues, organs, and organ systems.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

5-1 The Cell Theory

cell
cell theory

5-2 Cell Structure

cell membrane
cell wall
nucleus
eukaryote
prokaryote
nuclear envelope
nucleolus

5-3 Cytoplasmic Organelles

chromosome
cytoplasm
organelle
mitochondrion
chloroplast
ribosome
endoplasmic reticulum
Golgi apparatus

lysosome
vacuole
plastid
cytoskeleton

5-4 Movement of Materials Through the Cell Membrane

diffusion
selectively permeable
osmosis

facilitated diffusion
active transport

5-5 Cell Specialization

cell specialization

5-6 Levels of Organization

tissue
organ
organ system

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- The basic unit of structure and function in living things is the
 - cell.
 - tissue.
 - organ.
 - organ system.
- What is the outer boundary of an animal cell called?
 - cell wall
 - nuclear envelope
 - cell membrane
 - cytoplasm
- The control center of the cell is the
 - lysosome.
 - ribosome.
 - mitochondrion.
 - nucleus.
- Organisms whose cells do not have a nucleus are called
 - prokaryotes.
 - eukaryotes.
 - organelles.
 - plants.
- What structure is the site of protein synthesis?
 - nucleus
 - lysosome
 - mitochondrion
 - ribosome
- The process by which molecules of a substance move from areas of higher concentration of that substance to areas of lower concentration is
 - active transport.
 - endocytosis.
 - diffusion.
 - cell specialization.
- Which is an example of active transport?
 - diffusion
 - osmosis
 - endocytosis
 - facilitated diffusion
- A group of similar cells that perform a similar function is called a (an)
 - tissue.
 - organ.
 - organ system.
 - organism.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- Van Leeuwenhoek is given credit for developing the first microscope.
- All cells have a cell wall.
- Eukaryotes are organisms whose cells do not have a nucleus.
- Microtubules are the main components of the cytoskeleton.
- Osmosis is the diffusion of water.
- Facilitated diffusion is a form of active transport.
- Cell specialization is the process by which cells are suited to perform a particular function.
- A group of tissues that work together is called an organ system.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

- cytoplasm, cell membrane, cell wall, nuclear envelope
- diffusion, osmosis, endocytosis, facilitated diffusion
- tissue, ribosome, organ, organ system
- mitochondrion, cytoplasm, ribosome, vacuole

CONCEPT MASTERY

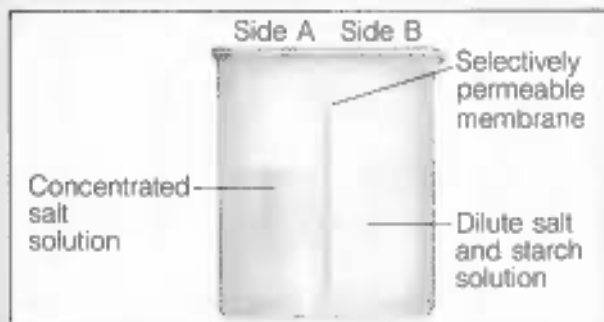
Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. What were the contributions of van Leeuwenhoek, Hooke, Schleiden, Schwann, and Virchow to the development of the cell theory?
2. Why is it important for the cell membrane to be selectively permeable?
3. Describe the makeup of the nucleus.
4. How do materials enter and leave the nucleus?
5. Describe the structure of a mitochondrion. What is its function?
6. What are the functions of vacuoles? How do they differ in plant and animal cells?
7. How do plant and animal cells differ?
8. What is the difference between diffusion and osmosis?
9. What is osmotic pressure? Why is it important?
10. Explain the relationship between cells, tissues, organs, and organ systems.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** The beaker in the diagram has a selectively permeable membrane separating two solutions. Assume that the salt molecules are small enough to pass through the membrane but the starch molecules are too large to pass through. Will the water level on either side of the membrane change? Explain your answer.



2. **Designing an experiment** You are given vegetable coloring and three beakers. The first beaker is filled with water at room temperature, the second beaker is filled with ice water, and the third with hot water. Design an experiment that will enable you to determine the effects of temperature on the rate of diffusion. Be sure to state your hypothesis and to include a control.
3. **Applying concepts** An animal cell contains about 10 to 20 Golgi apparatus, whereas a plant cell contains several hundred. Why do you think there is such a difference in the number of these organelles in each cell type?
4. **Using the writing process** Write a science fiction story entitled: "The Day Diffusion Stood Still."
5. **Using the writing process** One day, unicellular organisms got tired of being called simple organisms by the multicellular organisms. The unicellular organisms felt that they were rather complex individuals and should be recognized as such. In order to gain this recognition, they challenged the multicellular organisms to a debate. Pretend that you are a unicellular organism. What arguments would you use to defend your position?

CHAPTER 6

Cell Energy: Photosynthesis and Respiration



It may seem that little is happening in this peaceful sunny field. However, the trees, flowers, and grasses are actively involved in capturing energy from sunlight and transforming it into energy that can be used by all types of living things.

In contrast to the roar and fury of hurricanes and floods, a gentle sunrise over forest and field seems uneventful. But the movement of sunlight across a landscape is only the first event in the daily struggle of living things to obtain energy. The starting point for that struggle is the energy of sunlight and its conversion to chemical energy.

What kinds of organisms can trap the energy in sunlight? How is that energy changed into a form other organisms can utilize? In this chapter we shall examine these questions and, in so doing, discover one of the most important secrets of life: how organisms capture, store, and transform energy!

CHAPTER OUTLINE

6-1 Photosynthesis: Capturing and Converting Energy

- Photosynthesis
- Requirements for Photosynthesis

6-2 Photosynthesis: The Light and Dark Reactions

- The Light Reactions
- The Dark Reactions

6-3 Glycolysis and Respiration

- Glycolysis—Breaking Down Glucose
- Respiration
- Obtaining Energy from Food
- Breathing and Respiration
- Energy in Balance

6-4 Fermentation

- Lactic Acid Fermentation
- Alcoholic Fermentation

6-1 Photosynthesis: Capturing and Converting Energy

Section Objectives

- Describe the experiments that contributed to the understanding of photosynthesis.
- Discuss the requirements for photosynthesis.

Energy is the ability to do work, and there is always work to be done, even at the level of the cell. In this chapter we will explore some of the ways in which living things capture, convert, store, and use energy. We will concentrate our attention on the way in which energy is used within the individual cell.

Photosynthesis

The study of energy and living things begins with photosynthesis. **In the process of photosynthesis, plants convert the energy of sunlight into the energy in the chemical bonds of carbohydrates—sugars and starches.** Put another way, plants use the energy of sunlight to produce carbohydrates in a process called **photosynthesis**.

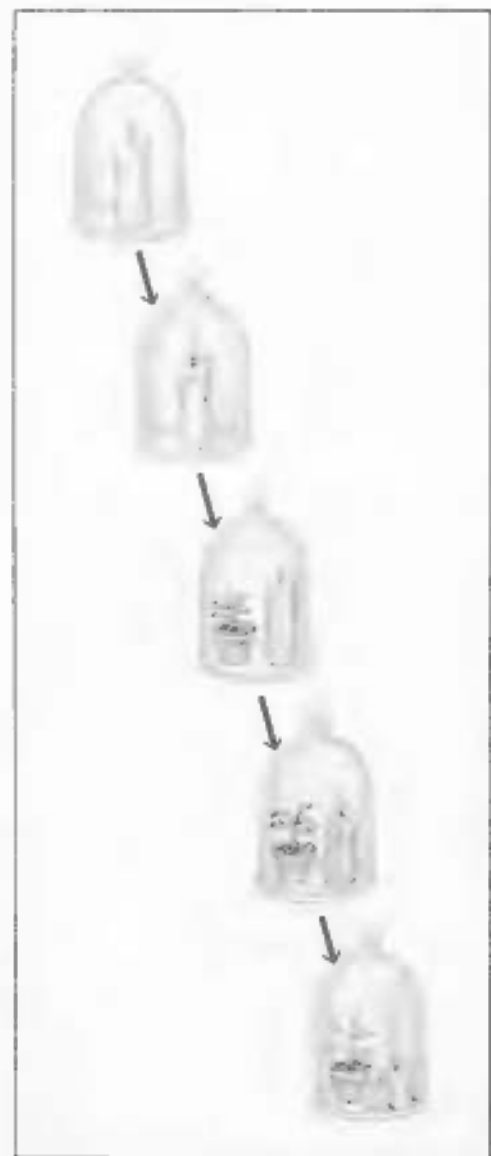
An understanding of photosynthesis was first developed from studies of plant growth. For years gardeners had asked a perplexing question about plant growth: When a seedling with a mass of only a few grams grows into a tall tree with a mass of several tons, where does the tree's increase in mass come from? From the soil? From the water? From the air? In the seventeenth century, the Dutch physician Jan van Helmont devised an experiment to find out.

Figure 6-1 *The very culture of a human society may revolve around the way energy is used to heat homes, cook food, light buildings and streets, and provide for other human needs. In nature, as in human societies, some of the most important activities concern the processes in which energy is produced and distributed.*



Figure 6-2 As a tiny seedling grows into a large tree, it uses water and air to make the chemicals needed for growth.

Figure 6-3 A burning candle soon uses up the oxygen in a glass jar and goes out. In the presence of light, a plant placed inside the jar releases oxygen. This allows the candle to be relighted. The candle continues to burn as long as enough oxygen is available.



Van Helmont carefully found the mass of a pot of dry soil and a small seedling. Then he planted the seedling in the pot of soil. He took care of it and watered it regularly for five years. At the end of five years, the seedling, which by then was a small tree, had gained about 75 kilograms. However, the mass of the soil was almost unchanged. Van Helmont concluded that most of the mass must have come from water because that was the only thing that he had added to the pot.

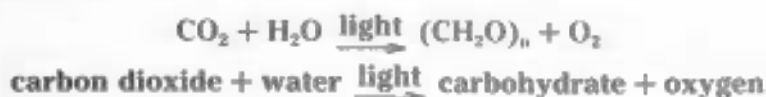
Van Helmont's experiment accounts for the *hydrate*, or water, portion of the carbohydrate produced by photosynthesis. But where does the carbon of the *carbo* portion come from? Although Van Helmont did not realize it, carbon dioxide in the air made a major contribution to the mass of his tree. And it is the carbon in carbon dioxide that is used to make carbohydrates in photosynthesis. Even though Van Helmont had only part of the story, he had made a major contribution to science.

Almost a hundred years after Van Helmont's experiment, Joseph Priestley performed an experiment that would give another insight into the process of photosynthesis. Priestley took a candle, placed a glass jar over it, and watched as the flame gradually died out. Something in the air, Priestley reasoned, was necessary to keep a candle flame burning. When that substance was used up, the candle went out. Today we call this substance oxygen.

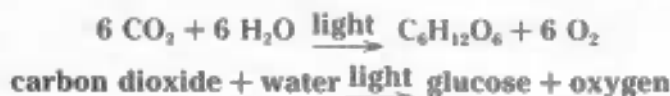
Priestley then found that if he placed a sprig of mint under the jar and allowed a few days to pass, the candle could be relighted and would remain lighted for a while. The mint plant had produced the substance required for burning. In other words, it released oxygen. Later, the Dutch scientist Jan Ingenhousz showed that the effect observed by Priestley occurred only when the plant was exposed to light. This means that light is necessary for plants to produce oxygen.

Requirements for Photosynthesis

The experiments performed by Van Helmont, Priestley, Ingenhousz, and other scientists reveal that in the presence of light, plants transform carbon dioxide and water into carbohydrates and release oxygen. This gives us the basic outline of the process of photosynthesis:



Because photosynthesis usually produces a particular carbohydrate—the sugar **glucose** ($\text{C}_6\text{H}_{12}\text{O}_6$)—we can rewrite and balance the equation for photosynthesis as follows:

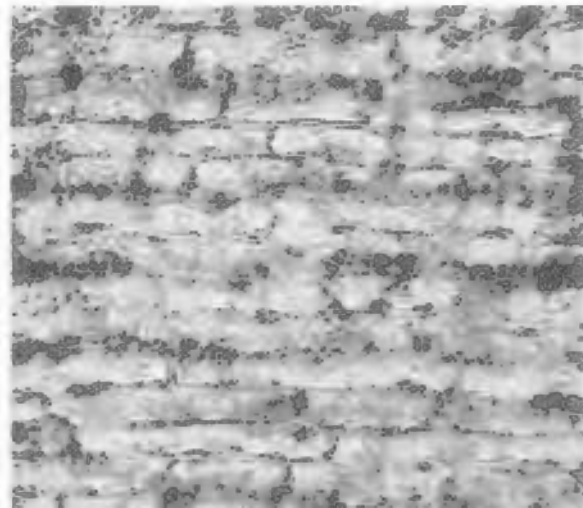


Do not be fooled by how simple this equation looks. In photosynthesis, a great deal happens between the beginning and the end of the equation. You do not get glucose and oxygen just by putting water and carbon dioxide together. Let us, then, examine some of the other requirements of photosynthesis.

SUNLIGHT Nearly all organisms on Earth depend on the sun for energy. Some organisms, such as green plants, can use the sun's energy directly. As a result, green plants are called **autotrophs** (AW-toh-trohfs). Autotrophs are organisms that are able to use a source of energy, such as sunlight, to produce food directly from simple inorganic molecules in the environment. Other organisms, such as animals, cannot use the sun's energy directly. These organisms, known as **heterotrophs**, (HEHT-er-oh-trohfs) obtain energy from the foods they eat. Heterotrophs may eat autotrophs, other heterotrophs, or both.

The sun bathes the Earth in a steady stream of light. What our eyes perceive as colorless “white” light is actually a mixture of different wavelengths of light. Many of these wavelengths are visible to our eyes and make up what is known as the visible spectrum. Our eyes perceive the different wavelengths of the visible spectrum as different colors.

Figure 6-4 Plant pigments absorb some wavelengths of light and reflect others. Our eyes perceive the reflected wavelengths as different colors (left). Chlorophyll—the principal photosynthetic pigment of green plants—gives the chloroplasts in these plant cells their characteristic color (right).



Absorption of Light by Chlorophyll *a* and Chlorophyll *b*

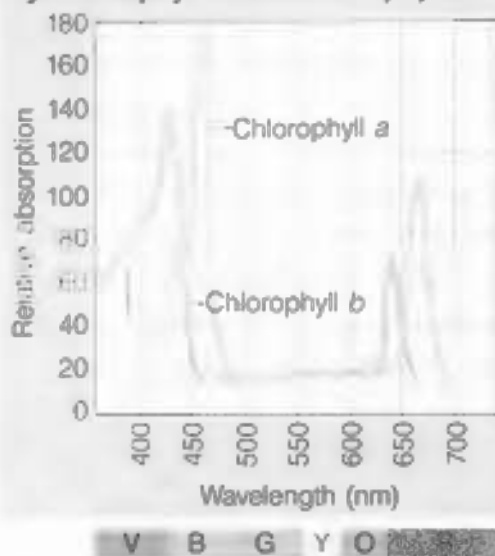


Figure 6-5 Chlorophyll absorbs red and blue light quite well. Different forms of chlorophyll have their peak absorption at different wavelengths of light.

PIGMENTS The process of photosynthesis begins when light is absorbed by **pigments** in the plant cell. Pigments are colored substances that absorb or reflect light. The principal pigment of green plants is known as **chlorophyll**. As you can see from the graph in Figure 6-5, chlorophyll absorbs red and blue light but does not absorb light in the middle region of the spectrum very well. Instead, it reflects these wavelengths.

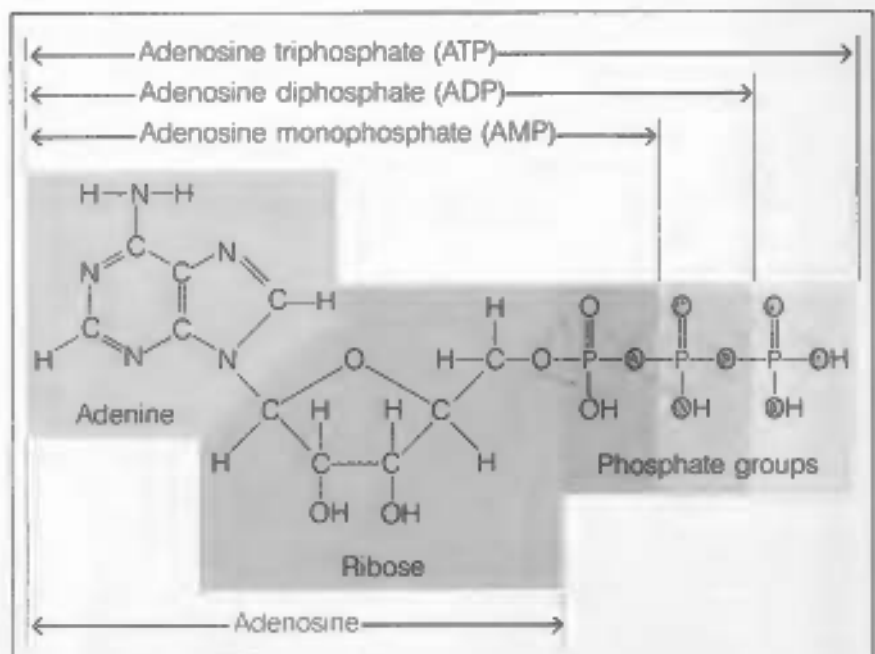
ENERGY-STORING COMPOUNDS Because energy is involved in the formation of chemical bonds, the production of certain compounds can be used to store energy in chemical form. The most important energy-storing compound—one used by every living cell—is **adenosine triphosphate**, or **ATP**. As you can see in Figure 6-6, an ATP molecule consists of a nucleotide called **adenine**, a 5-carbon sugar called **ribose**, and three phosphate groups. Energy can be stored when a phosphate group, abbreviated as **P**, is bonded to adenosine monophosphate (AMP) to produce adenosine diphosphate (ADP). And still more energy can be stored when a third phosphate group is added to ADP to produce ATP. The bonds between the phosphate groups are the key to ATP's energy-storing qualities. Each of these two bonds is capable of storing chemical energy—energy that is released when the bonds are broken.

Some of this stored energy is released when the third phosphate group is split from ATP to produce ADP. Energy is also released when ADP is broken down to AMP.



Enzymes control the synthesis and breakdown of ATP within the cell. These enzymes enable ATP to be produced from

Figure 6-6 Adenosine triphosphate, or ATP, is the most important energy-storing compound in living things.



energy-releasing reactions and allow ATP to be used as a source of energy for reactions that require energy. ATP provides energy for a large number of cellular activities, including muscle contraction, protein synthesis, and active transport across cell membranes. During photosynthesis, the ATP produced by the first part of the process is used to provide energy for the second part.

6-1 SECTION REVIEW

1. Define photosynthesis.
2. What did Van Helmont's experiment prove about the source of material for plant growth? What did it not prove?
3. What is ATP?
4. Why is chlorophyll's efficiency in absorbing light energy important for photosynthesis?

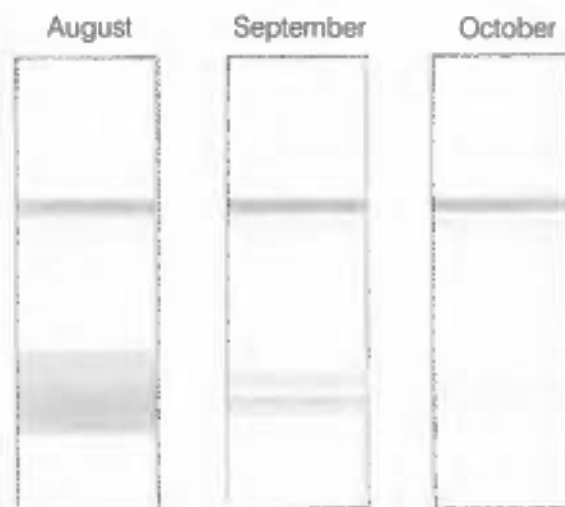
PROBLEM SOLVING IN BIOLOGY

THE COLORS OF AUTUMN

In many parts of the country, the beautiful colors of autumn leaves provide inspiration to artists and poets as the countryside turns into a lovely blaze of red, orange, and yellow. What is the source of these colors? Do plants produce them in response to the changing of the seasons?

The pigments in plant cells, including chlorophyll, can be separated from one another by a technique known as paper chromatography. Study the results of the paper chromatography experiment shown on this page. The green chlorophyll spots, red-orange carotene spots, and yellow xanthophyll spots are labeled on samples taken from the leaves of a single maple tree in August, September, and October.

Using these three chromatographs as evidence, can you explain what seems to happen as the leaves change color as summer ends and autumn begins?



Paper chromatography is based on the fact that different substances (such as plant pigments) in a solvent will move through a piece of paper at different rates.

Section Objectives

- Discuss the light reactions of photosynthesis.
- Relate the dark reactions of photosynthesis to the light reactions.

6-2 Photosynthesis: The Light and Dark Reactions

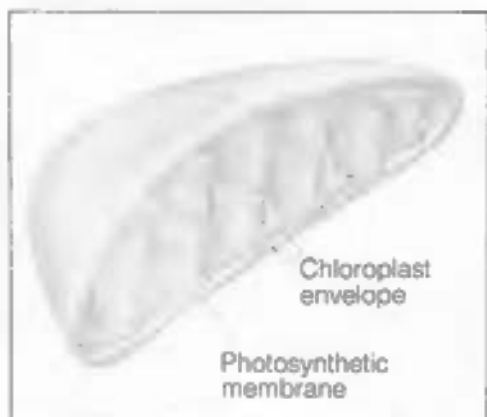
The process of photosynthesis is divided into two parts: the **light reactions** and the **dark reactions**. As their name implies, the light reactions require light. **In the light reactions, the energy of sunlight is captured and used to make energy-storing compounds.** The dark reactions do not require light and thus are also called nonlight or light-independent reactions. However, the dark reactions can—and do—occur in the light. The dark reactions use the energy stored by the light reactions to make glucose.

Photosynthesis takes place in an organelle known as the chloroplast. Within the chloroplast are saclike **photosynthetic membranes** that contain chlorophyll. As you can see in Figure 6-8, the light reactions occur in the photosynthetic membranes, whereas the dark reactions occur outside the photosynthetic membranes.

The Light Reactions

The light reactions absorb the energy of sunlight and convert it to the energy that is stored in chemical bonds. This process occurs very rapidly. However, the light reactions can be divided into four basic processes: light absorption, electron transport, oxygen production, and ATP formation. These processes are closely linked and are dependent on one another. As you examine the light reactions in more detail, keep in mind that these processes occur nonstop in green plants as long as the sun shines.

Figure 6-7 The chloroplast is the site of photosynthesis. The light reactions take place in the saclike photosynthetic membranes. The dark reactions take place in the areas surrounding the photosynthetic membranes.



LIGHT ABSORPTION The photosynthetic membrane contains clusters of pigment molecules, or **photosystems**, that are able to capture the energy of sunlight. There are two photosystems in green plants: photosystem I and photosystem II. See Figure 6-8.

Each photosystem contains several hundred chlorophyll molecules, as well as a number of accessory pigments. These accessory pigments absorb light in the regions of the spectrum where chlorophyll does not and thus allow more of the available light energy to be used. The absorption of light causes electrons in a pigment molecule to be raised to a higher level, an "excited" state. This excitation energy is then passed from one pigment molecule to another until it reaches a special pair of chlorophyll molecules. Although all the photosystem pigments can absorb light, only the special pair of chlorophyll molecules can process the light energy. The special pair of chlorophyll molecules are surrounded by an apparatus that enables the excitation energy to be captured in chemical form.

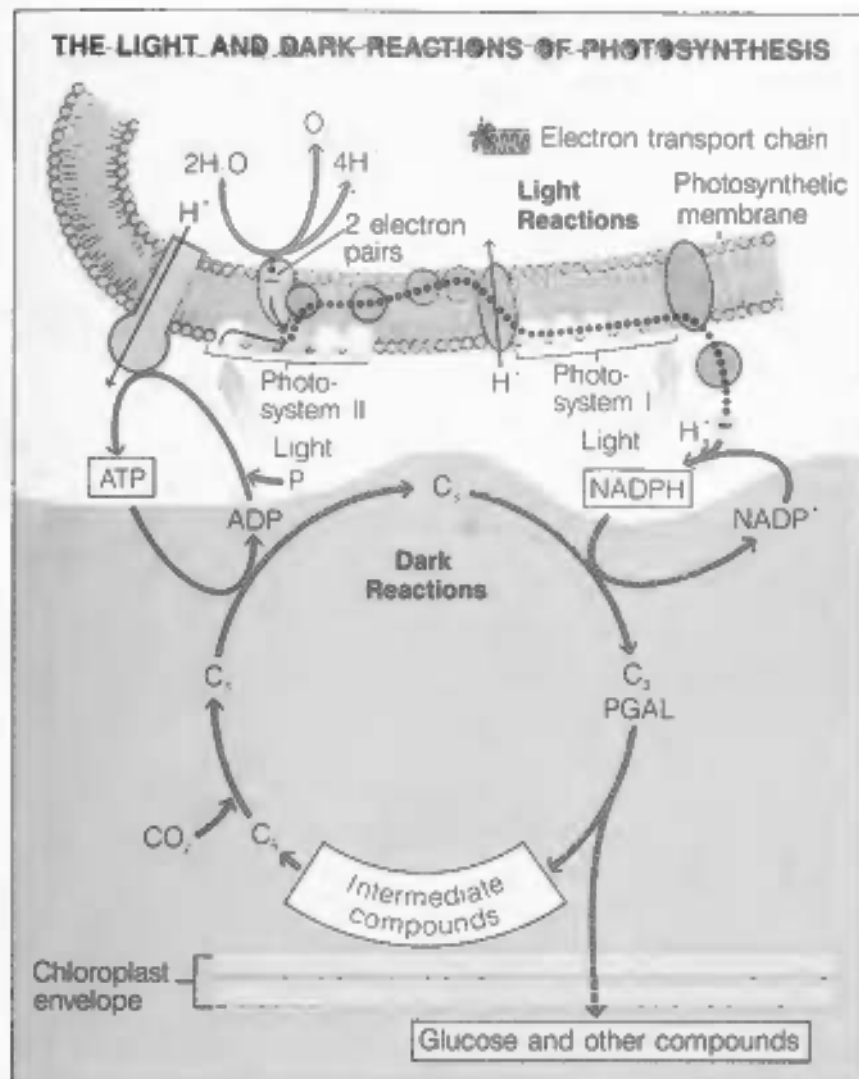


Figure 6-8 Clusters of pigment molecules known as photosystems are embedded in the photosynthetic membrane. Photosystems capture the energy of sunlight, which is used to make energy-storing compounds. The energy in these compounds, in turn, is used to make biologically important compounds such as glucose.

ELECTRON TRANSPORT The high-energy electrons produced by light travel from the special pair of chlorophyll molecules to an adjacent molecule called an electron carrier. This begins a process known as **electron transport**.

The high-energy electrons are transferred along a series of electron-carrier molecules in the photosynthetic membrane

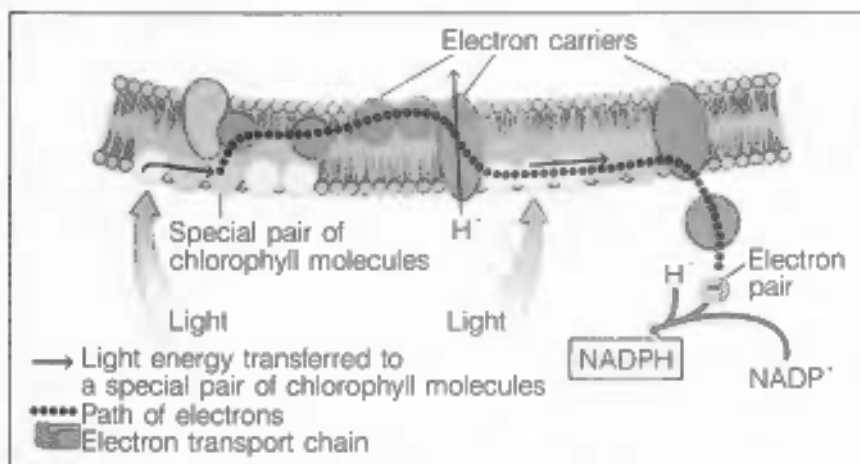


Figure 6-9 The high-energy electrons produced by light are transferred from chlorophyll to the electron transport chain. The electrons are passed from one carrier in the chain to the next. At the end of the chain, they are used to make the energy-storing compound NADPH.

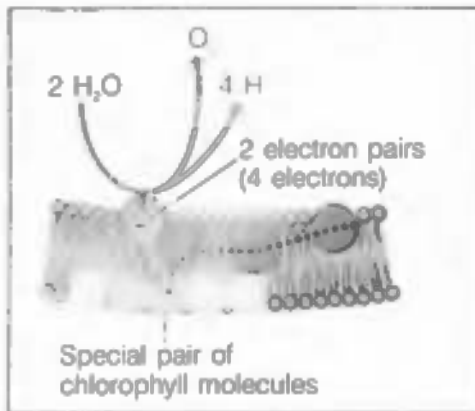


Figure 6-10 The breakdown of water produces electrons that replace the electrons lost by the special pair of chlorophyll molecules. This process also results in the formation of hydrogen ions and oxygen gas.

known as the electron transport chain. Electrons are passed from one carrier to another almost as pails of water are passed from one person to the next in a bucket brigade.

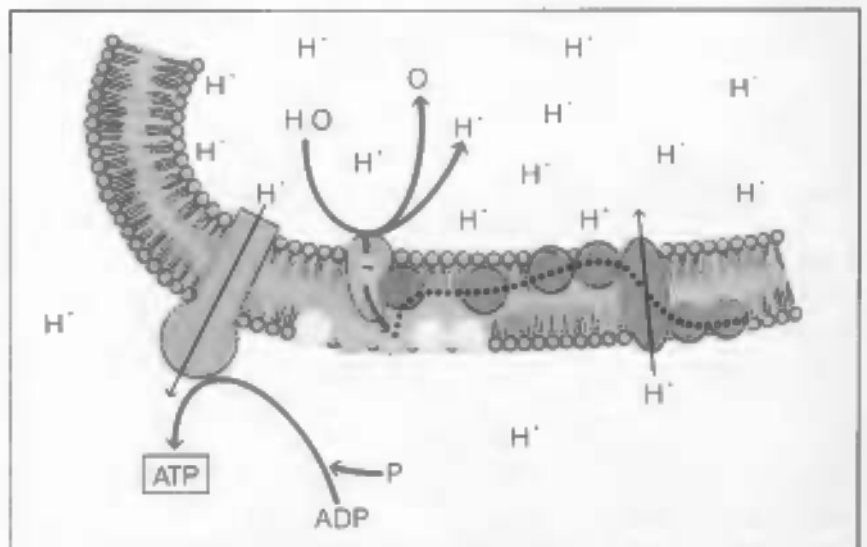
At the end of the chain is an enzyme that passes the high-energy electrons to an electron carrier called NADP^+ , converting it to NADPH . Adding a pair of electrons to this electron carrier requires energy. This is the first way in which part of the energy of sunlight is trapped in chemical bonds. The electrons and energy stored in the bonds of NADPH will be used later on.

OXYGEN PRODUCTION As the light continues to shine, what happens to chlorophyll? Does it run out of electrons? No. The photosynthetic membrane contains a system that provides new electrons to chlorophyll to replace the ones that wound up in NADPH . These electrons are taken from water. Four electrons are removed from 2 water molecules (H_2O), leaving 4 hydrogen ions (H^+) and 2 oxygen atoms (O). The 2 oxygen atoms form a single molecule of oxygen gas (O_2) that leaves the chloroplast and is eventually released into the air.

ATP FORMATION The hydrogen ions left behind when water is “split” are released inside the photosynthetic membrane. In addition, as electrons are passed from chlorophyll to NADP^+ , more hydrogen ions are pumped across the membrane. After a while, the inside of the membrane fills up with positively charged hydrogen ions. This makes the outside of the photosynthetic membrane negatively charged and the inside positively charged.

The difference in charges across the membrane is a source of energy. An enzyme in the photosynthetic membrane makes use of this energy to attach a phosphate molecule to ADP , forming ATP . This is the second way in which the energy of sunlight is trapped in chemical form.

Figure 6-11 The buildup of hydrogen ions (produced in the breakdown of water) inside the photosynthetic membrane produces a difference in charges across the membrane. This powers the formation of the energy-storing compound ATP .



A SUMMARY OF THE LIGHT REACTIONS As we have seen, the light reactions use water, ADP, and NADP^+ ; they produce O_2 (which is of no help in photosynthesis but is of great use to us!) and the energy-storing molecules ATP and NADPH. The next stage of photosynthesis, the dark reactions, will convert these energy-storing molecules to a more convenient form.

The Dark Reactions

Do not be confused by the term dark reactions. The dark reactions generally take place in sunlight. However, light does not play a role in the dark reactions. If ATP and NADPH are supplied, the dark reactions can be carried out in a test tube, even in total darkness and without ever being exposed to light!

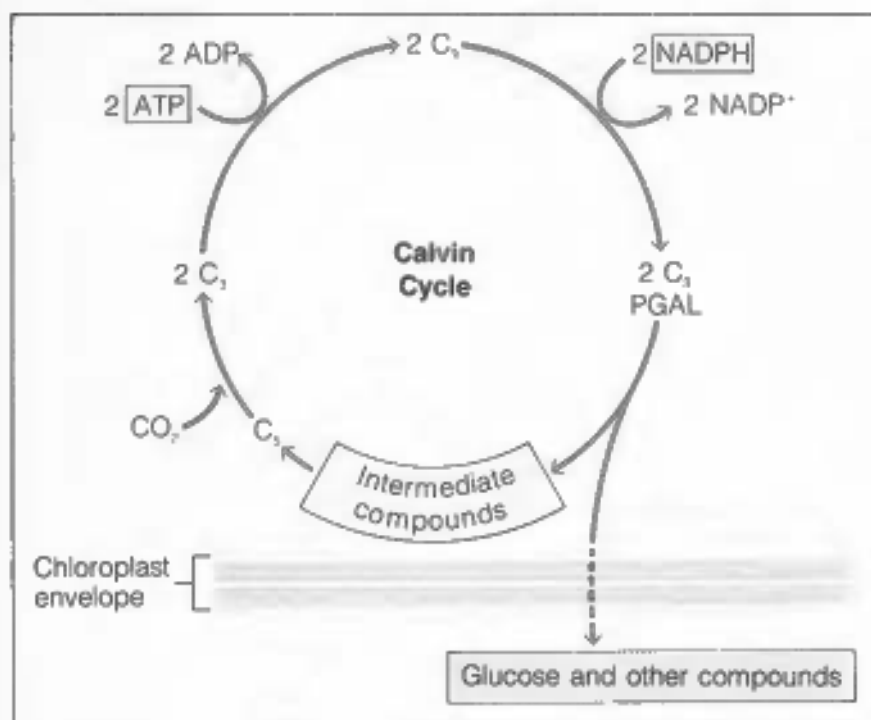


Figure 6-12 The dark reactions use carbon dioxide and the energy-storing compounds produced in the light reactions to form PGAL. PGAL is a chemical "building block" that can be used to make other organic compounds, such as the sugar glucose.

The series of chemical changes that make up the dark reactions is particularly critical to living things. In this part of photosynthesis, the simple inorganic molecule carbon dioxide is used to make a complex organic molecule. This molecule can be thought of as a building block that can be used to make other biologically important molecules, including glucose. The dark reactions form a cycle, or circular series of reactions. Because the chemistry of this remarkable cycle was worked out by the American scientist Melvin Calvin, the dark reactions are also known as the **Calvin cycle**.

Throughout this description of the Calvin cycle, you will find it helpful to refer to Figure 6-12. In the first reaction of the Calvin cycle, a 5-carbon sugar (C_5) combines with CO_2 to form two 3-carbon compounds (C_3). The first reaction of the Calvin

cycle tends to be relatively slow. In order to compensate for this, the chloroplast is loaded with an enzyme that catalyzes this reaction. This enzyme is known as rubisco. There is far more rubisco in an active plant cell than any other protein molecule. Because there are many more plant cells than animal cells on Earth, we can make a remarkable statement about rubisco: It is the most abundant protein in the world!

In the next two reactions of the Calvin cycle, using the chemical energy available in ATP and NADPH, these 3-carbon compounds are converted to PGAL (phosphoglyceraldehyde). Most PGAL molecules are recycled for the dark reactions, but 1

SCIENCE, TECHNOLOGY, AND SOCIETY

BREAKTHROUGH

"If at First You Don't Succeed . . ."

In the dark reactions of photosynthesis, simple inorganic molecules are used to form organic molecules—food—that can be used by living things. The process of putting carbon into a form that can be used by living things is known as carbon fixation. Although carbon fixation in photosynthesis is crucial to living things, this process remained a mystery until the late 1940s.

It was obvious that the key to understanding the chemical steps of the dark reactions—and carbon fixation—was to find the very first molecule into which CO_2 was fixed, or used to make an organic molecule. But how do you trace the path of a molecule in a chemical reaction? And how can you tell that a particular molecule is really the one you want to observe?

Working at the University of California at Berkeley in 1946, Melvin Calvin and his associates decided to use newly discovered carbon-14, a radioactive isotope of carbon, in their experiments on carbon fixation. They reasoned that the molecule that fixed carbon dioxide would become radioactive when it joined with radioactive carbon dioxide, or carbon dioxide that contained carbon-14. How-

ever, when radioactive CO_2 was added to growing plants, within a few minutes nearly every type of carbon-containing molecule in the plant was radioactive. So it was back to the drawing board for the scientists.



Melvin Calvin worked out the chemistry of the dark reactions of photosynthesis.

Melvin Calvin and his associate John Bassham decided that if carbon was fixed quickly, they would have to act quickly. They put a suspension of green algae into a special flask, injected radioactive CO_2 into it, flashed a bright light at it, and opened a valve at the bottom of the flask. The algae cells dropped suddenly into a beaker of boiling alcohol, which killed the cells and stopped photosynthesis instantly.

The molecules associated with carbon fixation, however, were preserved. This approach allowed Calvin and his associates to identify phosphoglyceric acid, a 3-carbon compound, as the product of the first reaction in carbon fixation.

The determination of these scientists to perform a difficult experiment produced the first (and most important) clue in working out the process of carbon fixation. Calvin and his associates continued their work, described the dark reactions, and made a major contribution to our understanding of photosynthesis.

out of every 6 is used to make glucose or other end products. How many times must the Calvin cycle go around to produce 1 molecule of glucose? (Hint: The formula for glucose is $C_6H_{12}O_6$.)

Although we have emphasized the production of glucose in the Calvin cycle, the intermediate compounds of the cycle are also important because they can be used by the chloroplast in many ways. Some of the intermediates may be used to form sugars other than glucose; some of them may be used to make amino acids; and some can be converted to lipids. The dark reactions of photosynthesis provide the raw materials to produce almost everything the cell needs.

6-2 SECTION REVIEW

1. What are the products of the light reactions?
2. Where in the cell do the light reactions take place? The dark reactions?
3. Describe the Calvin cycle. Why are the light reactions important to the Calvin cycle?

6-3 Glycolysis and Respiration

The ability of autotrophs to produce glucose and other food molecules reflects the fact that photosynthesis is able to trap some of the energy of sunlight in chemical bonds. In a way, the energy stored by photosynthesis is like money deposited in a savings account: It is available for future needs. But organisms—autotrophs and heterotrophs alike—must be capable of making “withdrawals” from that savings account; that is, they must be able to release energy by breaking down food molecules. In this section we will examine two processes used to release energy from glucose.

Glycolysis—Breaking Down Glucose

Glucose ($C_6H_{12}O_6$) is a simple 6-carbon sugar. If glucose is broken down completely in the presence of oxygen, carbon dioxide and water are produced:



This reaction gives off 3811 **calories** per gram of glucose. A calorie is the amount of heat energy required to raise the temperature of 1 gram of water 1 degree Celsius. As you can see, glucose obviously contains a lot of energy. (Those of you who watch your calories should not be alarmed. The Calorie associated with food and diet books is actually a kilocalorie, which is equal to 1000 calories.)

Section Objectives

- Discuss the process of glycolysis.
- Describe respiration.
- Explain how breathing is related to respiration.

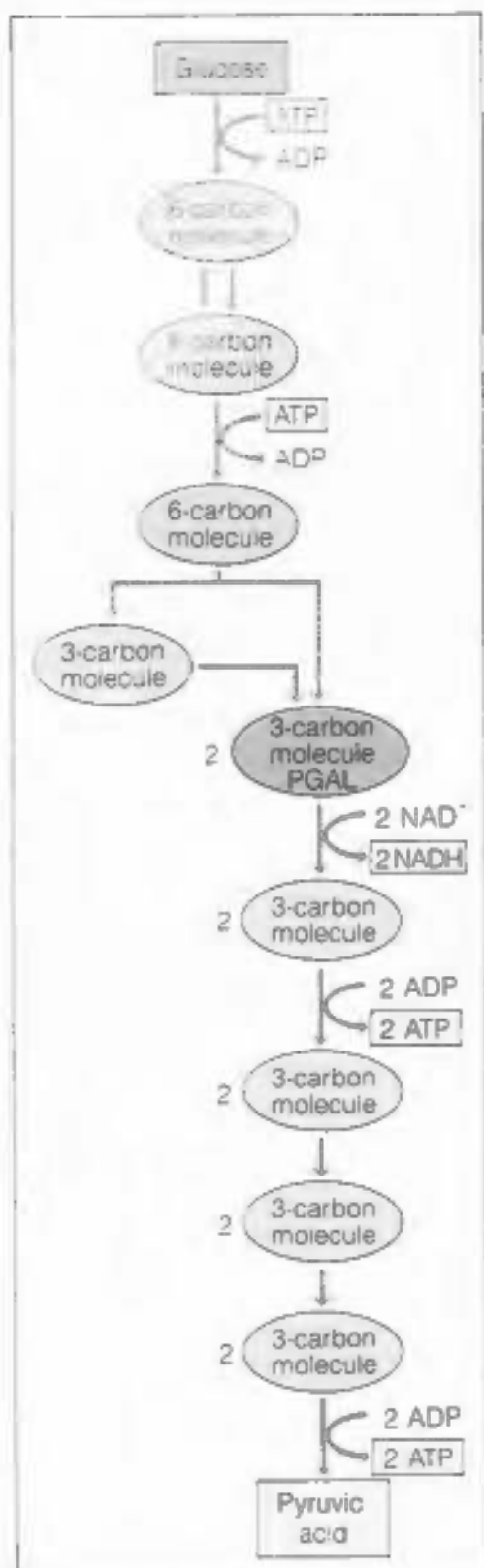


Figure 6-13 In the process of glycolysis, glucose is broken down and transformed into other molecules. In addition, energy is released in the form of 2 molecules of ATP.

A cell takes apart glucose slowly and captures the energy a little at a time. Remember, the energy stored in chemical bonds can be used when the bonds are broken. The first stage in this process is known as **glycolysis** (glic-KAHL-ih-sihs), which means glucose-breaking. Glycolysis takes place in the cytoplasm of a cell. In glycolysis, a series of enzymes catalyzes chemical reactions that change glucose, one step at a time, into different molecules.

In the first step, a glucose molecule undergoes several chemical reactions that ultimately split the 6-carbon sugar into two 3-carbon PGAL molecules. See Figure 6-13. Two molecules of ATP are used up in the process. This means that the cell must use up a bit of its stored chemical energy to begin the breakdown of glucose.

Several more chemical steps then occur that transform the 2 PGAL molecules into 2 molecules of pyruvic acid, a 3-carbon compound. The energy from the 2 PGAL molecules is used to make 4 molecules of ADP and 2 molecules of NADH. NADH is an energy-storing compound similar to the NADPH that is formed in the light reactions of photosynthesis.

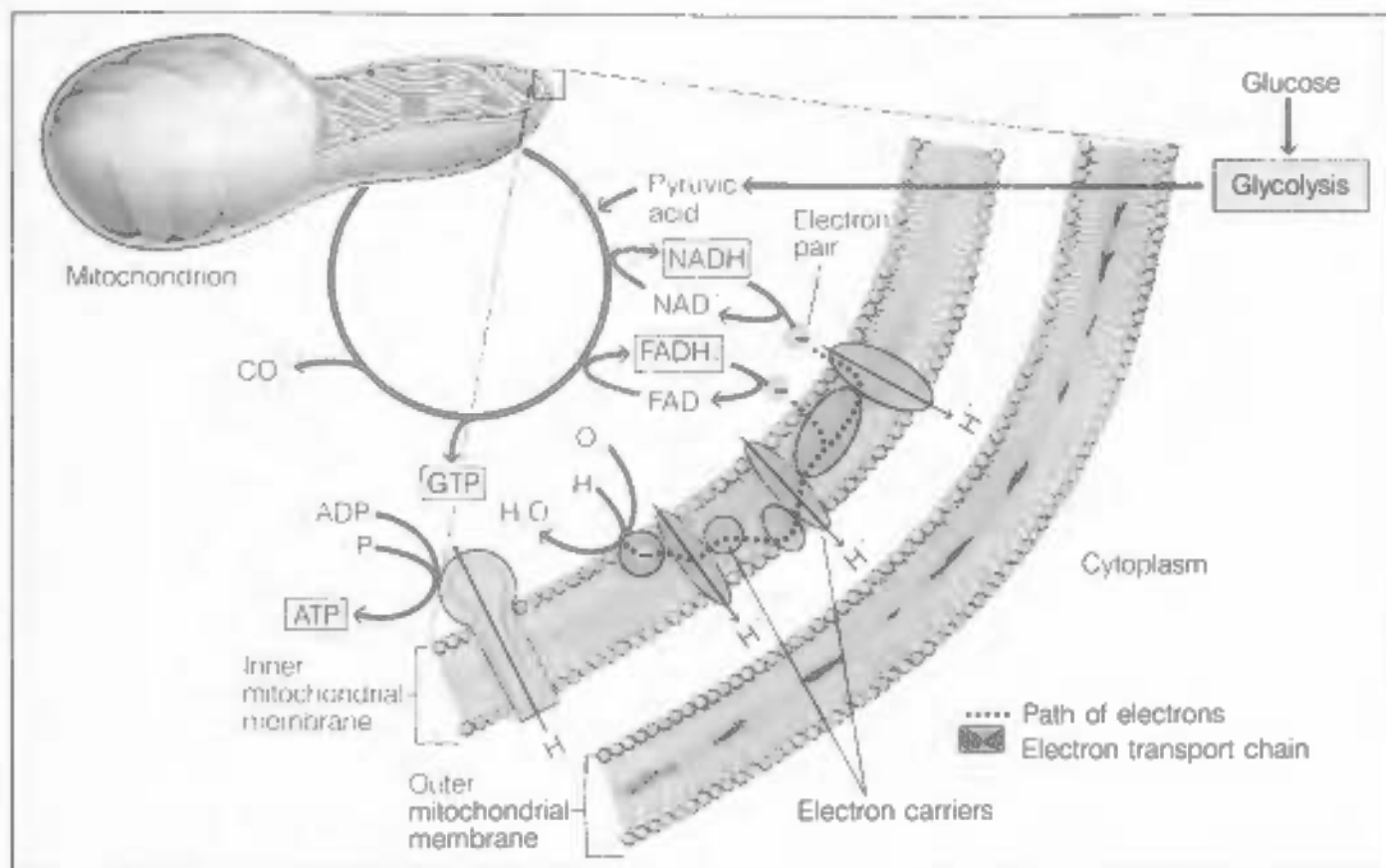
In the process of glycolysis, 4 molecules of ATP are synthesized from 4 molecules of ADP. Because 2 ATP molecules are used to start the process, we can do a little arithmetic and conclude that there is a net gain of 2 molecules of ATP during glycolysis.

The 2 ATP molecules produced in glycolysis represent no more than 2 percent of the total chemical energy in glucose. What happens to the rest? The answer depends on the presence of oxygen.

Respiration

If oxygen is available, a process known as **respiration** can take place. Because it requires oxygen, respiration is called an **aerobic** process. The word aerobic means with air—specifically, the part of the air called oxygen. **Respiration is the process that involves oxygen and breaks down food molecules to release energy.** Respiration uses the pyruvic acid formed in glycolysis. In breaking down pyruvic acid, respiration captures much of the remaining energy from glucose in the form of 34 additional molecules of ATP.

The term respiration may have a familiar ring. It is often used as a synonym for breathing. Because of this, some biologists use the term cellular respiration instead of respiration to refer to energy-releasing pathways within the cell. The double meaning of respiration points out a crucial connection between cell and organism: The energy-releasing respiratory pathways within the cells require oxygen, which animals take in by breathing—another type of respiration. Although plants do not breathe in the usual sense, they also need to take in oxygen for cellular respiration.



Respiration, like photosynthesis, is associated with a cell organelle. The chemical reactions of respiration take place in a cell's mitochondria. Recall from Chapter 5 that a mitochondrion consists of two membranes, an outer membrane and a folded inner membrane. The first set of reactions in respiration takes place in the area enclosed by the inner membrane. The second set of reactions takes place within the inner membrane itself. See Figure 6-14.

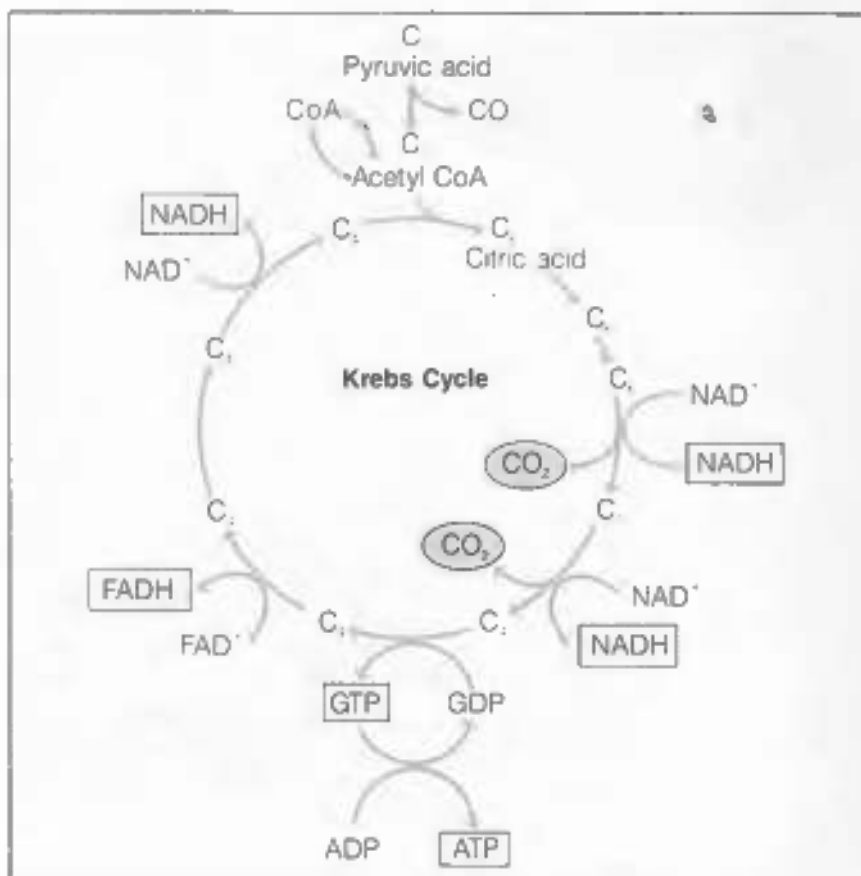
THE KREBS CYCLE The first set of reactions in respiration is the **Krebs cycle**, which is named for its discoverer, Hans Krebs. Unlike glycolysis, the Krebs cycle does not produce a final end product. Instead, it is a continuing series of reactions.

The pyruvic acid produced during glycolysis travels from the cytoplasm to the mitochondrion. In the first reaction of respiration, pyruvic acid is broken down into carbon dioxide and a 2-carbon compound called acetic acid. Acetic acid, bound to a carrier molecule called coenzyme A (CoA), enters the Krebs cycle by reacting with a 4-carbon compound to produce citric acid, a 6-carbon compound. Because citric acid is the first compound formed in this series of reactions, the Krebs cycle is known as the citric acid cycle.

There are nine reactions and nine intermediates in the Krebs cycle. At two places in the cycle, CO₂ is released. At four places in the cycle, a pair of high-energy electrons are

Figure 6-14 Respiration, an aerobic process, takes place in the mitochondrion. The Krebs cycle takes place in the area enclosed by the inner mitochondrial membrane. Electron transport and ATP formation involve complex molecules embedded in the inner membrane.

Figure 6-15 The Krebs cycle, a continuing series of nine reactions involving nine intermediate compounds, produces carbon dioxide and energy-storing compounds.



accepted by electron carriers, changing NAD^+ to NADH and FAD to FADH_2 . See Figure 6-15. At one place in the cycle, a molecule of GDP (similar to ADP) is converted to GTP (similar to ATP). The GTP may then be used to make ATP from ADP . We can summarize the events in the Krebs cycle as follows:

- 2 carbon atoms added (from the breakdown of pyruvic acid)
- 2 carbon atoms removed (in 2 molecules of CO_2)
- 3 molecules of NAD^+ converted to NADH
- 1 molecule of FAD converted to FADH_2
- 1 molecule of GDP converted to GTP

Step by step, the carbon atoms in glucose wind up as carbon dioxide. The carbon dioxide produced by the Krebs cycle is a waste product that is released from the cell. But what does the cell do with the other products of the Krebs cycle: NADH and FADH_2 ? And where does oxygen fit into the process?

ELECTRON TRANSPORT IN THE MITOCHONDRION

The high-energy electrons from NADH and FADH_2 are passed to a series of electron transport enzymes in the inner membrane of the mitochondrion. These enzymes form an electron transport chain along which electrons are passed. At the end of this chain is an enzyme that combines electrons from the electron

transport chain, hydrogen ions (H^+) from the fluid inside the cell, and oxygen (O_2) to form water (H_2O). This is where oxygen comes in. Oxygen is the final electron acceptor in the process of respiration. Thus, oxygen is essential for obtaining energy from both NADH and $FADH_2$.

ATP FORMATION Recall that the photosynthetic electron transport chain was associated with the movement of hydrogen ions (H^+) across the photosynthetic membrane in the chloroplast. Electron transport in the mitochondrion causes a similar movement of hydrogen ions. As they accept electrons, some of the enzymes in the electron transport chain pump a hydrogen ion from the inside of the inner membrane to the outside. As in photosynthesis, the movement of hydrogen ions powers the formation of ATP. On average, the movement of a pair of electrons down the electron transport chain produces enough energy to form 3 ATP molecules from ADP.

Electron transport produces a difference in electric charge across the membrane. There are more hydrogen ions outside the inner membrane of the mitochondrion than inside it. Thus, the outside of the membrane is more positively charged than the inside. The difference in charge created by the imbalance of hydrogen ions supplies the energy to make ATP from ADP.

Like the photosynthetic membrane, the inner mitochondrial membrane has two special properties that make this process work: The electron transport chains in the membrane are arranged so that hydrogen ions are pumped in one direction across the membrane; and the membrane does not allow ions to "leak" back across (otherwise there would not be enough of a charge difference to provide energy for ATP synthesis).

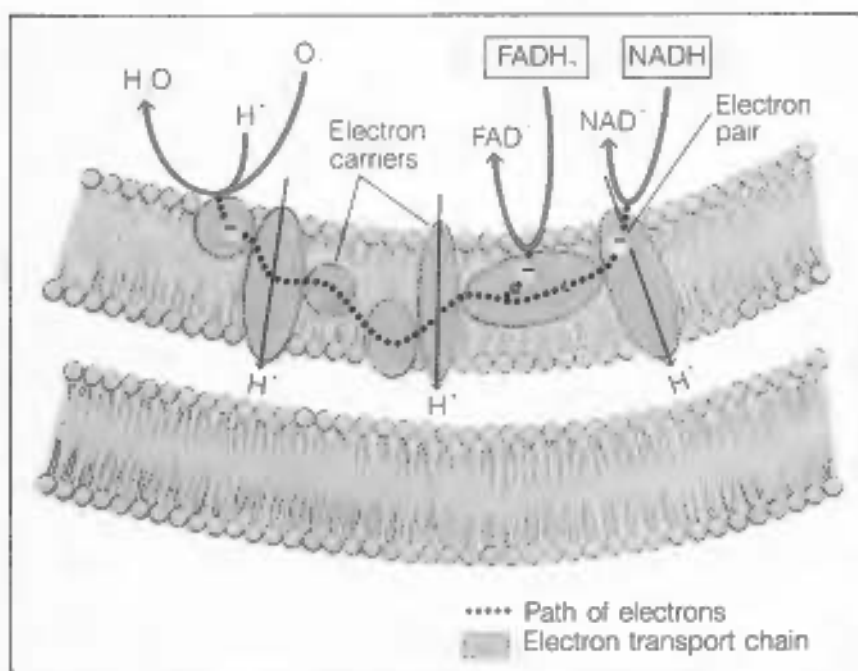
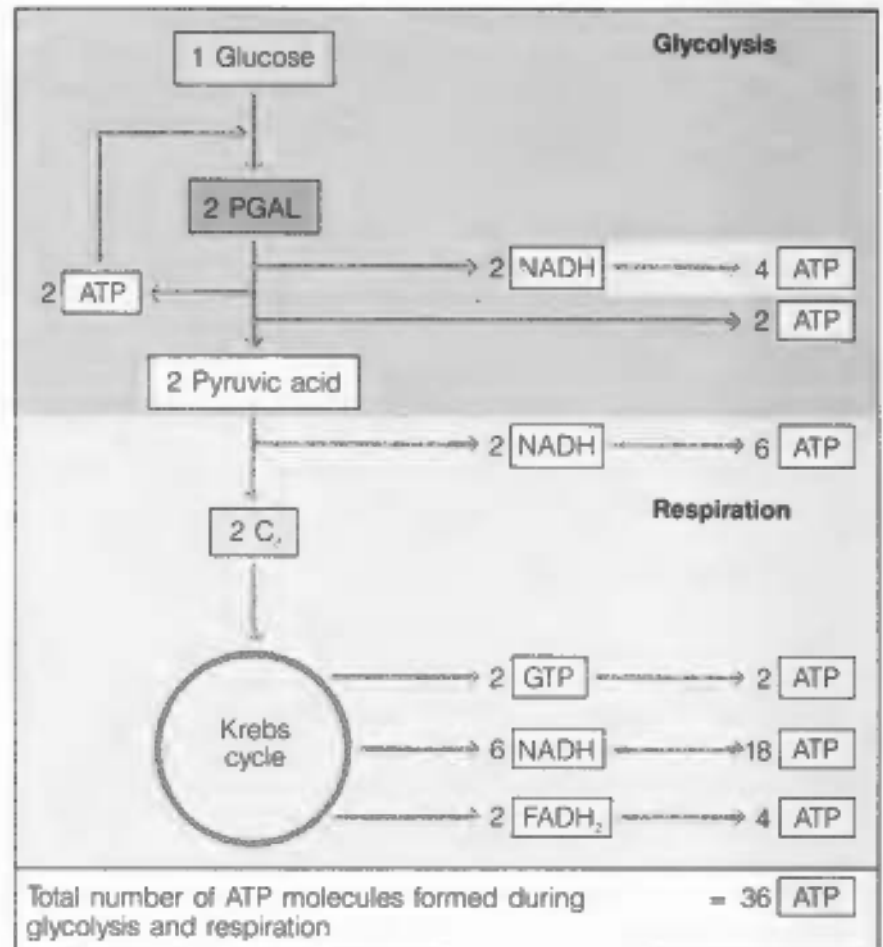


Figure 6-16 The high-energy electrons in the energy-storing compounds NADH and $FADH_2$ are transferred to the molecules of the electron transport chain, which is located in the inner mitochondrial membrane. At the end of the chain, the electrons react with hydrogen ions and oxygen to form water.

Figure 6-17 The complete breakdown of glucose through glycolysis and respiration results in the production of chemical energy in the form of 36 molecules of ATP.



THE TOTALS How much chemical energy is produced by the complete breakdown of glucose? Remember, glycolysis produces a net gain of 2 ATP molecules and passes high-energy electrons to 4 NADH molecules. The energy in these NADH molecules can be used to form 10 ATP molecules. In respiration, 6 more NADH, 2 GTP, and 2 FADH₂ molecules are produced in the Krebs cycle. The energy in the 2 GTP molecules can be used to form 2 ATP molecules. The electron transport chain uses the electrons in NADH and FADH₂ to produce 22 ATP molecules. See Figure 6-17. When the results of each of these biochemical pathways are considered, we find that a total of 36 molecules of ATP are produced from each glucose molecule. The energy in these 36 ATP molecules is about 37 percent of the total chemical energy available in glucose. That might not sound very impressive. However, the process of respiration is more efficient than the average automobile engine when it comes to converting fuel to usable energy.

Obtaining Energy from Food

Obviously very few of us eat a diet composed exclusively of glucose. But how is energy produced from foods other than glucose?

Complex carbohydrates are broken down into simple sugars that are then converted into glucose. At that point, the pathways we have discussed in this chapter can be used to produce energy. Most lipids and many proteins can be broken down into molecules that can enter glycolysis or the Krebs cycle at one of several places. Like a furnace that can burn wood, coal, or oil, the cell can generate chemical energy in the form of ATP from just about any source.

Breathing and Respiration

After all of this chemical detail, it is reasonable to point out why we have used the term respiration to refer to energy-releasing pathways. Remember that the final acceptor for all electrons produced in respiration is oxygen. Without oxygen, electron transport cannot operate, the Krebs cycle stops, and the synthesis of ATP in the mitochondrion stops. If we are starved for oxygen, our cells will attempt to make the ATP they require by glycolysis alone. But for most cells this is not sufficient.

With each breath we take, air flows into our lungs. Since ancient times, humans have realized that a constant supply of air into the lungs is necessary. But only in this century have we been able to understand why that air is necessary—oxygen has a critical role to play in the mitochondria of every cell!

Energy in Balance

Photosynthesis and respiration can be thought of as opposite processes. Earlier, we compared the chemical energy in glucose to money in a savings account. Photosynthesis is the process that “deposits” energy. Respiration “withdraws” energy. The equations for photosynthesis and for the complete breakdown of glucose (through glycolysis and respiration) are the reverse of each other. The products of photosynthesis are the reactants of glucose breakdown, and the products of glucose breakdown are the reactants of photosynthesis.



Figure 6-18 As this figure skater breathes, she takes in oxygen. The oxygen is used in the process of respiration, which provides energy in the form of ATP—energy that enables the skater to perform her feats on ice!

6-3 SECTION REVIEW

1. What is glycolysis?
2. List the products of the Krebs cycle. What happens to each of these products?
3. Why is breathing necessary for cellular respiration in animals?
4. None of the steps of the Krebs cycle involves oxygen. However, the Krebs cycle is considered to be an aerobic process. Explain why.

Section Objectives

- Relate fermentation to glycolysis.
- Compare lactic acid fermentation and alcoholic fermentation.

Figure 6-19 The process of glycolysis produces energy and converts NAD^+ to NADH . Fermentation is an anaerobic process that converts NADH back to NAD^+ , thus enabling cells to produce energy under anaerobic conditions.

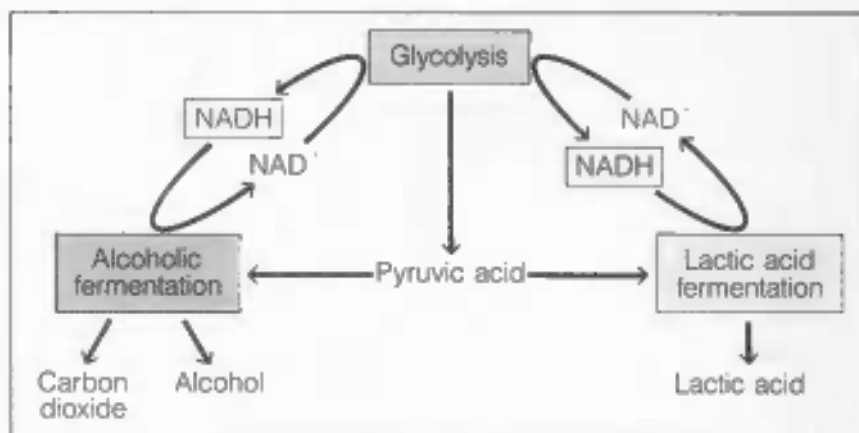
Figure 6-20 When the body cannot supply enough oxygen to muscles during vigorous exercise, muscle cells begin to produce energy by lactic acid fermentation. Even the best athletes are subject to the aches and pains that result from the buildup of lactic acid in the muscles.



6-4 Fermentation

If oxygen is present, a cell can use the process of respiration to extract a great amount of energy from glucose. But what happens when no oxygen is available? Does this mean that we can no longer get energy from glucose?

As you may remember, glycolysis produces 2 ATP molecules per molecule of glucose and does not require oxygen.



This enables cells to produce a limited amount of chemical energy in the form of ATP. Glycolysis also produces high-energy electrons that convert NAD^+ to NADH . In order for glycolysis to continue, NADH must be converted back to NAD^+ .

This is where the process of **fermentation** comes in. Fermentation is **anaerobic**, which means that it does not require oxygen. In fermentation, NADH is converted to NAD^+ by adding the extra electrons in NADH to an organic molecule that acts as an electron acceptor. **Thus, fermentation enables cells to carry out energy production in the absence of oxygen.** The combination of glycolysis and fermentation produces 2 ATP molecules from a molecule of glucose.

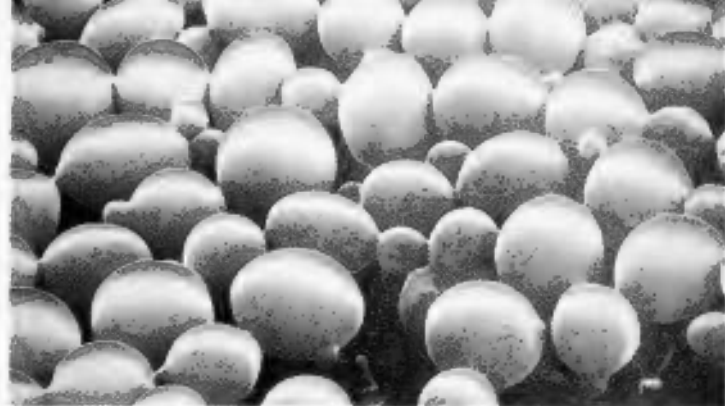
In bacteria, many different organic molecules can serve as the final electron acceptor in fermentation. However, most eukaryotic cells use one of two fermentation pathways to change NADH to NAD^+ . The two pathways are lactic acid fermentation and alcoholic fermentation.

Lactic Acid Fermentation

In many cells, the pyruvic acid that accumulates as a result of glycolysis can be converted to lactic acid. Because this type of fermentation produces lactic acid, it is known as **lactic acid fermentation**. This process regenerates NAD^+ so that glycolysis can continue:



Lactic acid is produced in muscles during rapid exercise when the body cannot supply enough oxygen to the tissues to



produce all of the ATP that is required. The buildup of lactic acid causes a burning, painful sensation that every athlete is familiar with. When you exercise vigorously by running, swimming, or riding a bicycle as fast as you can, the large muscles of your arms and legs quickly run out of oxygen. Your muscle cells rapidly begin to produce ATP by fermentation. During this process, lactic acid is produced. This is why muscles may feel sore after only a few seconds of very rapid activity.

Alcoholic Fermentation

Another type of fermentation occurs in yeasts and a few other microorganisms. In this process, pyruvic acid (which is a 3-carbon compound) is broken down to produce a 2-carbon alcohol and carbon dioxide (CO_2). Because this type of fermentation produces alcohol, it is known as **alcoholic fermentation**. As in lactic acid fermentation, the process that alters pyruvic acid also changes NADH back into NAD^+ :



Alcoholic fermentation is of particular importance to bakers and brewers. The carbon dioxide produced by yeast during fermentation causes dough to rise and forms the air spaces you see in a slice of bread. The CO_2 released by fermentation is the source of bubbles in beer and sparkling wines. To brewers, alcohol is a welcome byproduct of fermentation. However, it is not desirable from a yeast cell's point of view. Alcohol is toxic. When the level of alcohol reaches about 12 percent, yeast cells die. Thus alcoholic beverages must be processed if higher concentrations of alcohol are desired.



Figure 6-21 When yeast cells (left) undergo alcoholic fermentation, they produce alcohol and carbon dioxide. The carbon dioxide produces the air spaces in bread and the bubbles in champagne.

6-4 SECTION REVIEW

1. What is fermentation? What are two types of fermentation?
2. How are respiration and fermentation similar? How are they different?
3. When oxygen is present, yeast cells undergo respiration. Explain why brewers must take special care to prevent air from entering fermentation tanks.

PROBLEM

What is the relationship between the processes of photosynthesis and respiration?

MATERIALS (per group)

2 125-mL flasks
2 #5 rubber stoppers
100-mL graduated cylinder
bromthymol blue solution
2 *Elodea*
light source
drinking straw

PROCEDURE

1. Using a graduated cylinder, measure out 100 mL of bromthymol blue solution for each of the two flasks.

CAUTION: *Bromthymol blue is a dye and can stain your hands and clothing.*

2. Insert one end of a drinking straw into the bromthymol blue in one of the flasks. Gently

blow through the straw. Keep blowing until there is a change in the appearance of the bromthymol blue solution. Repeat this procedure with the other flask.

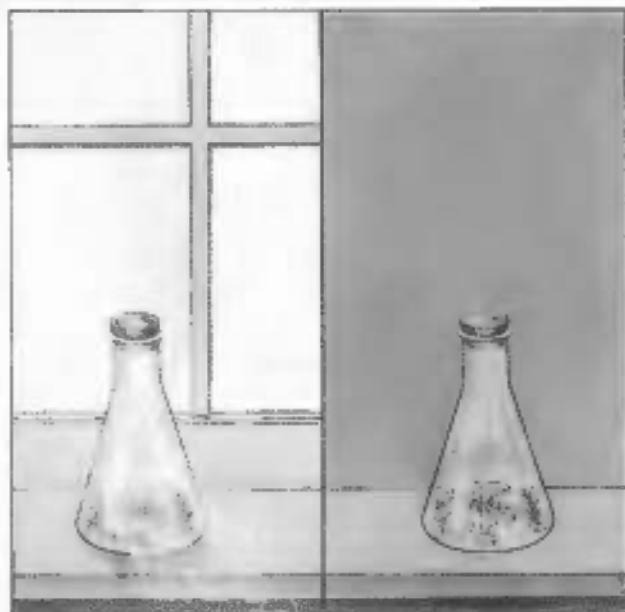
3. Place a sprig of *Elodea* into each flask. Stopper the flasks.
4. Place one flask in the dark for 24 hours. Place the other flask on a sunny windowsill for the same amount of time. Artificial light may be used to supplement the sunlight.
5. After 24 hours, examine each flask. Note any change in the appearance of the bromthymol blue solution.

OBSERVATIONS

1. What was the color of the bromthymol blue solution before you exhaled into it? After you exhaled into it?
2. What was the color of the bromthymol blue solution in the flask that was placed in the dark for 24 hours? In the flask that was placed in the light for 24 hours?

ANALYSIS AND CONCLUSIONS

1. What substance was released into the bromthymol blue solution when you exhaled into it? How is this substance produced?
2. Explain why the color of the bromthymol blue solution changed after you exhaled into it.
3. Why was *Elodea* placed in both flasks?
4. Which flask is the control? Describe additional controls that you might use for this experiment.
5. Why are the results for the two flasks different?
6. How are photosynthesis and respiration related?



SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

6-1 Photosynthesis: Capturing and Converting Energy

- In the process of photosynthesis, green plants capture the energy in sunlight and convert it into chemical energy. The balanced overall equation for photosynthesis is $6 \text{ CO}_2 + 6 \text{ H}_2\text{O} \xrightarrow{\text{light}} \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2$.

6-2 Photosynthesis: The Light and Dark Reactions

- The light reactions can be broken down into four parts: light absorption, electron transport, oxygen production, and ATP synthesis.
- The dark reactions occur outside the photosynthetic membrane in the chloroplast. In the Calvin cycle, CO_2 is used to make PGAL, which can then be used to form glucose and other important molecules.

6-3 Glycolysis and Respiration

- Glycolysis is a series of chemical reactions that ultimately produces 2 molecules of ATP and 2 molecules of pyruvic acid.
- Respiration is an aerobic process that breaks down food molecules to release energy. This energy is stored in the form of ATP.

6-4 Fermentation

- Fermentation is an anaerobic process that regenerates NAD^+ for use in glycolysis. In fermentation, organic molecules take electrons from NADH, changing it back to NAD^+ .
- Photosynthesis stores energy; respiration releases energy. Products of photosynthesis are used in respiration. Products of respiration are raw materials for photosynthesis.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

6-1 Photosynthesis: Capturing and Converting Energy

photosynthesis
glucose
autotroph
heterotroph
pigment
chlorophyll
adenosine
triphosphate (ATP)

6-2 Photosynthesis: The Light and Dark Reactions

light reactions
dark reactions
photosynthetic
membrane
photosystem
electron transport
Calvin cycle

6-3 Glycolysis and Respiration

calorie
glycolysis
respiration
aerobic
Krebs cycle

6-4 Fermentation

fermentation
anaerobic
lactic acid
fermentation
alcoholic
fermentation

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- Which process is anaerobic?
 - Krebs cycle
 - mitochondrial electron transport
 - glycolysis
 - respiration
- An experiment that showed that part of a growing plant's mass comes from water was performed by
 - Priestley.
 - Van Helmont.
 - Ingenhousz.
 - Calvin.
- Autotrophs include
 - ferns.
 - camels.
 - yeasts.
 - birds.
- Photosynthesis produces
 - carbon dioxide.
 - alcohol.
 - water.
 - glucose.
- In respiration, the final electron acceptor is
 - lactic acid.
 - alcohol.
 - oxygen.
 - NAD⁺.
- Which of these is produced by the dark reactions?
 - PGAL
 - oxygen
 - water
 - ATP
- A type of pigment found in green plants is
 - NAD⁺.
 - NADPH.
 - ATP.
 - chlorophyll.
- Which of these is not produced in the light reactions?
 - NADPH
 - glucose
 - ATP
 - oxygen

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- In the dark reactions of photosynthesis, the energy in sunlight is captured and used to make ATP and NADPH.
- Because they cannot make their own food, autotrophs rely on the food-making ability of green plants.
- Photosystems are clusters of pigment molecules that are able to capture the energy of sunlight.
- The light reactions occur outside the photosynthetic membrane.
- ATP is formed when enzymes move hydrogen ions across a membrane to an area of greater concentration.
- Glycolysis is an aerobic process that breaks down food molecules to produce energy.
- When there is no oxygen present, yeast cells break down glucose to form lactic acid and carbon dioxide.
- Approximately 36 molecules of ATP are formed during glycolysis.

Word Relationships

A. In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

- Calvin cycle, light absorption, electron transport, oxygen production
- fermentation, respiration, glycolysis, photosynthesis
- glucose, oxygen, water, energy

B. An analogy is a relationship between two pairs of words or phrases generally written in the following manner: *a:b::c:d*. The symbol *:* is read "is to," and the symbol *::* is read "as." For example, *cat:animal::rose:plant* is read "cat is to animal as rose is to plant."

In the analogies that follow, a word or phrase is missing. Complete each analogy by providing the missing word or phrase.

4. food and oxygen:respiration::_____:photosynthesis
5. oak tree:autotroph::human:_____
6. PGAL:Calvin cycle::pyruvic acid:_____
7. photosynthesis:chloroplast::respiration:_____

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. List the requirements for photosynthesis. Briefly describe how each is involved in the light reactions or the dark reactions.
2. Describe the process of ATP formation.
3. Name ten living things that you see every day. Identify each of these as an autotroph or a heterotroph.
4. What is the relationship between breathing and respiration?
5. How are photosynthesis and respiration related to each other?
6. Compare the reactants and products of two types of fermentation.

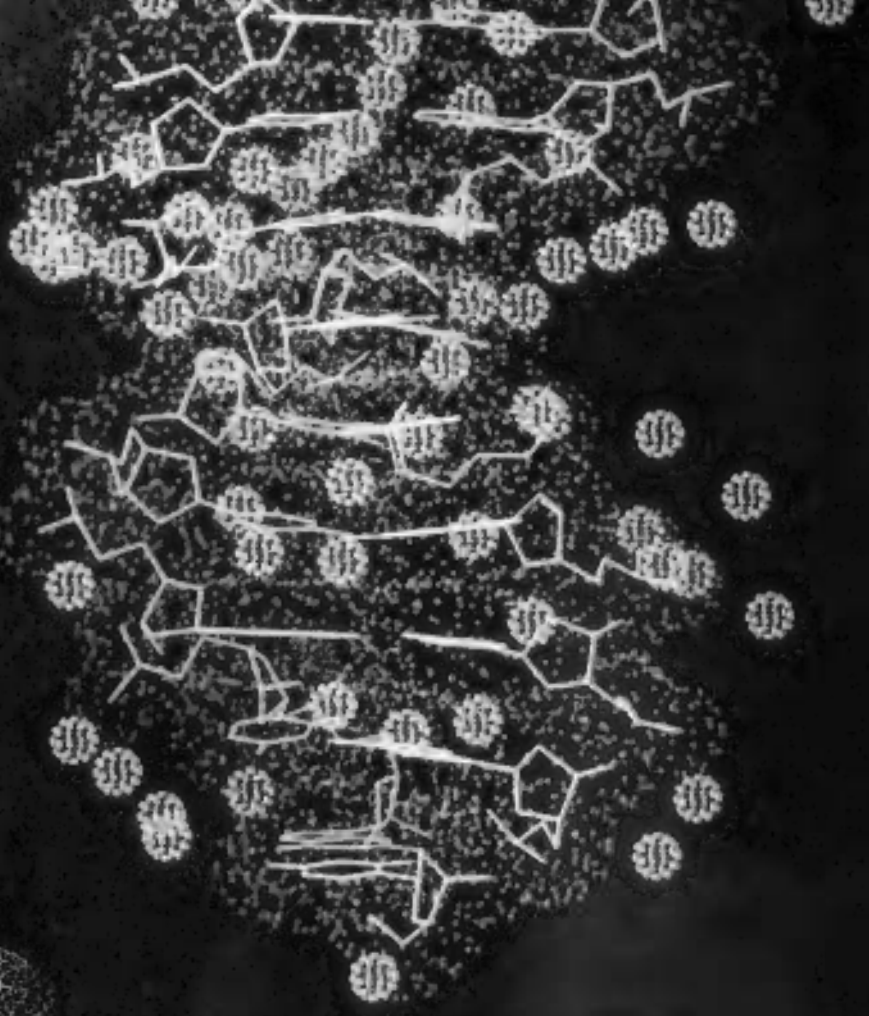
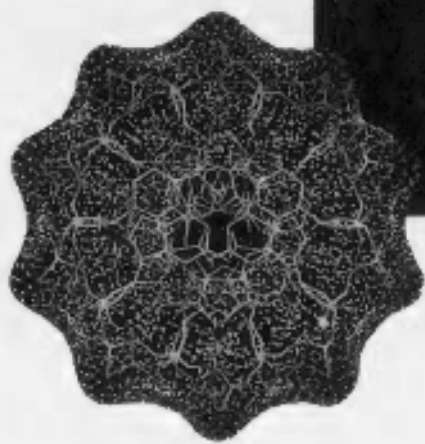
CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Making comparisons** Compare the chemical steps of the light and dark reactions of photosynthesis with those of glycolysis, the Krebs cycle, and the respiratory electron transport chain.
2. **Making an outline** Outline the process of photosynthesis.
3. **Applying concepts** Some desert animals such as the kangaroo rat never have to drink water. Explain how kangaroo rats can obtain the water they need to survive from the dry seeds they eat.
4. **Making inferences** Some scientists think that the dinosaurs may have become extinct because an asteroid struck the Earth and sent large amounts of dust into the upper atmosphere. The dust remained in the atmosphere a long time. Explain how this would have resulted in the dinosaurs dying off.
5. **Assessing concepts** Which is better: respiration or fermentation? Explain your answer.
6. **Using the writing process** You are a carbon atom. You have just returned to the air as carbon dioxide after being involved in the processes of photosynthesis and respiration. Describe what happened to you on your chemical journey. Where did you go? What other atoms (carbon and otherwise) did you find yourself bonded to? What molecules did you meet along the way, and what were they like?

CHAPTER 7

Nucleic Acids and Protein Synthesis



The double-helical structure of DNA is shown in these computer-generated images. The larger image shows a dark-blue structure and a purple structure coiling around each other. These structures represent the two linked strands of nucleotides in DNA. The smaller image shows DNA's double helix as it appears from above.

In the middle of the twentieth century, a great revolution began to take place in biology. Like many revolutions, its beginnings were modest. Its pioneers were a handful of investigators who sought to understand how information was transferred from one generation of life to the next. The discovery that nucleic acids carry and transfer that information has altered our view of living things. In this chapter we will begin to study the nucleic acids DNA and RNA, the genetic code they contain, and the way in which that code is put into action during protein synthesis.

CHAPTER OUTLINE

7-1 DNA

- The Genetic Code
- The Structure of DNA
- The Replication of DNA

7-2 RNA

- The Structure of RNA
- Transcription: RNA Synthesis

7-3 Protein Synthesis

- The Nature of the Genetic Code
- Translation

7-1 DNA

Section Objectives

- List the contributions of various scientists to the idea that DNA carries the genetic code.
- Describe the structure and function of DNA.
- Summarize the process of DNA replication.

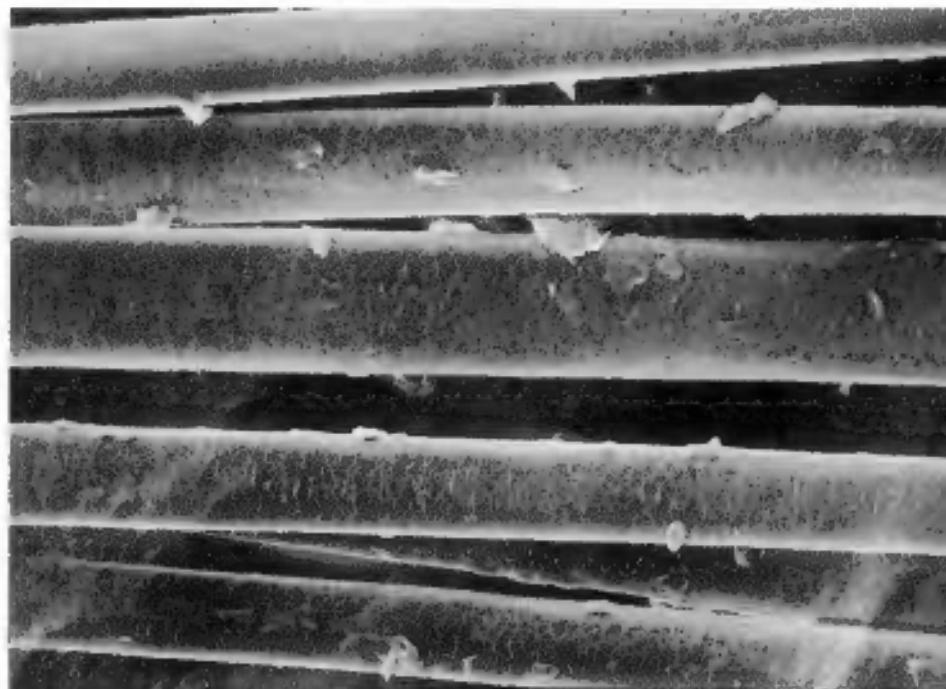
By now it should be clear that living cells are able to do some remarkable things. We might go so far as to say that cells “know” a great deal about the business of life: how to produce ATP, how to build cilia and centrioles, how to produce enzymes and membranes. It is as though cells are preinstructed by a code, or programmed, about what to do and how to do it.

A program, or code, in living cells must be able to duplicate itself quickly and accurately and must also have a means of being decoded and put into effect. In this chapter we will begin to learn about the nature of the cellular program—what biologists know and don’t know about the ways in which the program is constructed, duplicated, and carried out.

The Genetic Code

Biologists call the program of the cell the **genetic code**. The word genetic refers to anything that relates to heredity. The genetic code, therefore, is the way in which cells store the program that they seem to pass from one generation of an organism to the next generation.

Figure 7-1 The genetic code stores the program for making proteins, such as those that make up the strands of hair, and passes it on from generation to generation.



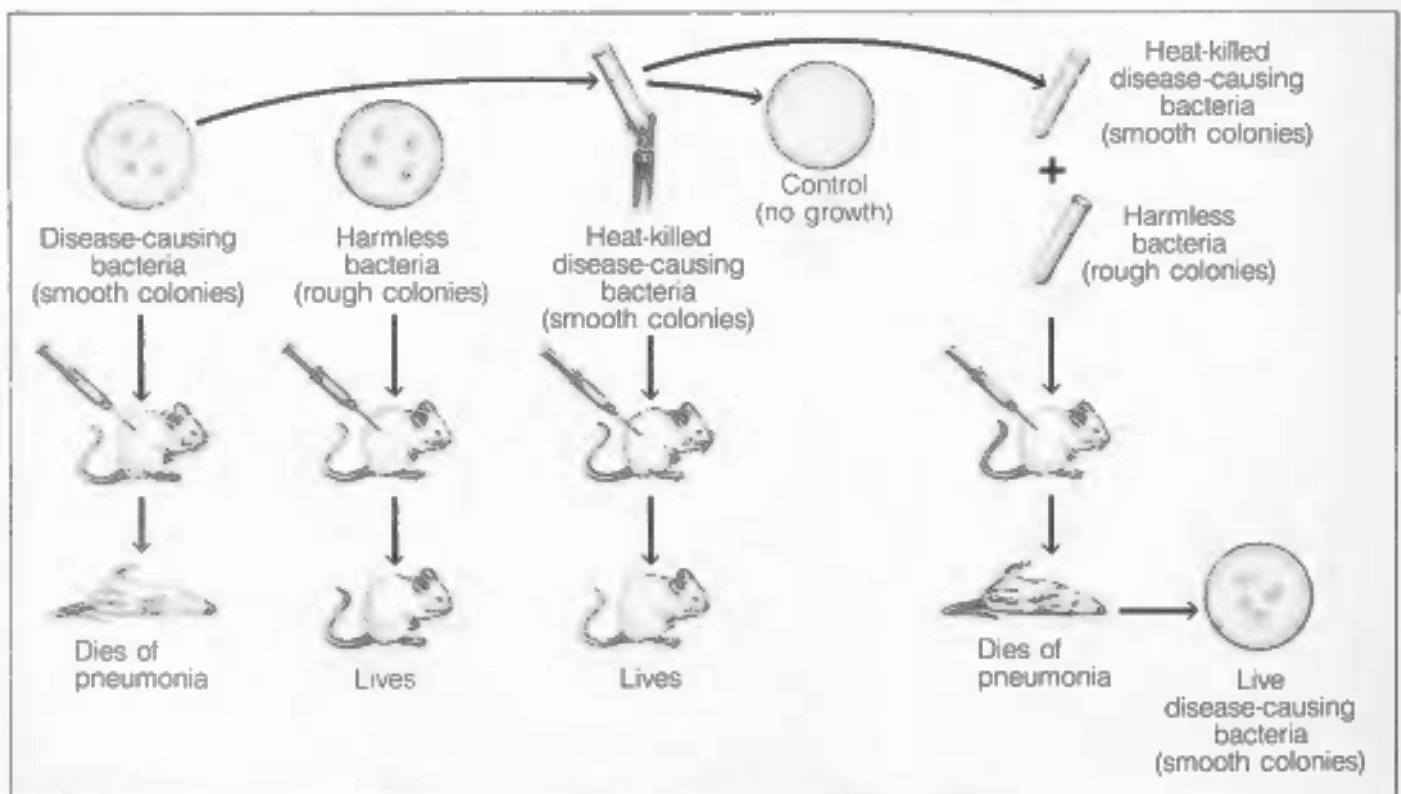
Is there a molecule that carries the genetic code? As often happens in science, an opportunity to answer this question presented itself to someone who was actually interested in something else.

In 1928, the British scientist Frederick Griffith was studying the way in which certain types of bacteria cause the disease pneumonia. Griffith had in his laboratory two slightly different strains, or types, of pneumonia bacteria. Both strains grew very well in culture plates in his lab, but only one strain actually caused the disease. The disease-causing strain of bacteria grew into smooth colonies on culture plates, whereas the harmless strain produced colonies with rough edges. The differences in appearance made the two strains easy to distinguish.

When Griffith injected mice with the disease-causing strain of bacteria, the mice got pneumonia and died. When mice were injected with the harmless strain, they did not get pneumonia and they did not die. And when mice were injected with the disease-causing strain that had been killed by heat, these mice too survived. By performing this third experiment, Griffith proved to himself that the cause of pneumonia was not a chemical poison released by the disease-causing bacteria.

Figure 7-2 The results of Griffith's experiments showed that "something" had been transferred from the heat-killed disease-causing bacteria to the live harmless bacteria, transforming them into live disease-causing bacteria. This something was later isolated and identified as DNA.

TRANSFORMATION Next Griffith did an experiment that produced an astonishing result. He injected mice with a mixture of live cells from the harmless strain and heat-killed cells from the disease-causing strain. To Griffith's surprise, the mice developed pneumonia!



Somehow Griffith's heat-killed strain had passed on its disease-causing ability to the live harmless strain. It was almost as if a farmer had scattered ground beef in a henhouse and then returned the next morning to discover that some of the eggs had begun to hatch into calves instead of baby chicks!

To confuse matters even more, Griffith recovered bacteria from the animals that had developed pneumonia. When these bacteria were grown on culture plates, they formed smooth colonies characteristic of the disease-causing strain. For all practical purposes, one strain of bacteria had been transformed into another. Griffith called this process **transformation**.

THE TRANSFORMING FACTOR Griffith theorized that when the live harmless bacteria and the heat-killed bacteria were mixed together, a factor was transferred from the heat-killed cells into the live cells. In 1944, a group of scientists at the Rockefeller Institute in New York City led by Oswald Avery, Maclyn McCarty, and Colin MacLeod decided to repeat Griffith's work and see if they could discover which molecules were Griffith's transforming factor, that is, which molecules were responsible for transformation.

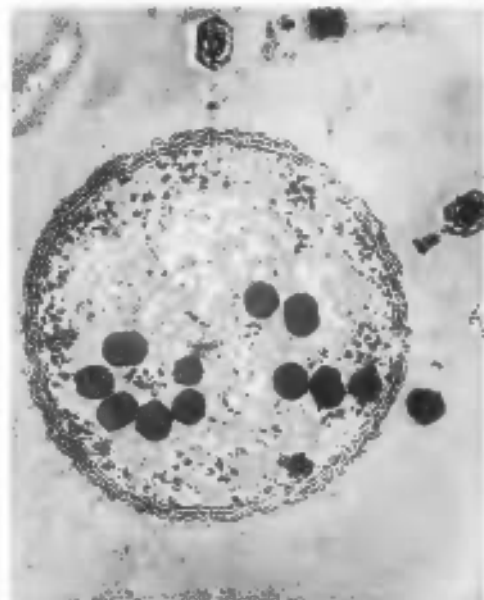
Avery and his colleagues made an extract, or juice, from the heat-killed bacteria. When they treated the extract with enzymes that destroy lipids, proteins, and carbohydrates, they discovered that transformation still occurred. Obviously these molecules were not responsible for the transformation. If they were, transformation would not have occurred because the molecules would have been destroyed by the enzymes.

Avery and the other scientists repeated the experiment, this time using enzymes that would break down RNA (ribonucleic acid). The scientists found that again transformation took place. But when they performed the experiment again, now using enzymes that would break down DNA (deoxyribonucleic acid), transformation did not occur. DNA was the transforming factor! **DNA is the nucleic acid that stores and transmits the genetic information from one generation of an organism to the next.** In other words, DNA carries the genetic code.

BACTERIOPHAGES The work of Avery and his colleagues clearly demonstrated the role of DNA in the transfer of genetic information. Scientists, however, are notorious for being a skeptical group, and it sometimes takes many successful experiments to convince everyone.

One of the most important of these experiments was performed in 1952 by two American scientists, Alfred Hershey and Martha Chase. Hershey and Chase were interested in the kinds of viruses that infect bacteria. Such viruses are known as bacteriophages (bak-TIHR-ee-uh-fayj-uhz), which means bacteria eaters. Bacteriophages are composed of a DNA core and a protein coat. They attach themselves to the surface of a bacterium and then inject a material into the bacterium.

Figure 7-3 This electron micrograph shows some T-2 bacteriophages attached to the bacterium E. coli. Once inside, the bacteriophages take over the bacterium's DNA and instruct it to make many copies of themselves (black ovals in the bacterium).

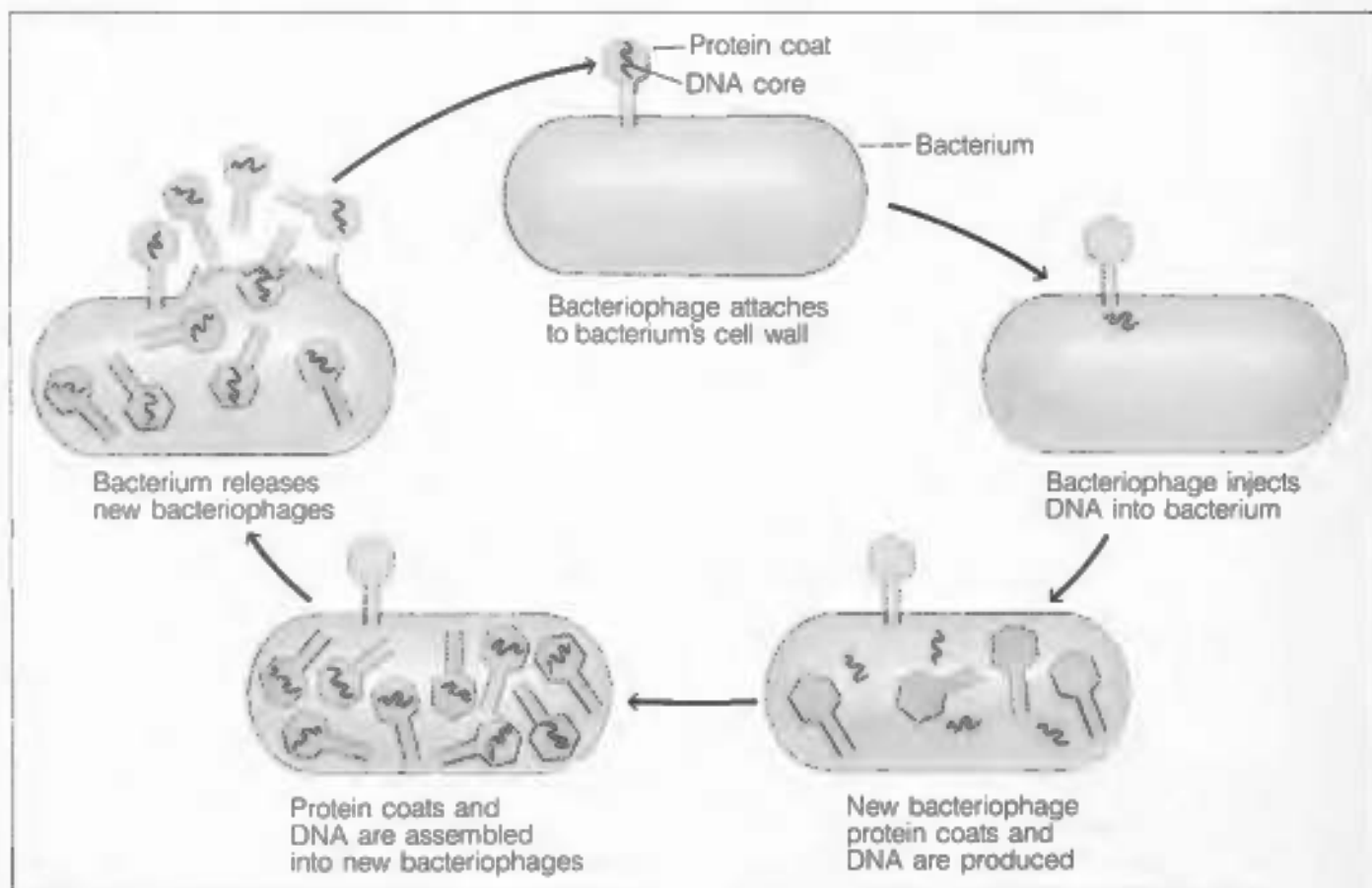


Once inside the bacterium, the injected material begins to reproduce, making many copies of the bacteriophage. Soon the bacterium bursts, and several hundred bacteriophages are released to infect other cells. Because the material injected into the bacterium produces new bacteriophages, it must contain the genetic code.

In their experiments, Hershey and Chase set out to learn whether the protein coat, the DNA, or both of these parts of the infecting virus was the material that entered the bacterium. First they prepared two batches of the virus. They added radioactive sulfur-35 to one batch and radioactive phosphorus-32 to the other batch. Sulfur-35 and phosphorus-32 are radioactive isotopes. You will recall from Chapter 3 that radioactive isotopes can be used as tracers to follow the pathway of certain materials.

By adding the radioactive isotopes to the viruses, Hershey and Chase were "labeling" the viruses' protein and DNA. The protein was labeled with sulfur-35, and the DNA was labeled with phosphorous-32. This was an excellent strategy because proteins contain little or no phosphorous, whereas DNA does not contain sulfur. If sulfur-35 was found in the bacteria, it would mean that the viruses' protein was injected into the bacteria. If phosphorous-32 was found in the bacteria, then it was the DNA that had been injected.

Figure 7-4 As a result of their experiments, Hershey and Chase discovered that the DNA of a bacteriophage is injected into a bacterium, whereas the bacteriophage's protein coat remains outside the bacterium. New bacteriophages are produced inside the bacterium, indicating that DNA, not the protein, is the hereditary material of the bacteriophage.



The two scientists mixed the radioactively labeled viruses with the bacteria. They waited a few minutes for the viruses to attach and inject the genetic material. Then they separated the viruses from the bacteria by placing the mixture in a mechanical blender and then centrifuging the mixture.

Hershey and Chase discovered that nearly all the radioactive sulfur remained within the viruses. By contrast, nearly all the radioactive phosphorous had entered the bacteria!

From these results, it was clear that the viruses' DNA enters the bacteria, and the protein coats remain outside the bacteria. This was convincing evidence that DNA contains the genetic information. When considered along with the earlier experiments on the transformation of pneumonia bacteria, the Hershey-Chase experiments showed conclusively that DNA was the molecule that carried the genetic code.

The Structure of DNA

Even if DNA was shown to be the crucial molecule for the passing on of genetic information, a question of overwhelming importance remained. How could a molecule such as DNA perform two significant tasks: store information and duplicate itself easily? Let's take a look at the structure of DNA to see if that explains how it accomplishes these tasks.

As you will recall from Chapter 4, DNA is a polymer formed from units called **nucleotides**. Each nucleotide is a molecule made up of three basic parts: a 5-carbon sugar called deoxyribose (dee-ahks-ee-RIGH-bohz), a phosphate group, and a nitrogenous, or nitrogen-containing, base.

DNA contains four nitrogenous bases. Two of the nitrogenous bases, **adenine** (AD-uh-neen) and **guanine** (GWAH-neen), belong to a group of compounds known as purines (PYOOR-eenz). The remaining two, **cytosine** (SIGHT-oh-seen) and **thymine** (THIGH-meen), are known as pyrimidines (pih-RIHM-uh-deenz).

Individual nucleotides are joined together to form a long chain. Notice in Figure 7-7 on page 142 that the sugars and phosphate groups form the backbone of the chain, and the nitrogenous bases stick out from the chain.

X-RAY EVIDENCE In the early 1950s, the British scientist Rosalind Franklin turned her attention to the DNA molecule. She purified a large amount of DNA and then stretched the DNA fibers in a thin glass tube so that most of the strands were parallel. Then she aimed a narrow X-ray beam on them and recorded the pattern on film. When X-rays pass through matter, they are scattered, or diffracted. This X-ray scattering produces a pattern that provides important clues to the structure of many molecules.

Franklin worked hard to prepare better and better samples until the X-ray patterns became clear. The result of her work is

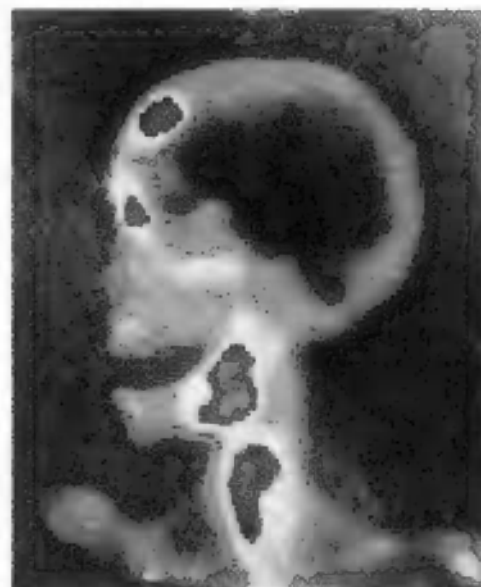
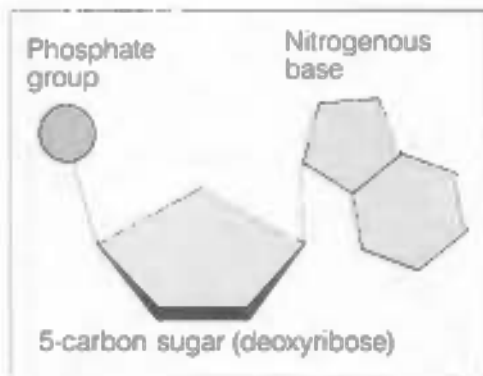


Figure 7-5 Radioactive isotopes are used not only to follow the pathway of certain materials, but also to detect the presence of some types of cancer. This photograph shows how a radioactive isotope becomes more concentrated in a cancerous part of the body, in this case in bone, than in a healthy part of the body. The cancerous part appears in red.

Figure 7-6 DNA is a polymer formed from units called nucleotides. A nucleotide is composed of three basic parts: a phosphate group, a 5-carbon sugar, and a nitrogenous base. What is DNA's 5-carbon sugar called?



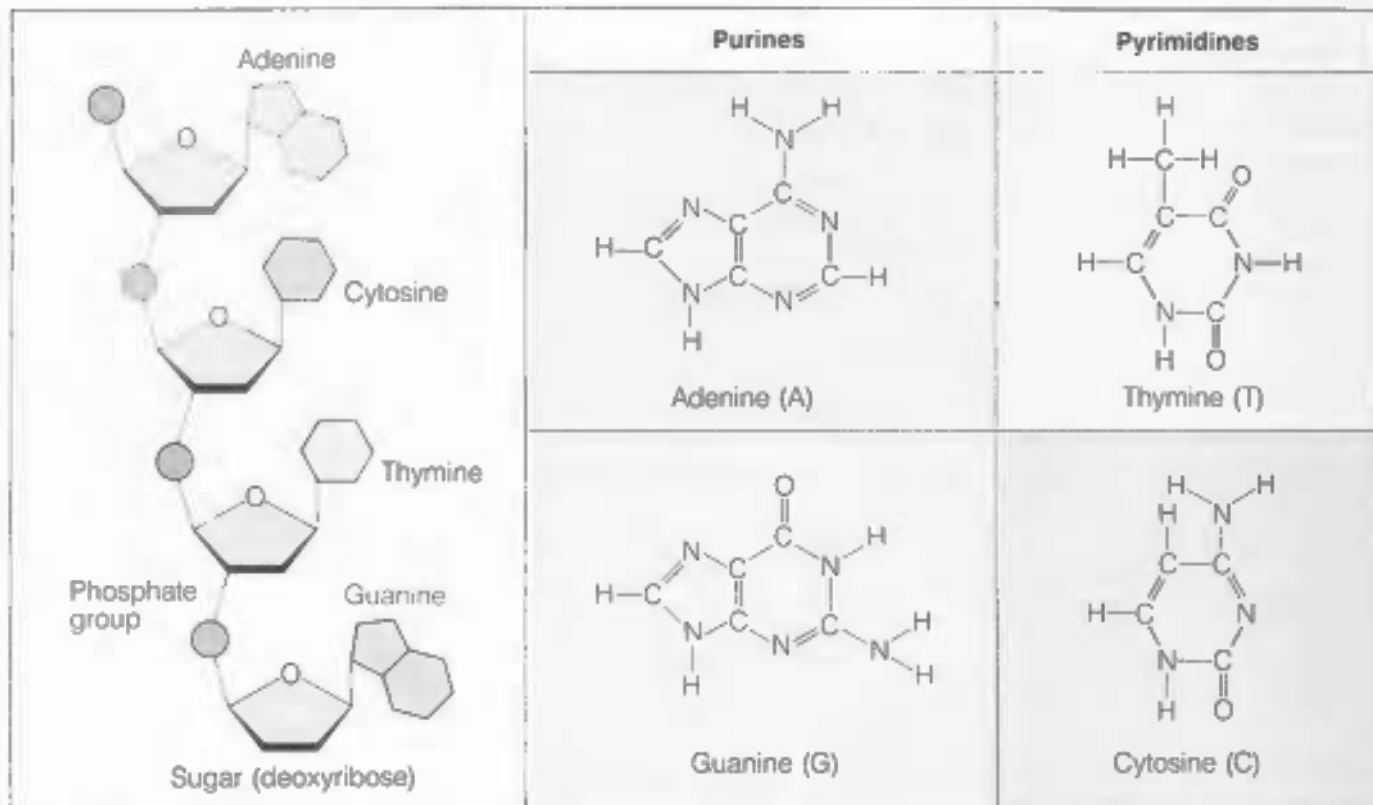
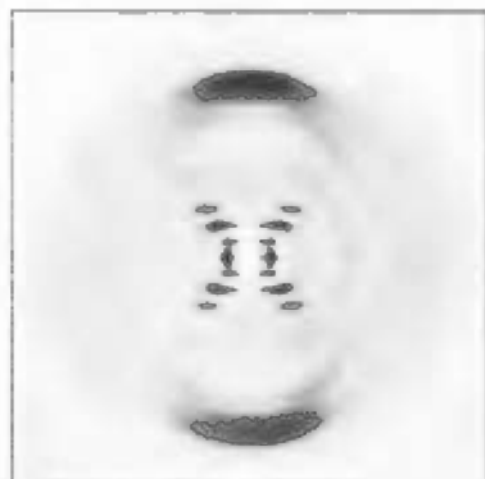


Figure 7-7 Individual nucleotides join together to form a DNA chain. Note that each nucleotide contains one nitrogenous base.

Figure 7-8 This X-ray diffraction photograph of DNA was taken by Rosalind Franklin in the early 1950s. The X-shaped pattern in the center indicates that the structure of DNA is helical.



the X-ray pattern shown in Figure 7-8. This pattern does not prove anything immediately, but it does provide some very important clues about the structure of DNA. One important clue is that the fibers that make up DNA are twisted, like the strands of a rope. This is shown by the small X near the center of the pattern. The other important clue is that large groups of molecules in the fiber are spaced out at regular intervals along the length of the fiber.

Taken alone, neither of these facts was enough to determine the structure of DNA. The X-ray pattern was like a fingerprint or a scrap of cloth at the scene of a crime. Crucial evidence, perhaps, but it would only make sense when put into a larger picture by a clever detective—or an inventive scientist!

BUILDING A MODEL OF DNA At the same time that Franklin and her colleague, Maurice Wilkins, were doing their research, two young scientists working in Cambridge, England, were also trying to determine the structure of DNA. One of the scientists was Francis Crick, a British physicist. The other was James Watson, a 25-year-old American biochemist.

Watson and Crick had been trying to solve the mystery of DNA structure by building three-dimensional models of the atomic groups in DNA. They twisted and stretched the models in various ways to see if any of the structures that formed made any sense. Watson and Crick had some interesting ideas, but nothing to test them against.

Then, during a visit to London, Watson was able to observe Franklin's remarkable X-ray pattern of DNA. At once Watson and Crick realized that there was something important in that pattern. They immediately set out to use the clues that Franklin had provided. Within weeks, Watson and Crick had figured out the structure of DNA.

THE DOUBLE HELIX Working with these clues, Watson and Crick began, quite literally, to play with their models of the DNA fiber. What they needed to do was to twist their model into a shape that would account for Franklin's X-ray pattern. Before long, they developed a shape that seemed to make sense. They called this shape a helix because it was similar to a spiral, or the way in which the threads are arranged in a screw. Using Franklin's idea that there were probably two strands of DNA, Watson and Crick imagined that the strands were twisted around each other, forming a double helix.

Watson and Crick's model explained one more characteristic about DNA's structure. The nitrogenous bases on each of the strands of DNA are positioned exactly opposite each other. This positioning allows weak hydrogen bonds to form between the nitrogenous bases adenine (A) and thymine (T), and between cytosine (C) and guanine (G).

Another interesting piece of information that helped Watson and Crick in working out their model of DNA's structure was provided by Erwin Chargaff, an American biochemist. Chargaff observed that in any sample of DNA, the number of adenine molecules was equal to the number of thymine molecules. The same was true for the number of cytosine and guanine molecules. Chargaff's observation enabled Watson and Crick to determine that adenine only bonds to thymine and cytosine only bonds to guanine. The two scientists further reasoned that the attraction of these bases for each other is very specific. The attraction between such bases is known as **base pairing**. Base pairing is the force that holds the two strands of the DNA double helix together. As you can see, Watson and Crick set out to solve one puzzle and found the answer to another puzzle too!

In 1953, after making careful drawings of their model of DNA, Watson and Crick submitted their findings to a scientific journal. Their model, although speculative in some areas, was almost immediately accepted by scientists the world over. Why? Because, as we will see, it contained a feature that explained a great mystery: how DNA could copy itself!

The importance of this work on DNA was acknowledged in 1962 by the awarding of the Nobel prize for medicine or physiology—the highest prize the international community can give for a scientific discovery—to its discoverers. Because Rosalind Franklin had died in 1958 and Nobel prizes are given only to living scientists, the prize was shared by Watson, Crick, and Franklin's associate, Maurice Wilkins.

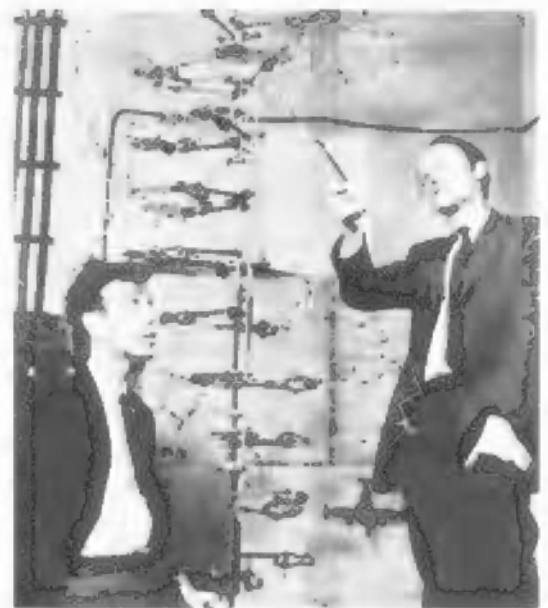
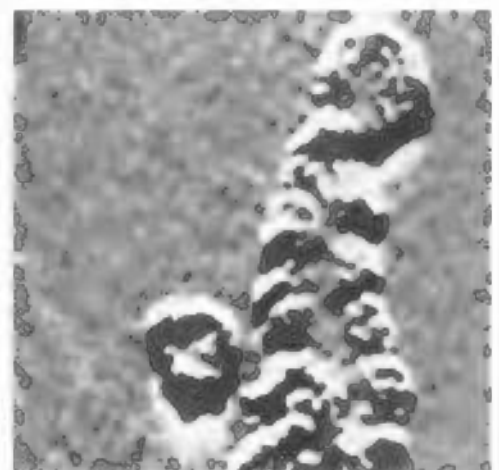


Figure 7-9 This photograph of Watson and Crick with one of their first models of DNA was taken in 1953.

Figure 7-10 This three-dimensional image of DNA magnified one million times was made through a scanning tunneling microscope (STM). This recently invented microscope can distinguish individual atoms.



The Replication of DNA

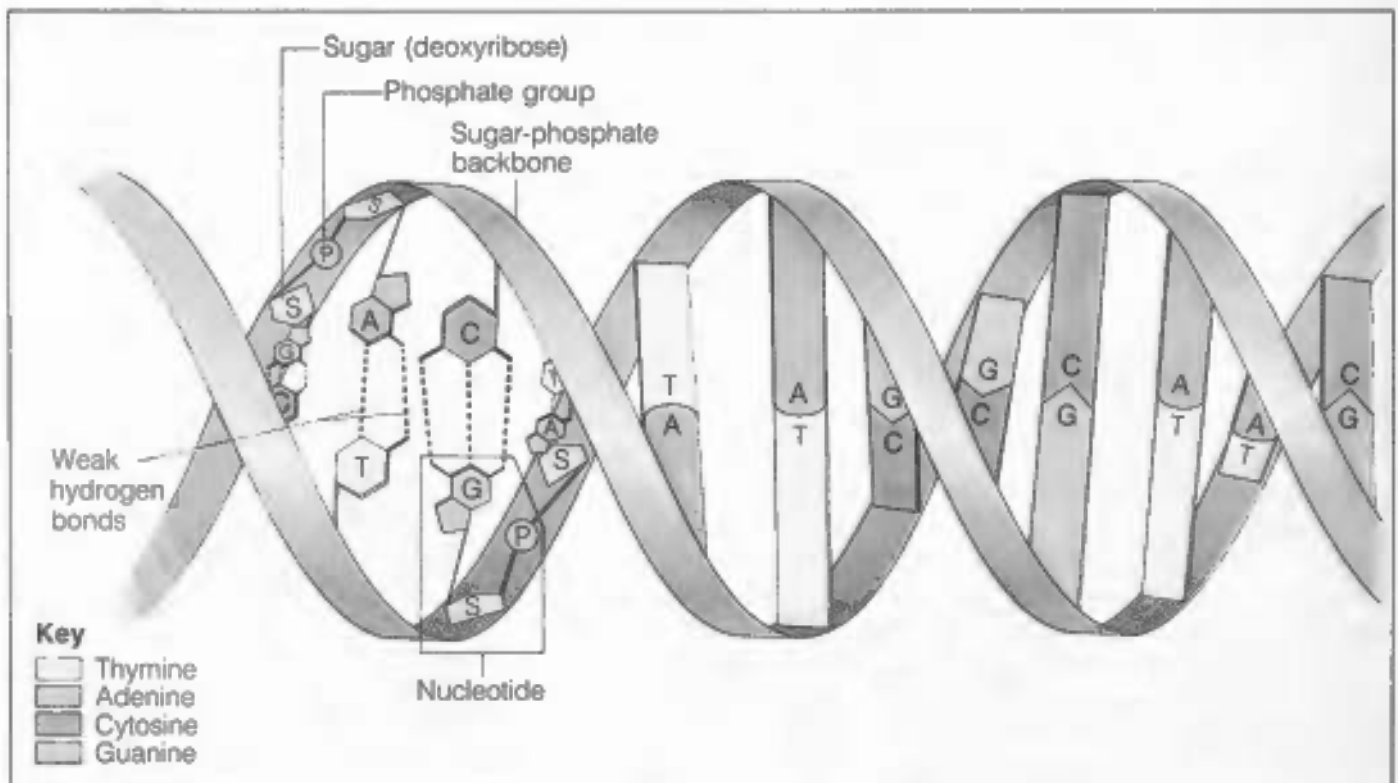
Because each of the two strands of the DNA double helix has all the information, by the mechanism of base pairing, to reconstruct the other half, the strands are said to be complementary. To illustrate this concept, we can use the analogy of a dollar bill that has been torn in half. Each half of the dollar bill tells us just what the other half must look like, even though the two halves are not identical.

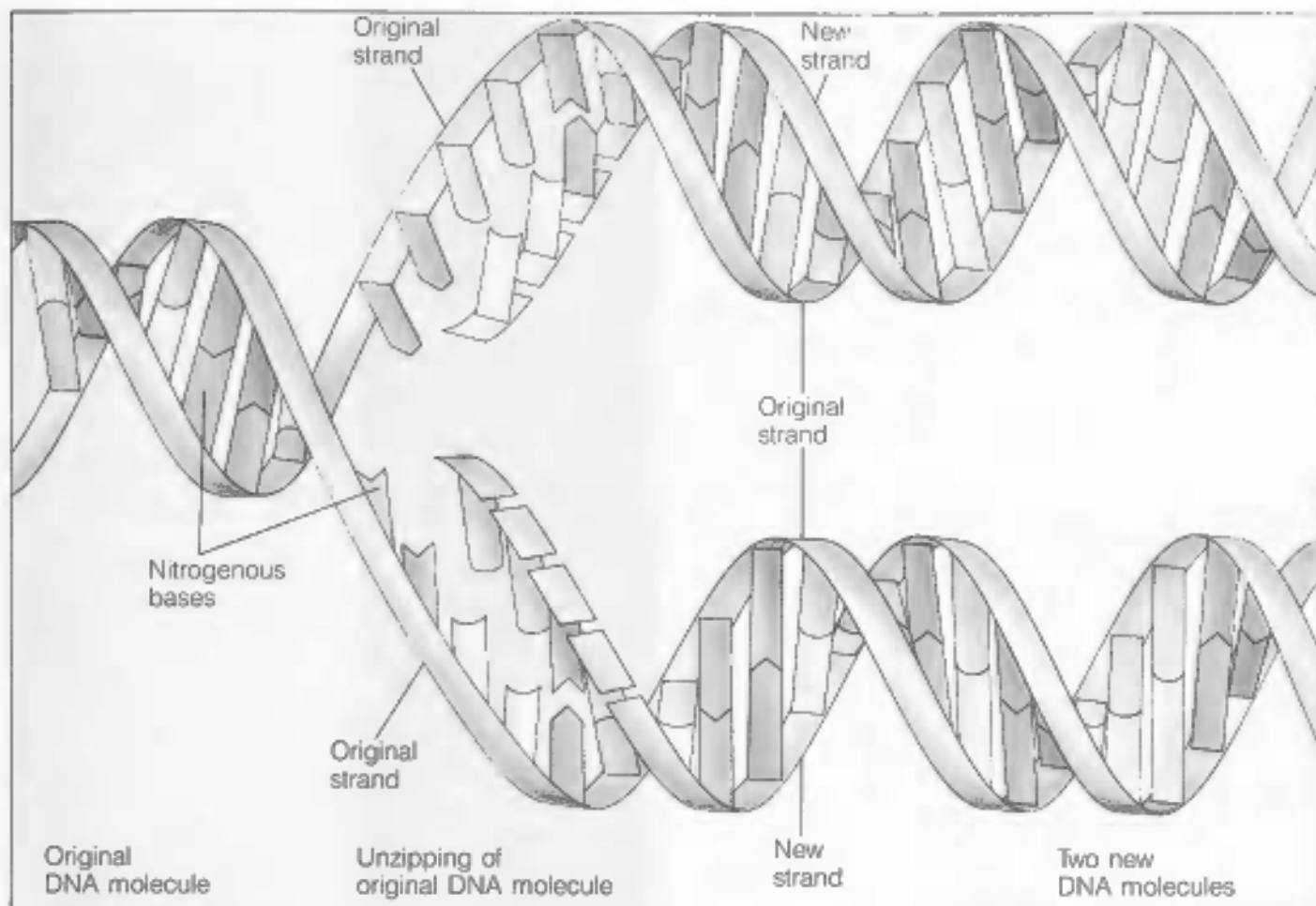
Although there are four nitrogenous bases in DNA, the situation is really quite similar to that of the dollar bill. As you can see from Figure 7-11, even in a long and complicated DNA molecule, each half can specifically direct the sequence of the other half by complementary base pairing. This allows us to imagine a very simple scheme for copying the double helix, as shown in Figure 7-12. In effect, each strand of the double helix of DNA serves as a template, or pattern, against which a new strand is made.

Before a cell divides, it must duplicate its DNA. This ensures that each resulting cell will have a complete set of DNA molecules. This copying process is known as **replication**. DNA replication, or DNA synthesis, is carried out by a series of enzymes. These enzymes separate, or "unzip," the two strands of the double helix, insert the appropriate bases, and produce covalent sugar-phosphate links to extend the growing DNA chains. The enzymes even "proofread" the bases that have been inserted to ensure that they are paired correctly.

As proposed by Watson and Crick, DNA replication begins

Figure 7-11 The structure of the DNA double helix resembles a twisted ladder. The sugar-phosphate backbones form the sides of the ladder and the nitrogenous bases form the rungs of the ladder. What holds the nitrogenous bases together?





when a molecule of DNA “unzips.” The unzipping occurs when the hydrogen bonds between the base pairs are broken and the two strands of the molecule unwind. Each of the separated strands serves as a template for the attachment of complementary bases. For example, a strand that has the bases T-A-C-G-T-T produces a strand with the complementary bases A-T-G-C-A-A. In this way, two DNA molecules identical to each other and to the original molecule are made.

Figure 7-12 When DNA undergoes replication, each of the original strands unzips down the middle as the base pairs separate at the hydrogen bonds. Each of the original strands serves as the template along which a new complementary strand of DNA forms.

7-1 SECTION REVIEW

1. Why was Griffith’s work on transformation important in identifying DNA as the genetic material?
2. How did Hershey and Chase show that DNA was the molecule that carried the genetic code?
3. What is the function of DNA?
4. What are the parts of a DNA nucleotide?
5. Describe the shape of a DNA molecule.
6. Why is DNA replication necessary to life?

Section Objectives

- State the function of RNA.
- Compare the structures of RNA and DNA.
- Describe the process of transcription.

7-2 RNA

The double helix structure explains how DNA can be replicated, or copied. However, it does not explain how information is contained in the molecule or how that information is put to good use. As we will see, DNA contains a set of instructions that are coded in the sequence, or order, of nucleotides. The first step in decoding that message is to copy part of the sequence into **RNA** (ribonucleic acid). **RNA is the nucleic acid that acts as a messenger between DNA and the ribosomes and carries out the process by which proteins are made from amino acids.** As you will recall from Chapter 5, ribosomes are the organelles in which proteins are made.

The Structure of RNA

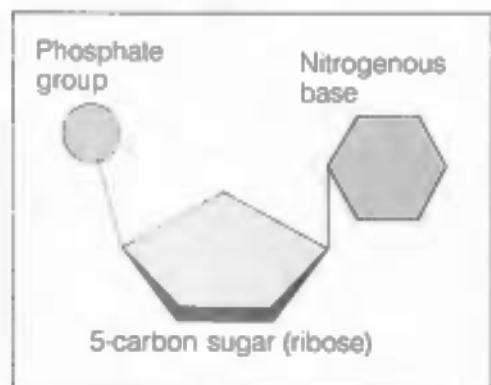
RNA, like DNA, consists of a long chain of macromolecules made up of nucleotides. Each nucleotide is made up of a 5-carbon sugar, a phosphate group, and a nitrogenous base. The alternating sugars and phosphate groups form the backbone of the RNA chain.

There are three major differences between RNA and DNA. The sugar in RNA is ribose, whereas the sugar in DNA is deoxyribose. Another difference between RNA and DNA is that RNA consists of a single strand of nucleotides, although it can form double-stranded sections by folding back on itself in loops. DNA, as you will recall, is double-stranded. Lastly, the nitrogenous bases found in DNA are adenine, thymine, cytosine, and guanine. RNA also contains adenine, cytosine, and guanine, but **uracil** (YOOR-uh-sihl) is present instead of thymine. Like DNA, RNA follows the base-pairing rules. Adenine bonds to uracil, and cytosine bonds to guanine.

Although a cell contains many different forms of RNA, there are three main types that are involved in expressing the genetic code. Each of the three main types of RNA will be discussed later in this section.

In its own way, an RNA molecule is a disposable copy of a segment of DNA. The ability to copy a DNA base sequence into RNA makes it possible for a specific place on the DNA molecule to produce hundreds or even thousands of RNA molecules with the same information as DNA.

Figure 7-13 Like DNA, RNA consists of units called nucleotides. The nucleotides in RNA, however, contain the 5-carbon sugar ribose instead of deoxyribose and the nitrogenous base uracil instead of thymine.



Transcription: RNA Synthesis

As you will recall, DNA replication is also known as DNA synthesis because the molecule being synthesized turns out to be the same as the molecule being copied. In RNA synthesis, the molecule being copied is just one of the two strands of a DNA molecule. Thus the molecule being synthesized is different from the molecule being copied. The term **transcription** is used to describe this process. **Transcription is the process by**

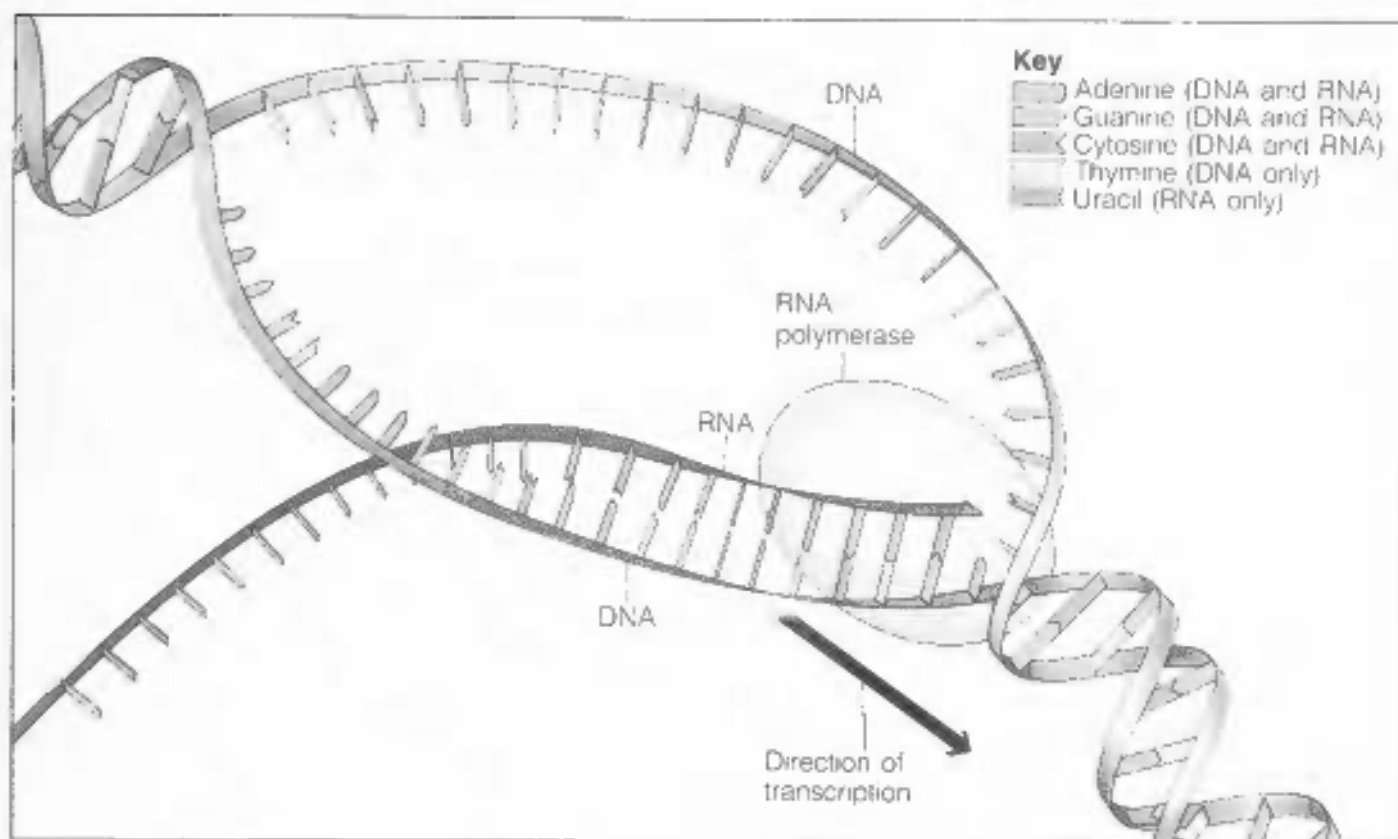


Figure 7-14 During transcription, the enzyme RNA polymerase attaches to an area on the DNA molecule, causing it to open up. As the RNA polymerase moves along the DNA molecule, the two strands of DNA separate. Then RNA nucleotides link to the complementary bases on DNA. Which of RNA's nitrogenous bases pairs with adenine in DNA?

which a molecule of DNA is copied into a complementary strand of RNA. In other words, transcription is the process of transferring information from DNA to RNA.

Why is it necessary for DNA to transfer its genetic information to RNA? Recall from Chapter 5 that DNA is found in the nucleus and ribosomes are located in the cytoplasm. Because DNA does not leave the nucleus, a messenger, or carrier, must bring the genetic information from the DNA in the nucleus out to the ribosomes in the cytoplasm. The molecule that performs this function is **messenger RNA (mRNA)**, one of the three main types of RNA.

In order to more fully understand how transcription takes place, we must discuss the role that an enzyme known as RNA polymerase (PAHL-ih-mer-ayz) plays in this process. In Chapter 4 you learned that an enzyme is specific, that is, it works on only one substance. For this reason, part of its name is usually derived from the substance on which it works. Then the suffix *-ase* is added. Thus RNA polymerase works on the polymers RNA and DNA.

During transcription, RNA polymerase attaches to special places on the DNA molecule, separates the two strands of the double helix, and synthesizes a messenger RNA strand. The messenger RNA strand is complementary to one of the DNA strands. The base-pairing mechanism ensures that the messenger RNA will be a complementary copy of the DNA strand that serves as its template.

Special sequences in DNA serve as "start signals" and are recognized by RNA polymerase and other proteins associated with transcription. Other areas on the DNA molecule are recognized as termination sites where RNA polymerase releases the newly synthesized messenger RNA molecules.

7-2 SECTION REVIEW

1. What is the function of RNA?
2. What are three differences between RNA and DNA?
3. What is transcription?
4. Using the base-pairing rules, identify the bases on the messenger RNA strand that are transcribed from the following DNA strands: A-C-C-G-T-C-A-C; T-C-G-C-A-C-G-T.

Section Objectives

- List some of the functions of proteins in cells.
- Describe the process of translation.
- Explain the term codon.
- Identify the three main types of RNA.

Figure 7-15 If a single nucleotide coded for one amino acid, only four amino acids could be specified (top). If two nucleotides specified for one amino acid, there could be 16 amino acids (bottom)—still not enough to code for all 20 amino acids contained in proteins.

Four Code Letters			
A		G	
C		U	
Sixteen Doublets from the Four Code Letters			
AA	AC	AG	AU
CA	CC	CG	CU
GA	GC	GG	GU
UA	UC	UG	UU

7-3 Protein Synthesis

The information that DNA transfers to messenger RNA is in the form of a code. This code is determined by the way in which the four nitrogenous bases are arranged in DNA. To understand how the code works, we must answer two questions: What kind of information is contained in DNA, and how is that information decoded?

The nitrogenous bases in DNA contain information that directs protein synthesis. Why proteins and not other molecules? you might ask. The answer can be found in the diversity of things that proteins are capable of doing. Because most enzymes are proteins, proteins control biochemical pathways within the cell. Not only do proteins direct the synthesis of lipids, carbohydrates, and nucleotides, but they are also responsible for cell structure and cell movement. Like the manager of a factory, DNA does not work on the assembly line but can control what the cell factory makes by issuing orders to the organelles (workers). Together, DNA and its assistant, RNA, are directly responsible for making proteins. As you can see, DNA and RNA are like nucleic-acid executives who run the entire cell factory.

The Nature of the Genetic Code

As you will recall from Chapter 4, proteins are made by stringing amino acids together to form long chains called polypeptides. Each polypeptide contains a combination of any or all of the 20 different amino acids. How, then, can a particular order of nitrogenous bases in DNA and RNA be translated into a particular order of amino acids in a polypeptide?

As you know, DNA and RNA each contain different nitrogenous bases (DNA contains A, T, C, G; RNA contains A, U, C, G); hence, different nucleotides. For this reason, the genetic code must have a four-letter "alphabet." In order to code for the 20 different amino acids, more than one nucleotide must make up the code word for each amino acid. If code words were two nucleotides long, there would be 4^2 , or 16, different code words. This is not enough for 20 amino acids. The four nucleotides arranged in triplets, or threes, however, produce 4^3 , or 64, different code words. This is more than enough to produce a different code word for each amino acid. Therefore, the smallest size for a code word in DNA is three nucleotides.

The code words of the DNA nucleotides are copied onto a strand of messenger RNA. Each combination of three nucleotides on the messenger RNA is called a **codon** (KOH-dahn), or three-letter code word. **Each codon specifies a particular amino acid that is to be placed in the polypeptide chain.** See Figure 7-17. It is interesting to note that there is more than one codon for each amino acid. For example, the amino acid leucine (LOO-seen) has six different codons. There is also one codon, AUG, that can either specify the amino acid methionine (muh-THIGH-uh-neen) or serve as a starter for the synthesis of a protein. For this reason, AUG is called an "initiator" codon. Notice also that there are three "stop" codons. They do not code for an amino acid. Instead, these codons act like the period at the end of a sentence: They signify the end of a polypeptide.

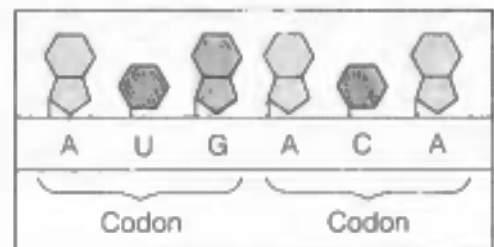
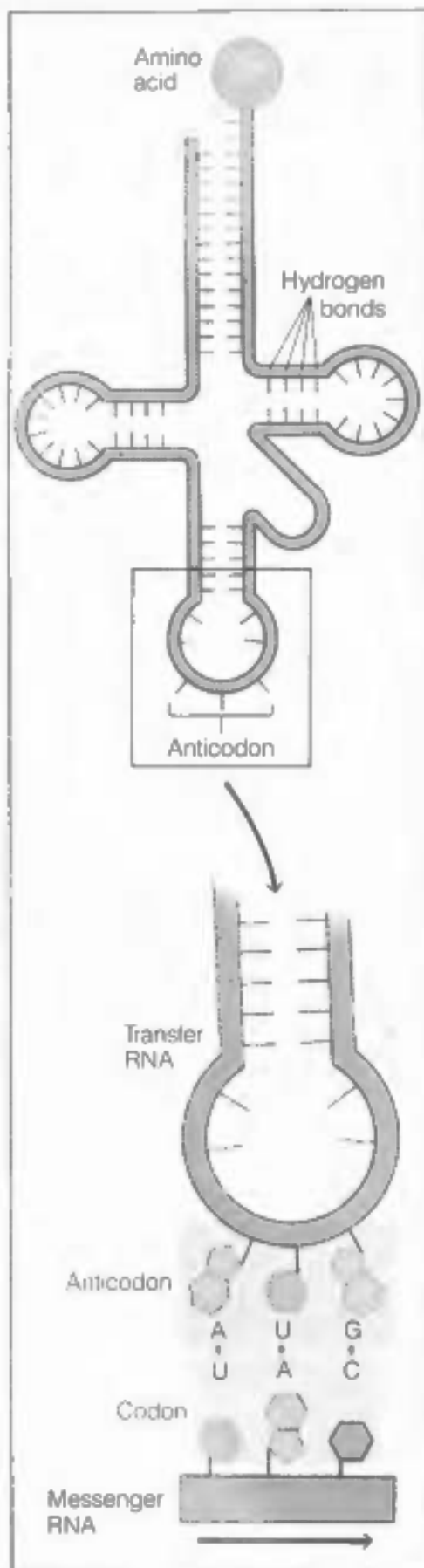


Figure 7-16 Each combination of three nucleotides on messenger RNA is called a **codon**, or three-letter code word.

First Base in Code Word					Third Base in Code Word
	A	G	U	C	
A	Lysine	Arginine	Isoleucine	Threonine	A
	Lysine	Arginine	Methionine	Threonine	G
	Asparagine	Serine	Isoleucine	Threonine	U
	Asparagine	Serine	Isoleucine	Threonine	C
G	Glutamic acid	Glycine	Valine	Alanine	A
	Glutamic acid	Glycine	Valine	Alanine	G
	Aspartic acid	Glycine	Valine	Alanine	U
	Aspartic acid	Glycine	Valine	Alanine	C
U	"Stop" codon	"Stop" codon	Leucine	Serine	A
	"Stop" codon	Tryptophan	Leucine	Serine	G
	Tyrosine	Cysteine	Phenylalanine	Serine	U
	Tyrosine	Cysteine	Phenylalanine	Serine	C
C	Glutamine	Arginine	Leucine	Proline	A
	Glutamine	Arginine	Leucine	Proline	G
	Histidine	Arginine	Leucine	Proline	U
	Histidine	Arginine	Leucine	Proline	C
Second Base in Code Word					

Figure 7-17 The genetic code consists of 64 codons along with their corresponding amino acids. These codons are found on messenger RNA. Of the 64 codons, 61 specify a particular amino acid. The other three are stop codons, which signify the end of a polypeptide chain. What are the three-letter code words for each of the stop codons?



Translation

How does a messenger RNA molecule actually produce a polypeptide? The decoding of a messenger RNA message into a polypeptide chain (protein) is known as **translation**. Translation is an appropriate word for this process because it emphasizes that the message is being translated from the language of nucleic acids into a polypeptide. The messenger RNA molecule does not produce a polypeptide by itself. Instead, there is an elaborate mechanism that involves the two other main types of RNA—**transfer RNA (tRNA)** and **ribosomal RNA (rRNA)**—and the cytoplasmic organelle known as the ribosome.

Transfer RNA carries amino acids to the ribosomes, where the amino acids are joined together to form polypeptides. Transfer RNA is a single strand of RNA that loops back on itself. See Figure 7-18. There are different transfer RNA molecules for each of the 20 amino acids. Ribosomal RNA makes up the major part of the ribosomes.

THE ROLE OF TRANSFER RNA In order to translate the information from a single codon of messenger RNA, such as AUG, we would have to find out which amino acid is coded for by AUG. Look at Figure 7-17 on page 149. As you just read, the codon AUG codes for the amino acid methionine. Methionine is then brought to the polypeptide chain by transfer RNA.

Look at Figure 7-18. You will notice that there are three exposed bases on each transfer RNA molecule. These nucleotides will base pair with a codon on messenger RNA. Because the three nucleotides on transfer RNA are complementary to the three nucleotides on messenger RNA, the three transfer RNA nucleotides are called the **anticodon**.

Attached to each transfer RNA molecule is the amino acid specified by the codon to which it base pairs. By matching the transfer RNA anticodon to the messenger RNA codon, the correct amino acid is put into place. Each transfer RNA acts like a tiny beacon for its specific amino acid.

THE ROLE OF THE RIBOSOME Messenger RNA molecules do not automatically line up transfer RNA molecules and link their amino acids together any more than model airplane parts glue themselves together automatically. Instead, this process of protein synthesis takes place in organelles known as

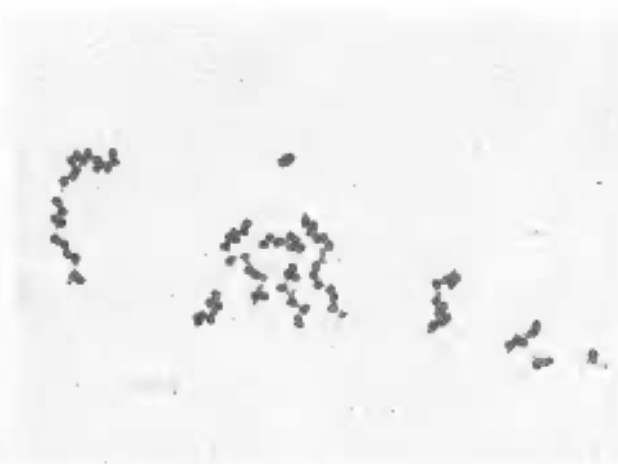
Figure 7-18 Transfer RNA is a single strand of RNA that loops back on itself. Each transfer RNA molecule has two important sites of attachment. One site, called the anticodon, binds to the codon on the messenger RNA molecule. The other site attaches to a particular amino acid. During protein synthesis, the anticodon of a transfer RNA molecule base pairs with the appropriate messenger RNA codon.

Seeing DNA in Action

In this chapter we have been talking about the roles of DNA and RNA in primarily eukaryotic cells, or cells that have a nucleus. However, there exist major groups of living organisms that do not have a nucleus. These organisms are called prokaryotes. Bacteria are examples of prokaryotes.

Because the DNA of a prokaryote is not tucked away in a separate compartment, there is nothing to stop protein synthesis from beginning as soon as the free end of a messenger RNA is available. This means that translation can begin at one end of a messenger RNA molecule before transcription is even completed. It is as if builders started to build one side of a house before the drawings for the other end were even completed!

Oscar Miller, a scientist at the University of Virginia, has pioneered a number of special techniques designed to allow DNA and RNA to be seen in the electron microscope in the act of translation and transcription. Miller's electron micrographs show how simultaneous transcription and translation actually take



This electron micrograph of E. coli genes shows transcription and translation occurring simultaneously.

place. A strand of DNA is being made into messenger RNA at several places at once. Even before the RNA molecules have been completed, several ribosomes have attached themselves to the free ends of the RNA molecule and have begun to make polypeptides. The living cell, obviously, is in a big hurry!

ribosomes. Ribosomes are made up of two subunits, a large one and a smaller one. Each subunit consists of ribosomal RNA and proteins (about 70 different types).

The first part of protein synthesis occurs when the two subunits of the ribosome bind to a molecule of messenger RNA. Then the initiator codon AUG binds to the first anticodon of transfer RNA, signaling the beginning of a polypeptide chain. Soon the anticodon of another transfer RNA binds to the next messenger RNA codon. This second transfer RNA carries the second amino acid that will be placed into the chain of the polypeptide.

As each anticodon and codon bind together, a peptide bond forms between the two amino acids. You will recall from

Key

-  Adenine
-  Uracil
-  Guanine
-  Cytosine

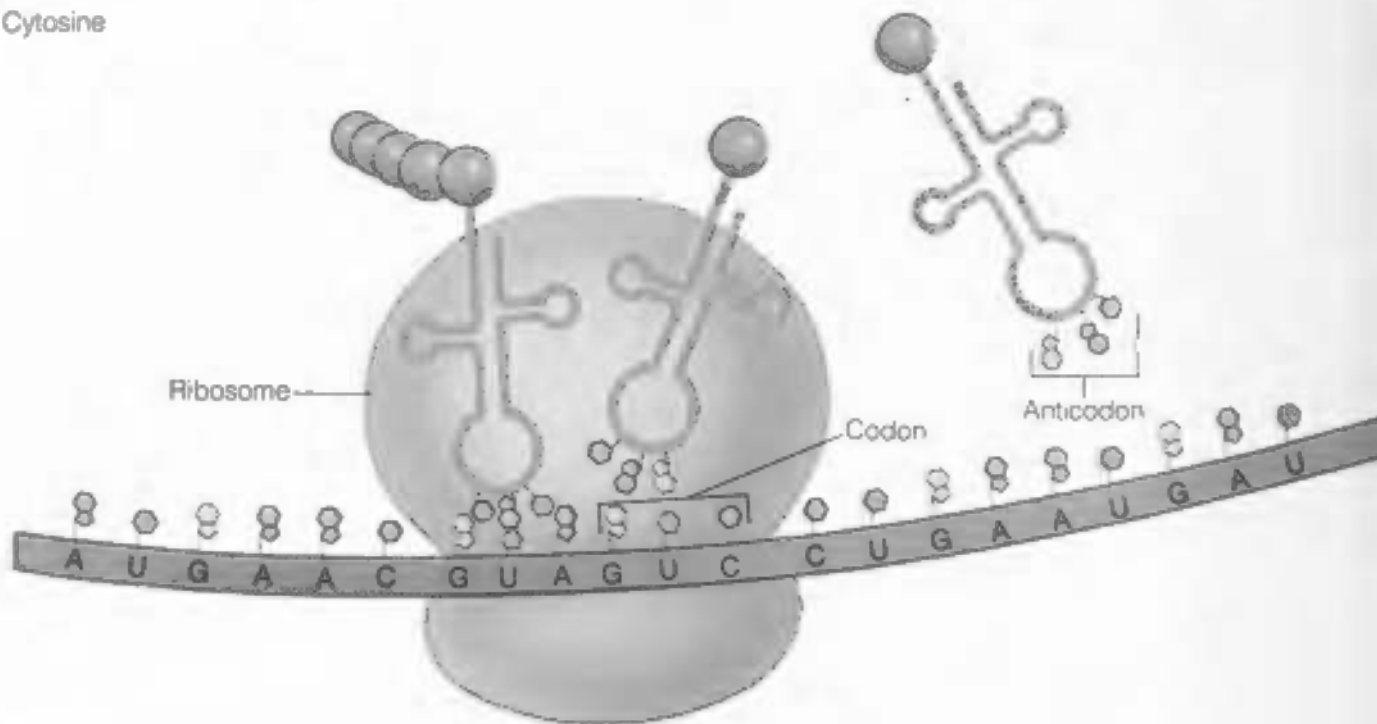
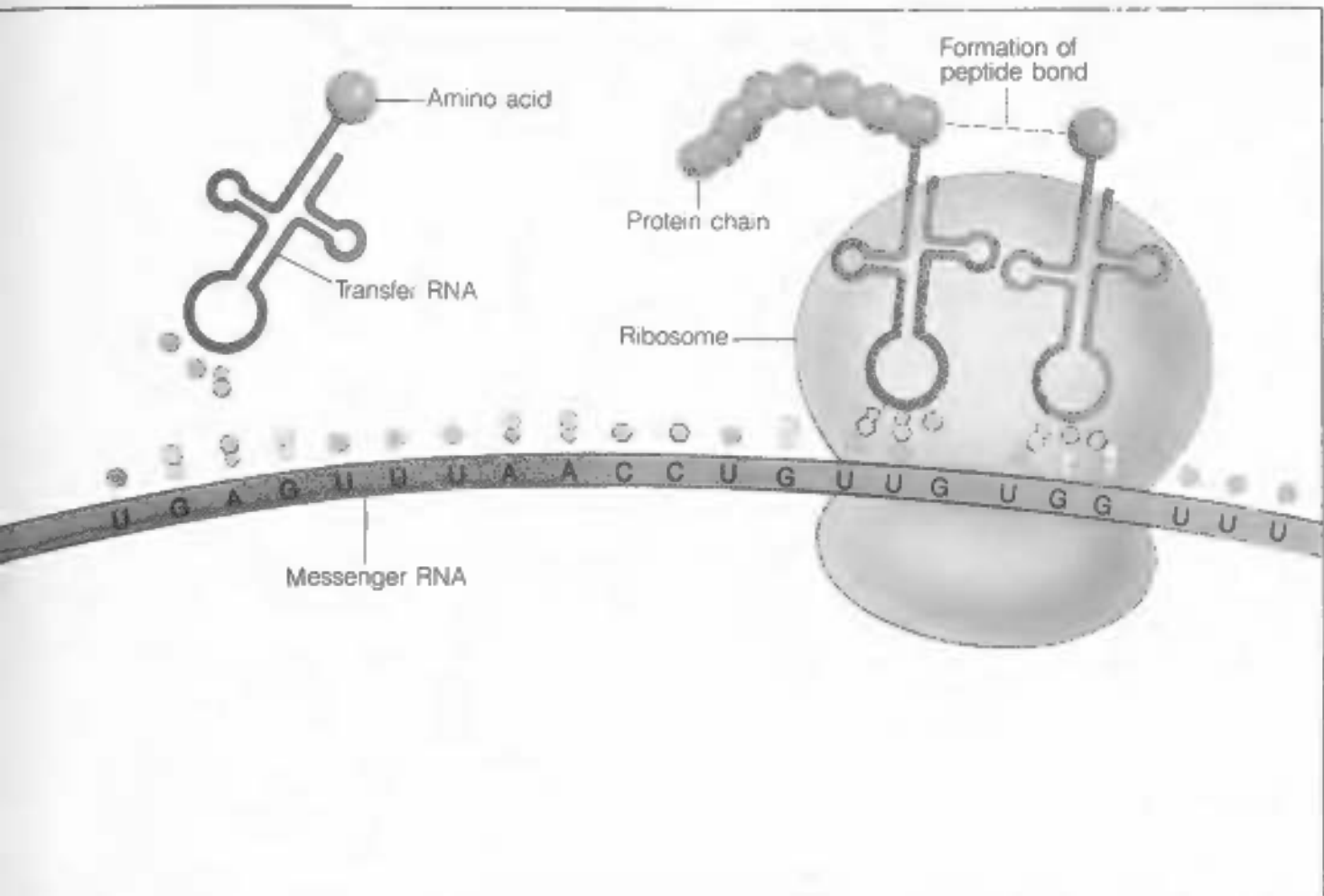


Figure 7-19 During translation, the language of the nucleic acids (DNA and RNA) is transferred to the language of the amino acids. In which cellular organelle does this process take place?

Chapter 4 that a peptide bond is the covalent bond that joins two amino acids together. The polypeptide chain continues to grow until the ribosome reaches a stop codon on the messenger RNA. A stop codon is a codon for which no transfer RNA molecules exist. When the stop codon reaches the ribosome, the ribosome releases the newly formed polypeptide and messenger RNA, completing the process of translation.

As you can now see, the ribosome, in its own way, is at the center of the whole business of making the genetic code work. In the nucleus, DNA directs the formation of three different kinds of RNA: transfer RNA, ribosomal RNA, and messenger RNA. They all leave the nucleus and then seem to go their separate ways. Despite these different paths, however, they all meet again in the ribosome where protein synthesis takes place. So the ribosome can be considered the place where a kind of "class reunion" of RNA molecules occurs. Here each type of RNA molecule plays a role in carrying out the instructions specified in the genetic code. And the genetic code stores the program for protein synthesis and passes it on from generation to generation.



7-3 SECTION REVIEW

1. What is translation? Transcription?
2. UAG is a stop codon. What might happen if the uracil in this codon was changed to cytosine?
3. What is a codon? An anticodon?
4. Name and give the function of the three main types of RNA molecules.
5. Why is a ribosome essential for protein synthesis?
6. What is the role of transfer RNA in translation?
7. If a code on a DNA molecule is CTA for a specific amino acid, what is the messenger RNA codon? The transfer RNA anticodon?
8. A certain protein is made up of 100 amino acids. What is the smallest number of bases in the messenger RNA molecule that is needed to carry the code for the synthesis of this protein?

PROBLEM

How does DNA replicate?

MATERIALS (per group)

colored construction paper:

white	light blue
red	dark green
dark blue	light green

metric ruler
scissors
transparent tape

PROCEDURE

1. With the scissors, cut out the pieces of colored construction paper as indicated in the chart.
CAUTION: Be careful when using scissors. Write the name of each part of your DNA model on the appropriate piece of construction paper.
2. To construct a model of a DNA nucleotide, tape a phosphate group, a sugar, and a guanine (G) together in the same manner as shown in Figure 7-6 on page 141. Then assemble eight additional nucleotide models with the following nitrogenous bases: T, T, A, C, A, A, T, C.

Part of DNA Model	Color	Size (cm x cm)	Number
Sugar	White	2 x 2	54
Phosphate group	Red	1 x 2	54
Adenine (A)	Dark blue	1 x 2	18
Thymine (T)	Light blue	1 x 2	18
Guanine (G)	Dark green	1 x 2	9
Cytosine (C)	Light green	1 x 2	9

3. Attach the nine nucleotide models together in the sequence given in step 2 (G, T, T, A, C, A, A, T, C) by taping the sugar on one nucleotide to the phosphate group on the next nucleotide. This will form the single strand of your DNA model.
4. Using the rules for base pairing, construct a second strand of the DNA model that is complementary to the first strand. Tape the nucleotides together as you did in step 3. Do not tape the two strands of DNA together.
5. Separate the two strands and use each to construct a new complementary strand.
6. Reassemble the original double strand of DNA. Tape this model of DNA together at its nitrogenous bases.
7. Again using the base-pairing rules, construct a complementary strand for each of the single strands of DNA you made in step 5. Tape these two new DNA models together at their nitrogenous bases. Compare the new double-stranded DNA models with your original DNA model.

OBSERVATIONS

1. What is the sequence of nitrogenous bases in the complementary strand of your original DNA model?
2. How many models of DNA did you construct from your original model of DNA? What is the base sequence for each of these new models?

ANALYSIS AND CONCLUSIONS

1. Why do you think complementary base pairing is necessary for replication?
2. Compare the base sequences of the original DNA model with the replicated models. Compare the base sequences of the replicated models.
3. If each triplet of nitrogenous bases on DNA codes for a specific amino acid, how many amino acids will your original DNA model code for?

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

7-1 DNA

- DNA is the nucleic acid that stores and transmits the genetic information from one generation of an organism to the next.
- DNA is a polymer that is made up of units called nucleotides. Each nucleotide is a molecule made up of three parts: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous base.
- DNA has four nitrogenous bases: adenine, thymine, cytosine, and guanine. Adenine and guanine belong to a group of compounds called purines. Thymine and cytosine belong to a group of compounds called pyrimidines.
- During replication, the DNA molecule unzips, or separates, into two strands. Each of the separated strands serves as a template, or pattern, for the attachment of complementary nucleotides.

7-2 RNA

- There are three major differences between

DNA and RNA: RNA contains the sugar ribose instead of deoxyribose; RNA is usually single-stranded instead of double-stranded; and RNA contains the nitrogenous base uracil instead of thymine.

- During transcription, the DNA code is transferred to messenger RNA, which carries the code out of the nucleus into the cytoplasm.

7-3 Protein Synthesis

- During translation, messenger RNA binds to the ribosomes on which ribosomal RNA is found. Amino acids in the cytoplasm are picked up by transfer RNA and are carried to messenger RNA. The anticodons in transfer RNA attach to the proper codons in messenger RNA. Thus the messenger RNA acts as the pattern for protein synthesis. In this way, amino acids are brought together in the correct sequence to form a protein molecule.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meaning. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

7-1 DNA

genetic code	guanine
transformation	cytosine
DNA	thymine
nucleotide	base pairing
adenine	replication

7-2 RNA

RNA
uracil
transcription
messenger
RNA

7-3 Protein Synthesis

codon
translation
transfer RNA
ribosomal RNA
anticodon

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- The process of changing one strain of bacteria into another is called
 - transformation.
 - translation.
 - replication.
 - transcription.
- DNA is a
 - carbohydrate.
 - lipid.
 - nucleic acid.
 - sterol.
- A nucleotide of DNA would contain
 - uracil, deoxyribose, and phosphate.
 - phosphate, deoxyribose, and thymine.
 - nitrogenous base, phosphate, and glucose.
 - adenine, ribose, and phosphate.
- Watson and Crick described the DNA molecule as a
 - branching chain.
 - straight chain.
 - single strand.
 - double helix.
- Between which types of compounds in a double-stranded DNA molecule must the bonds break before replication takes place?
 - phosphate-base
 - sugar-phosphate
 - adenine-thymine
 - sugar-base
- To which organelles does messenger RNA attach?
 - chloroplasts
 - ribosomes
 - mitochondria
 - lysosomes
- The coded information in a DNA molecule directly determines the formation of
 - polysaccharides.
 - lipids.
 - monosaccharides.
 - polypeptides.
- If the code for an amino acid is ATG on the DNA molecule, this code on the transfer RNA molecule may be written as
 - ATG.
 - CTG.
 - AUG.
 - CTA.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- A molecular group consisting of a sugar molecule, a phosphate group, and a nitrogenous base is a nucleic acid.
- In a DNA molecule, a base pair would be composed of adenine and guanine.
- Cytosine and adenine are purines.
- During the replication of DNA, bonds are broken between the phosphate groups.
- RNA contains the nitrogenous base uracil.
- There are 20 different amino acids in a cell.
- The coded message carried by messenger RNA is translated into polypeptides at organelles called chloroplasts.
- The decoding of a messenger RNA message into a polypeptide chain is known as translation.

Word Relationships

A. In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

- deoxyribose, phosphate, DNA, uracil
- amino acid, polypeptide, protein, translation
- ribose, RNA, thymine, adenine
- A—T, C—G, A—U, C—T

- B. *Replace the underlined definition with the correct vocabulary word.*
5. The attraction between nitrogenous bases is the force that holds the two strands of DNA together.
 6. Each combination of three nucleotides on messenger RNA specifies a specific amino acid that is to be placed in the polypeptide chain.
 7. The RNA that carries amino acids to the ribosomes is a single strand of RNA that loops back on itself.
 8. As a ribosome moves along a strand of messenger RNA, each codon is paired with its three nucleotides on transfer RNA that are complementary to the three nucleotides on messenger RNA.

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Describe Griffith's experiments involving bacterial transformation.
2. How did the study of bacteriophages lead scientists to support the idea that DNA carries hereditary material?
3. What was the contribution made by Hershey and Chase to understanding the genetic code?
4. How did Franklin's work contribute to the discovery of the structure of DNA?
5. Describe the contribution of Watson and Crick.
6. Describe DNA replication. What is its importance?
7. List three differences between DNA and RNA.
8. How is messenger RNA formed during transcription?
9. What is the function of the ribosomes?
10. What is the relationship between an amino acid and a codon?

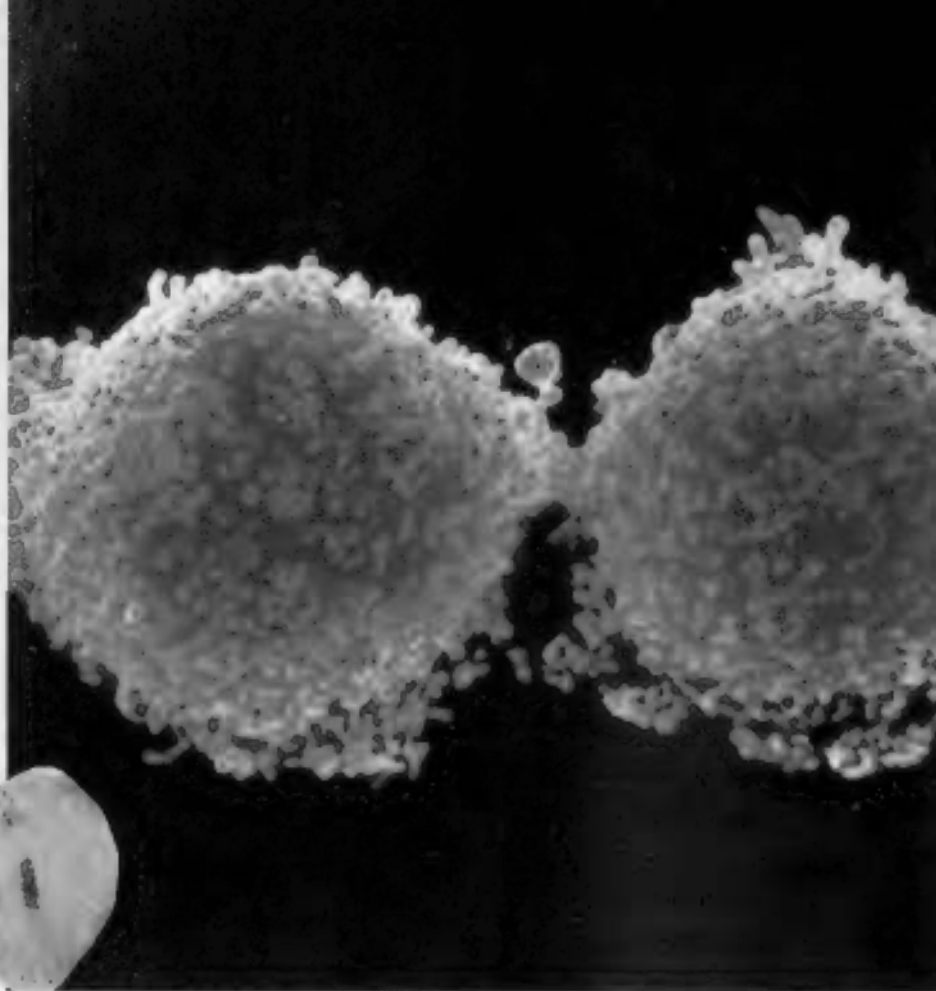
CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Identifying patterns** Oxytocin is a hormone that helps to regulate blood pressure and stimulates the uterus to contract during childbirth. Following is a DNA sequence that could code for a part of a molecule of oxytocin: ACA ATA TAG CTT TTG ACG GGG AAC CCC ATT. Write the sequence of messenger RNA codons that would result from the transcription of this portion of DNA.
2. **Relating facts** How many guanines are in a DNA molecule 1000 base pairs long if 20% of the molecule consists of thymines?
3. **Applying concepts** Write out the messenger RNA sequence that would be transcribed from the following strand of DNA: T-A-C-A-A-G-T-A-C-T-T-G-T-T-T-C-T-T. Then using Figure 7-17 on page 149, write the amino acid sequence that would be translated when the messenger RNA combines with a ribosome.
4. **Using the writing process** Write a short story that follows a protein molecule from its point of origin in a corn kernel, through its use as cattle food, to a position of importance as a protein in your body.

CHAPTER 8

Cell Growth and Division



As a cell undergoes cell division the two daughter cells pull apart. Before the cell divides, the nucleus must go through a series of stages that ensure that the daughter cells are exact copies of the parent cell (inset).



One of the major characteristics of a living thing is the ability to grow. Growth is obvious when it involves an increase in size. We all notice the growth of grass and flowers in the spring and summer or the growth of a newborn animal into an adult. The growth of an organism results from an increase in the number and the size of the cells within it. But growth occurs even in organisms that are no longer increasing in size—continued cell growth is essential for life.

How do cells grow? Is there a limit to the growth of a cell? In this chapter we will examine how cells grow in size and increase in number, and why growth is so essential to living things.

8-1 Cell Growth

- Limits of Cell Growth
- Rates of Cell Growth
- Controls on Cell Growth
- Uncontrolled Cell Growth

8-2 Cell Division: Mitosis and Cytokinesis

- Chromosomes
- The Cell Cycle
- Interphase
- Prophase
- Metaphase
- Anaphase
- Telophase
- Cytokinesis

8-1 Cell Growth

Section Objectives

- Describe cell growth.
- Define cell division.
- Relate cell growth to cell division.

As you already know, living things are made up of cells. And living things grow, or increase in size. Does a living thing grow because its cells get larger and larger or does it grow because it produces more and more cells? **In most cases, a living thing grows because it produces more and more cells.** The cells of a human adult are no larger than the cells of a human baby, but there are certainly more of them.

Does growth have to occur in this way? Or could an organism grow simply by allowing its cells to get larger and larger? Let's consider what would happen if this could occur.

Limits of Cell Growth

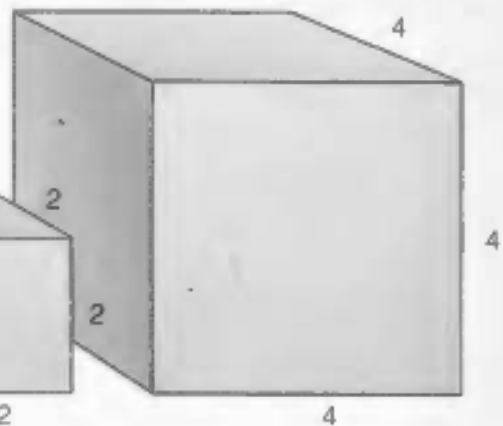
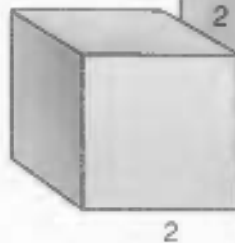
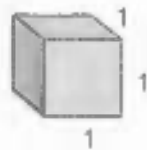
You will recall from Chapter 5 that it is through the cell membrane that food, oxygen, and water enter the cell and waste products leave the cell. How quickly this exchange takes place depends on the surface area of the cell, or the total area of the cell membrane. How quickly food and oxygen are used up and waste products are produced depends on the cell volume, or the amount of space within the cell.

If we were to take a typical cell and double its diameter, what would happen to the amount of membrane (surface area) compared to the amount of material inside the cell (cell volume)? Look at Figure 8-2 on page 160. Notice that as the cell

Figure 8-1 As living things grow they produce more cells. Although this adult white bengal tiger is larger than its cub, the sizes of its cells are the same as those of the cub's.



Surface-to-Volume Ratio in Cells



Volume	1 cm ³	8 cm ³	64 cm ³
Surface Area	6 cm ²	24 cm ²	96 cm ²
Surface-to-Volume Ratio	6	3	1.5

Figure 8-2 If the length of each side of a cube-shaped cell doubles from 1 to 2 to 4, the volume increases more rapidly than does the surface area. As a result, the ratio of surface area to volume decreases and the cell with the largest volume has a more difficult time getting materials in and waste products out.

increases in size, its volume increases at a faster rate than its surface area. For example, if the diameter of the cell increases 10 times, its surface area increases 100 times. Its volume, however, increases 1000 times!

The fact that surface area and volume do not increase at the same rate creates problems for the cell. The larger cell will have a more difficult time getting oxygen and nutrients in and waste products out.

To help you understand why the larger cell has a more difficult time than the smaller cell, let's compare the cells to a small and a large office building. Suppose the small office building that is serviced by a two-lane highway is replaced by a large office building. Now more people work in the office building. But the highway leading to the large building has not increased in size. It is the same two-lane highway that serviced the small office building. As a result, the people in the large building will have difficulty with traffic getting to the office in the morning and leaving the office in the evening.

A larger cell will experience similar problems—materials will have trouble entering and leaving the cell. This is one reason why cells do not grow much larger even if the organism of which they are a part does. There is another reason too.

As you will recall from Chapter 7, information for the cell's function and survival is stored in the sequence of nitrogenous bases in DNA. In eukaryotic cells, the DNA is stored in the nucleus of the cell. When the cell is small, copies of DNA that are stored in the nucleus are able to produce enough messenger RNA to make all the proteins the cell needs. But even though the cell increases in size, it does not make extra copies of DNA.

(There are a few exceptions that we will learn about later.) If a cell were to grow without limit, an “information crisis” would occur. Like a town that has tripled in size but has not added a single book to its library, the cell must now make greater demands on its available genetic library.

In many cases, the amount of messenger RNA that is produced in the cell increases—but within limits. After a time, the cell’s DNA may no longer be able to make enough RNA to supply the increasing needs of the growing cell. The cell must slow down its growth, thus becoming less efficient. The cell undergoes a process called **cell division** to solve these problems. **Cell division is the process whereby the cell divides into two daughter cells.** We will discuss cell division in more detail later in the chapter.

Rates of Cell Growth

Cells can grow at astonishing rates. For example, the bacterium *Escherichia coli* (ehsh-uh-RIHK-ee-uh KOH-ligh), or *E. coli*, is a single-celled organism that can easily double its volume in about 30 minutes. It can then divide to form two new cells. If conditions are ideal, each of these cells can grow to form two new cells in the next 30 minutes.

Ideal conditions for this kind of growth can never be maintained for very long, however. A quick look at the consequences of rapid growth will explain why. In just one day, a single cell would grow into a 14-kilogram mass of bacteria. In three days, the mass of the cells would equal the mass of the Earth! Real conditions, or the circumstances that cells normally face, are very different.

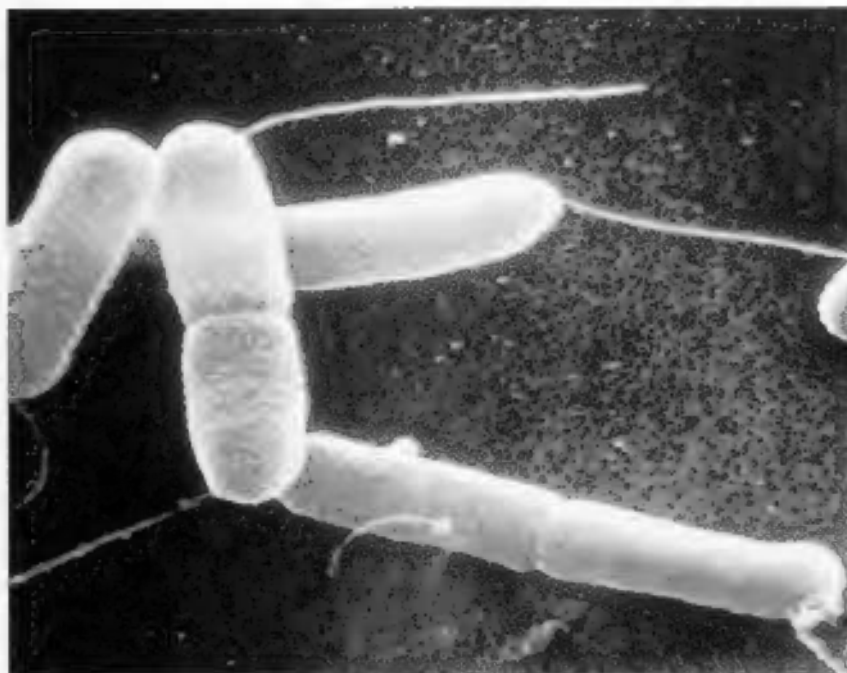


Figure 8-3 Single-celled prokaryotic organisms reproduce by cell division. In this scanning electron micrograph of bacteria (*E. coli*), you can see two bacteria undergoing cell division.



Figure 8-4 The scientist in this photograph is growing pine tree cells on culture plates. As the cells divide they will form a continuous layer, one cell thick, across the surface of each culture plate. But when the cells come in contact with adjacent cells, they will stop growing and dividing.

Controls on Cell Growth

One of the most striking aspects of cell behavior in a multicellular organism is how carefully cell growth and cell division are controlled. Cells in certain places in the body, such as the heart and the nervous system, rarely divide—if they divide at all. In contrast, the cells of the skin and digestive tract grow and divide rapidly throughout life, providing new cells to replace those that are worn out or broken down due to daily wear and tear.

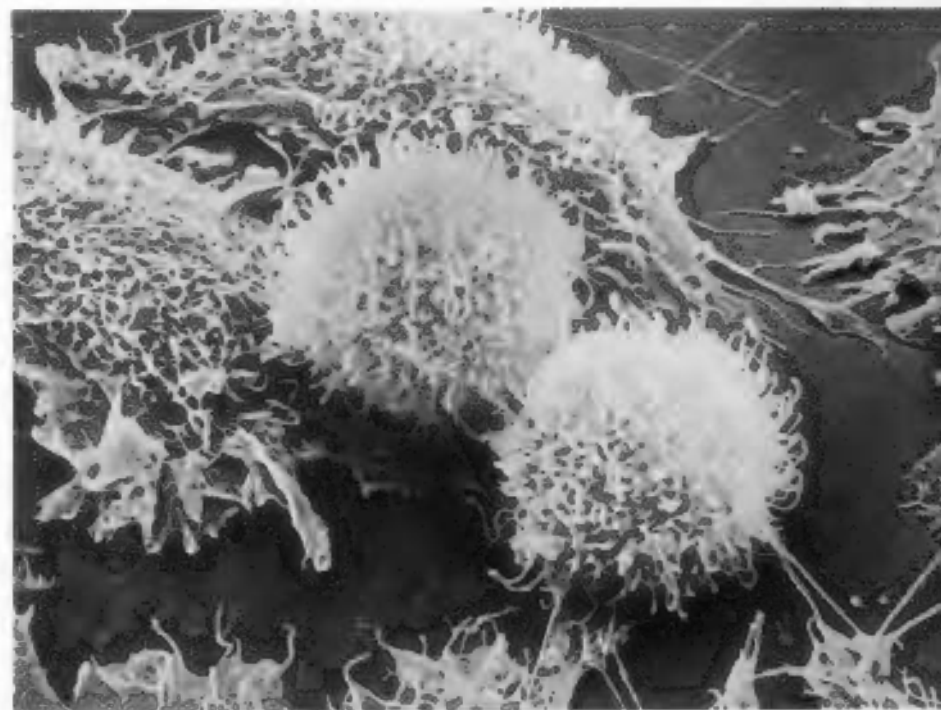
We can observe the effects of controlled cell growth in the laboratory by placing some cells in a petri dish containing nutrient broth. The nutrient broth provides food for the cells. Most cells will grow until they form a thin layer covering the bottom of the dish. Then the cells will stop growing. Why do they stop growing? When cells come into contact with other cells, they respond by not growing. At present, scientists are trying to understand how this process works.

Controls on cell growth and cell division can be turned on and off. When an injury—such as a cut in the skin or a break in a bone—occurs, cells at the edges of the injury are stimulated to divide rapidly. This action produces new cells, starting the process of healing. When the healing process nears completion, the rate of cell division slows down, controls on growth seem to be reimposed, and everything returns to normal.

Uncontrolled Cell Growth

The consequences of uncontrolled cell growth in a multicellular organism are severe. Cancer, a disorder in which some

Figure 8-5 Unlike normal cells, cancer cells do not stop growing and dividing even if they come in contact with other cells. Actually, cancer cells, such as those shown in this scanning electron micrograph, have lost their ability to control their own rate of growth.



PROBLEM SOLVING IN BIOLOGY

SCIENTIFIC NOTATION

How many cells would you suspect there are in the human body? There are approximately 100,000,000,000,000 cells. And all these cells arise from a human egg cell that is only 0.0001 meter in diameter!

As you can see, there are numbers associated with biology that are so large that they are also difficult to write and understand. For this reason, scientific notation is used. Scientific notation is also known as exponential notation because it uses the exponential form of a number.

The exponential form of a number is made up of two parts: $M \times 10^n$. The first part, M , is a number between 1 and 10. The second part, n , is an exponent, or power, to which the base 10 is raised. An exponent indicates how many times the base is to be multiplied by itself.

Because the base is 10, what the exponent actually does is locate the decimal point in the number being represented. It does this by indicating how many places the decimal point in M must be moved. The decimal point is moved to the right if the exponent is positive and to the left if the exponent is negative. A negative exponent is a negative power of 10. It is shorthand for 1 divided by a power of 10.

To convert a large number to scientific notation, follow these steps.

1. Determine M by moving the decimal point in the number (100,000,000,000,000) to the left or the right so that only one digit is to the left of it.

$$\begin{array}{r} 100,000,000,000,000. \\ 1:00,000,000,000,000 \end{array}$$

2. Determine n by counting the number of places the decimal point has been moved. If moved to the left, n is positive; if moved to the right, n is negative.

$$\begin{array}{r} 1.00,000,000,000,000 \\ \text{14 places} \\ \text{to the left} \end{array}$$

3. Then write the number 1 multiplied by the base 10 with its exponent.

$$1 \times 10^{14} = 100,000,000,000,000$$

To convert a small number to scientific notation, follow these steps.

1. Determine M by moving the decimal point in the number (0.0001) to the left or the right so that only one digit is to the left of it.

$$\begin{array}{r} 0.0001 \\ 0.0001: \end{array}$$

2. Determine n by counting the number of places the decimal point has been moved. If moved to the left, n is positive; if moved to the right, n is negative.

$$\begin{array}{r} 0.0001 \\ \text{4 places} \\ \text{to the right} \end{array}$$

3. Then write the number 1 multiplied by the base 10 with its exponent.

$$1 \times 10^{-4} = 0.0001$$

Complete the following exercises. Check your answers by using a calculator or computer, if one is available.

A. Expressing Numbers in Scientific Notation

1. The average length of a mitochondrion is 0.00000001 cm.
2. A rat contains approximately 10,000,000,000 cells.

B. Converting Scientific Notation into Numbers

1. The average diameter of a bacterium is 2×10^{-6} cm.
2. The resolving power of an electron microscope is 1×10^6 times greater than that of the human eye.

cells have lost the ability to control their own rate of growth, is one such example. When cancer cells are placed in a culture of living tissue, they do not stop growing even though they come into contact with other cells. Cancer cells will continue to grow and divide until the supply of nutrients is exhausted.

Cancer is a serious disorder that claims many lives and affects all of us, directly or indirectly. To cell biologists, cancer provides valuable information concerning the importance of controls on cellular growth.

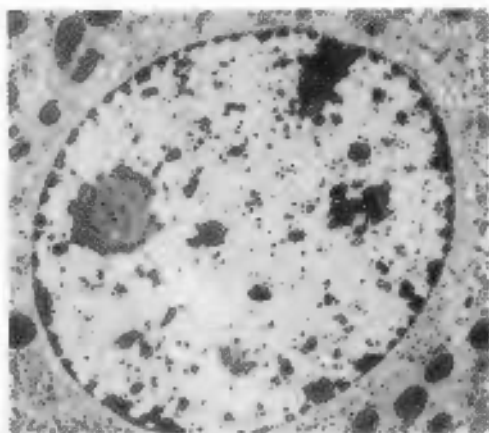
8-1 SECTION REVIEW

1. What is growth? What controls cell growth?
2. What is cell division?
3. A newly discovered strain of bacteria divides once every 60 minutes under ideal conditions. After 24 hours, a single bacterium produces cells that have a mass of 1 kilogram. From this information, calculate the average mass of a single bacterium.

Section Objectives

- Define mitosis and cytokinesis.
- Describe the cell cycle and the changes that take place during interphase.
- Discuss the events and the significance of mitosis.

Figure 8-6 When a cell is not dividing, the chromatin forms condensed and dispersed regions.



8-2 Cell Division: Mitosis and Cytokinesis

In this section we will discuss how eukaryotic cells divide and form two cells. The division of eukaryotic cells occurs in two main stages. The first stage of cell division is called **mitosis** (migh-TOH-sihs). **Mitosis is the process by which the nucleus of the cell is divided into two nuclei, each with the same number and kinds of chromosomes as the parent cell.**

The second stage of cell division is known as **cytokinesis** (sight-oh-kih-NEE-sihs). **Cytokinesis is the process by which the cytoplasm divides, thus forming two distinct cells.**

Because the structure of a eukaryotic cell is complex, the process of cell division in this type of cell is complex too. The reason for this complexity may be found in the need to separate large amounts of DNA accurately and efficiently. With as many as 100 chromosomes to take care of, a mechanism must exist in the eukaryotic cell to make certain that each new cell gets one (and only one) copy of each chromosome. A mistake in the process could make it impossible for one or both daughter cells to remain alive.

Chromosomes

You will recall from Chapter 5 that **chromosomes** are structures in the cell that contain the genetic information that is passed on from one generation of cells to the next. The word

chromosome, meaning colored body, was derived from the fact that when a dye was added to the cell, the chromosomes picked up the color of the dye and were easily seen through the light microscope during cell division. Unfortunately, chromosomes are not visible in most cells except during mitosis.

Chromosomes contain the genetic information in the form of DNA. In prokaryotic cells, the chromosomes are made up of long circular molecules of DNA. In eukaryotic cells, the chromosomes are made up of distinct lengths of DNA. The cells of every organism contain a specific number of chromosomes. Human cells, for example, contain 46 chromosomes; goldfish cells contain 94 chromosomes. See Figure 8-7.

COMPOSITION OF CHROMATIN Chromosomes are made up of a material called **chromatin** (KROH-muh-tihn). During the period of time between cell divisions, chromatin forms condensed and dispersed regions. See Figure 8-6. During the early stages of mitosis, the chromatin condenses and the chromosomes become visible.

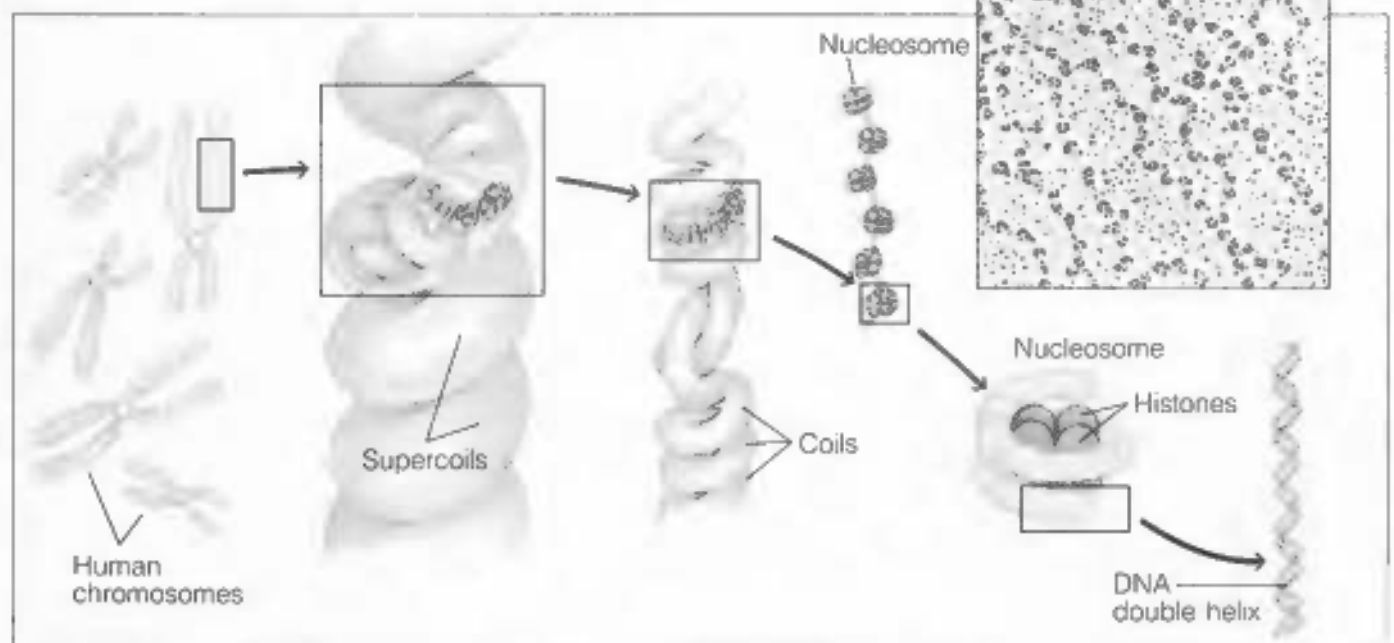
Chromatin is composed of DNA and protein. Much of this protein is involved in the folding of DNA so that it can fit within the nucleus. This is an important job because the DNA double helix that makes up a chromosome is much longer than the chromosome itself. In fact, the total length of DNA in a typical human chromosome is about 10,000 times the length of the chromosome! How does all that DNA fit into the chromosome?

In 1973, the American scientists Don Olins, Ada Olins, and Christopher Woodcock discovered that the chromosomes' DNA was coiled around special proteins called histones. Together, the DNA and histone molecules formed beadlike structures

Organism	Chromosome Number
Ameba	50
Carrot	18
Cat	32
Chimpanzee	48
Dog	78
Earthworm	36
Goldfish	94
Human	46
Lettuce	18

Figure 8-7 Which organism's chromosome number is closest to that of an ameba?

Figure 8-8 Chromosomes contain highly coiled and supercoiled strands of DNA. Notice that a small part of the supercoil is made up of nucleosomes (inset).



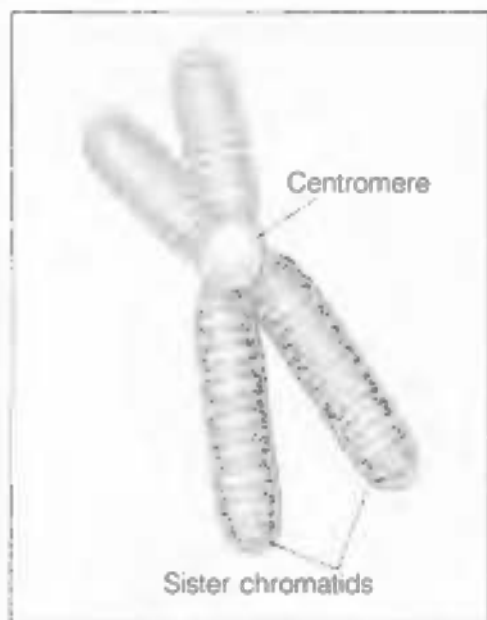


Figure 8-9 The diagram of a chromosome shows that it consists of two chromatids attached by means of a centromere. A human chromosome is shown as it appears through an electron microscope.

called nucleosomes (NOO-klee-oh-sohmz). The nucleosomes interact with one another to form a thick fiber, which is shortened by a system of loops and coils. The result is the tightly packed chromosomes that are seen through a light microscope in dividing cells. The tight packing of nucleosomes may be necessary in order to form a compact structure that can be separated during mitosis.

CHROMOSOME STRUCTURE After DNA replication, the chromosomes become visible by condensing. This is the beginning of mitosis. The chromosome contains two **chromatids** (KROH-muh-tihdz), or identical parts, which are often called sister chromatids. Each pair of chromatids is attached at an area called the **centromere** (SEHN-troh-mihr). Centromeres are usually located near the middle of the chromatids, although some centromeres lie near the ends of the chromatids. A human cell entering mitosis contains 46 chromosomes, each of which consists of two chromatids.

The Cell Cycle

At one time biologists described the life of a cell as one mitosis after another separated by an "in-between" period of growth called interphase. We now know more and can represent some of the events in the life of a cell by using a concept known as the **cell cycle**. The cell cycle is the period from the beginning of one mitosis to the beginning of the next. **During a cell cycle, a cell grows, prepares for division, and divides to form two daughter cells, each of which begins the cycle anew.**

The cell cycle includes mitosis, a period of active division, and interphase, a period of nondivision during which other processes take place. It also includes a process in which cytoplasm and its contents divide forming the two daughter cells. You will learn about this process, called cytokinesis, later in this section. Mitosis is represented as the M phase. During mitosis, the nucleus divides into two nuclei. Interphase is usually divided into three phases: G₁ (gap 1), S (DNA synthesis), and G₂ (gap 2). G₁ and G₂ were once thought to be gaps but are now known as periods of growth and activity.

The time required to complete a single turn of the cycle is the time required for a cell to reproduce itself. Not all cells move through the cell cycle at the same rate. In the human body, most muscle cells and nerve cells do not divide at all once they have developed. In contrast, the cells that line the organs of the digestive system grow and divide rapidly. In fact, these cells may pass through a complete cycle every six hours.

Interphase

Within the normal cell cycle, **interphase**, or the period between cell divisions, can be quite long, whereas the actual divi-

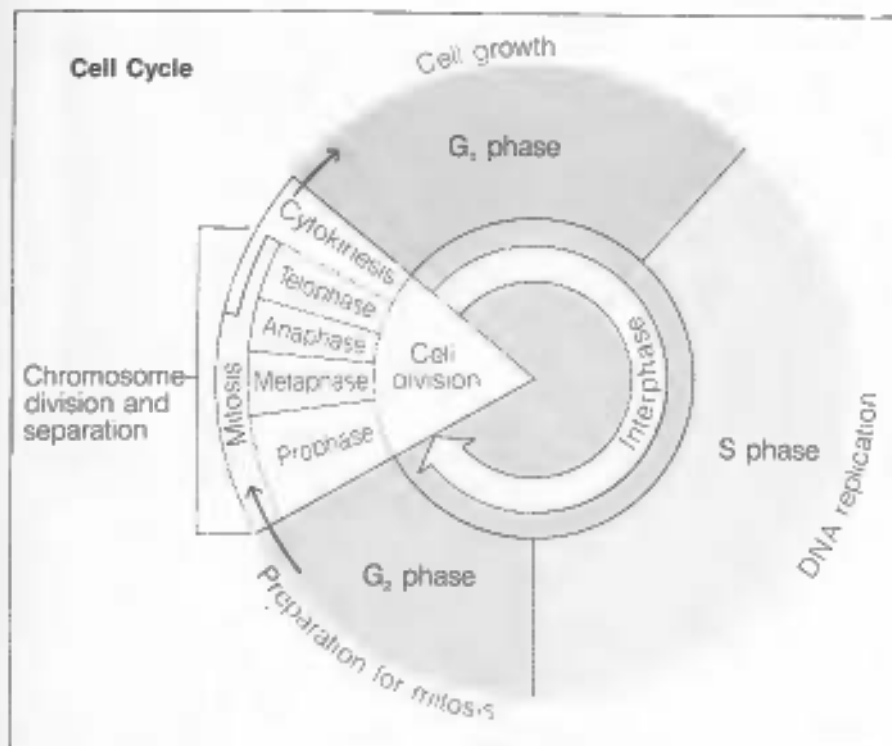


Figure 8-10 The cell cycle includes mitosis, cytokinesis, and the three phases of interphase. What are the names of the three phases of interphase?

sion of the cell takes place quickly. As you read, interphase is divided into three phases: G_1 , S, and G_2 . Each of these phases is characterized by specific events.

The G_1 , or gap 1, phase is a period of activity in which cellular growth and development take place. G_1 is followed by the S, or DNA synthesis, phase. During this phase, DNA replication takes place. Several proteins, including those associated with the chromosomes, are synthesized during the S phase.

Finally, when the S phase is completed, the cell enters the G_2 , or gap 2, phase. This phase is usually the shortest of the three phases of interphase. The G_2 phase involves the synthesis of organelles and materials required for cell division.

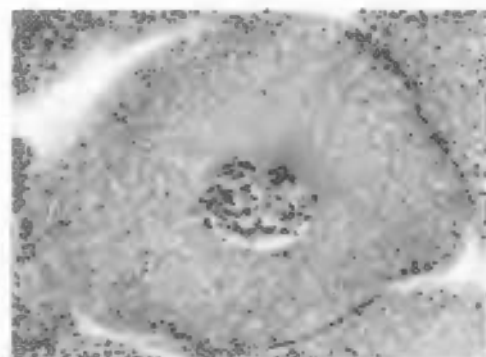
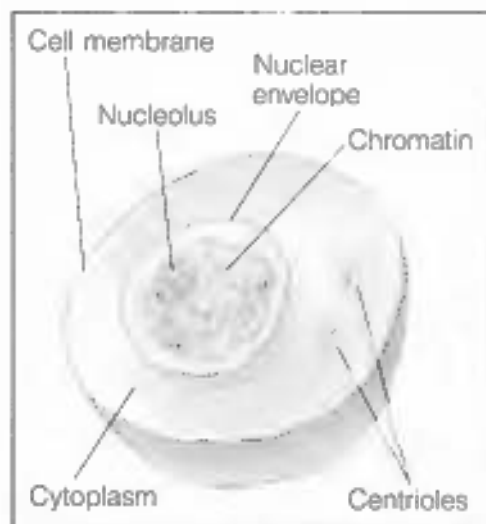
During interphase, the nucleus is active in synthesizing messenger RNA in order to direct cellular activities. Although the cell seems to be “quiet” during interphase, it is actually a period of intense activity. Proteins are made; DNA is copied; ATP is made and utilized. In multicellular organisms, cells that are specialized for jobs such as secretion, movement, and signaling do most of their work during interphase.

Prophase

Recall that mitosis, or the M phase of the cell cycle, is the process by which the cell’s nucleus divides into two nuclei. Mitosis may last anywhere from a few minutes to several days, depending on the type of cell. **Mitosis is divided into four phases: prophase, metaphase, anaphase, and telophase.**

The first phase of mitosis, **prophase**, is the longest phase, frequently taking 50 to 60 percent of the total time required to

Figure 8-11 Interphase is the part of the cell cycle that occurs before mitosis can take place. Notice that the chromatin in the nucleus appears as an indistinct mass of threadlike structures.



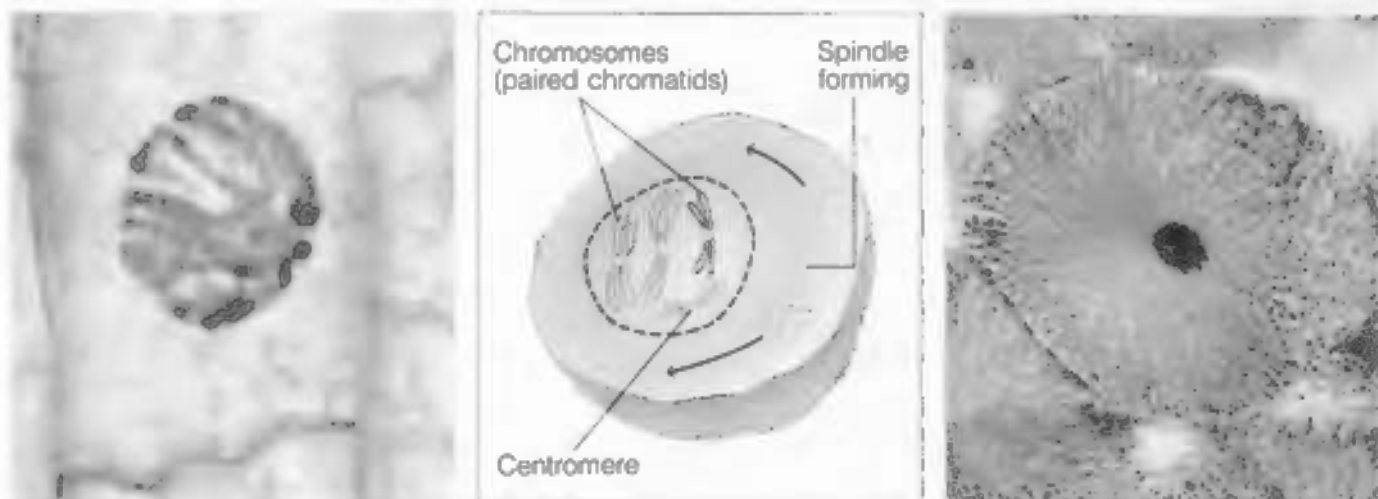


Figure 8-12 During prophase, the first stage of mitosis, the chromatin condenses into distinct chromosomes and the nucleolus disappears. The photomicrographs show prophase in a plant cell (left) and an animal cell (right).

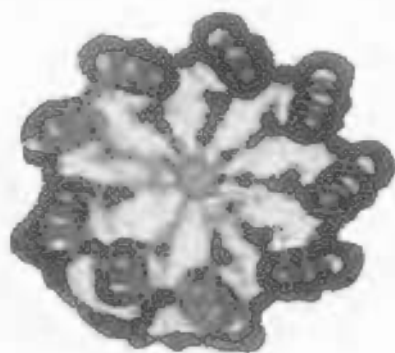
complete mitosis. The first clue that prophase is beginning is the appearance of chromosomes. Chromosomes become visible as a result of the condensing and coiling of the yarnlike chromatin. Under a light microscope, each chromosome is seen as two identical chromatids lying side by side. Recall that the area where two chromatids are attached to each other is called the centromere.

During prophase, the **centrioles**, two tiny structures located in the cytoplasm near the nuclear envelope, separate from each other and take up positions on the opposite sides of the nucleus. Centrioles are structures that contain tubulin, a microtubule protein.

During prophase, the condensed chromosomes become attached to fibers in the **spindle** at a point near the centromere of each chromatid. The spindle, a meshlike structure that helps move the chromosomes apart, develops from the centrioles. Recall from Chapter 5 that plant cells do not contain centrioles. However, plant cells form a spindle that is almost identical in structure to that of animal cells. Like the centrioles, the fibers of the spindle are composed of microtubules.

Near the end of prophase, the coiling of the chromosomes becomes tighter. In addition, the nucleolus disappears and the nuclear envelope breaks down.

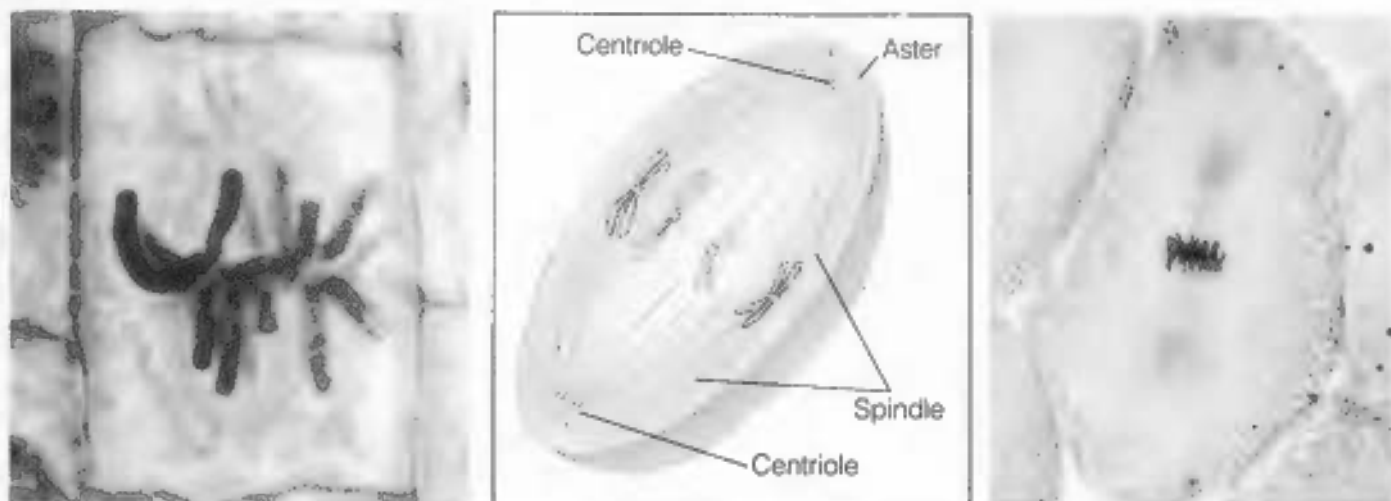
Figure 8-13 Notice the ringlike shape of a centriole in this electron micrograph. Centrioles are cellular structures that are found near the nuclear envelope of an animal cell and play a part in mitosis.



Metaphase

As prophase ends, **metaphase**, or the second phase of mitosis, begins. Metaphase is the shortest phase of mitosis. It often lasts only a few minutes.

During metaphase, the chromosomes line up across the center, or equator, of the cell. Microtubules connect the centromere of each chromosome to the poles of the spindle. Because of their starlike arrangement around the poles of the spindle, these microtubules are called **asters**, which is the Greek word for star. See Figure 8-14.



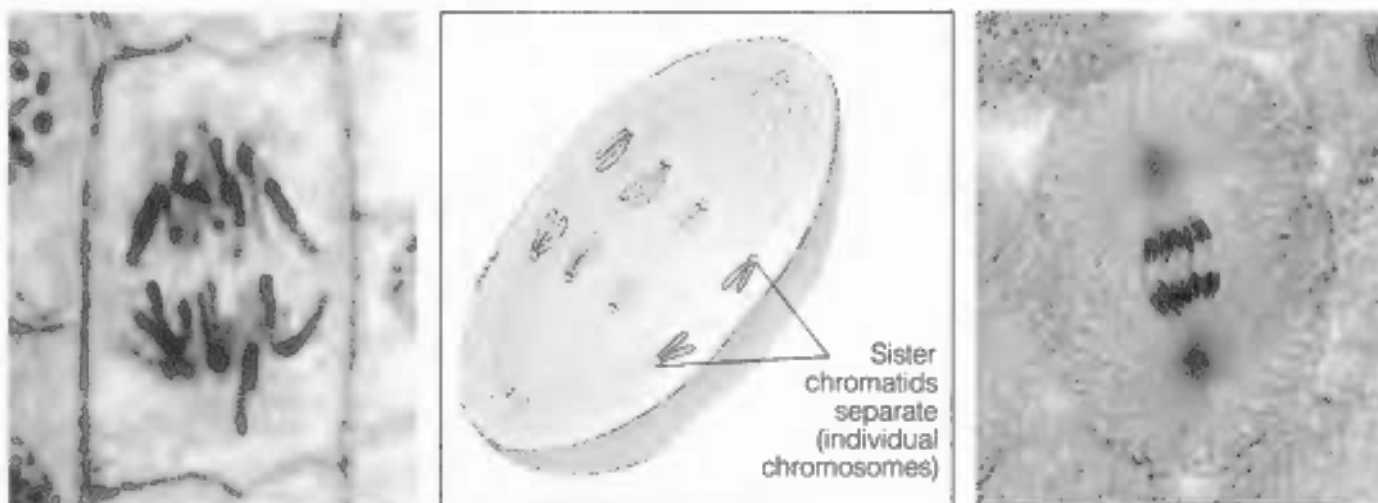
Anaphase

Anaphase, the third phase of mitosis, begins when the centromeres that join the sister chromatids split. This action causes the sister chromatids to separate, becoming individual chromosomes. As the two groups of chromosomes separate, the spindle itself grows longer. The chromosomes continue to move until they have separated into two groups near the poles of the spindle. See Figure 8-15. Anaphase ends when the movement of chromosomes stops.

For years, cell biologists have wondered what provides the force that separates the chromosomes during anaphase. Surprisingly, the answer is still not known. There is evidence that some proteins form bridges between the microtubules extending from opposite poles and use energy from ATP to push each microtubule toward its own pole. However, there is also a suggestion that the rapid assembly and breakdown of microtubules may cause chromosome movement. For the time being, this remains one of the cell's most intriguing riddles.

Figure 8-14 Notice how the chromatid pairs line up across the center of the plant cell (left) and the animal cell (right). This arrangement of chromatids marks metaphase, or the second phase of mitosis.

Figure 8-15 Anaphase, the third phase of mitosis, begins when the centromeres that link the sister chromatids split, allowing each chromatid to become an individual chromosome. Notice that centrioles are present in the animal cell (right) but not in the plant cell (left).



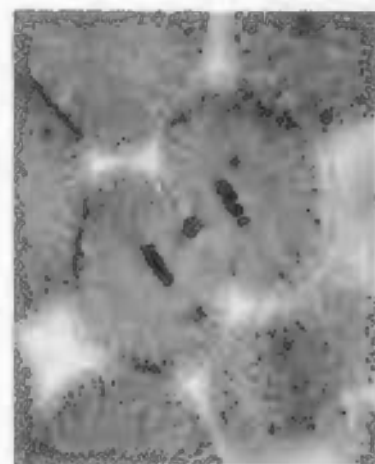
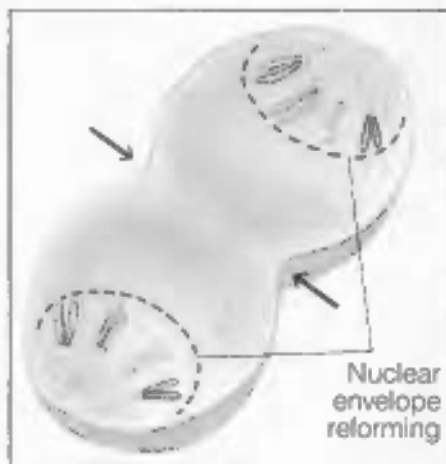
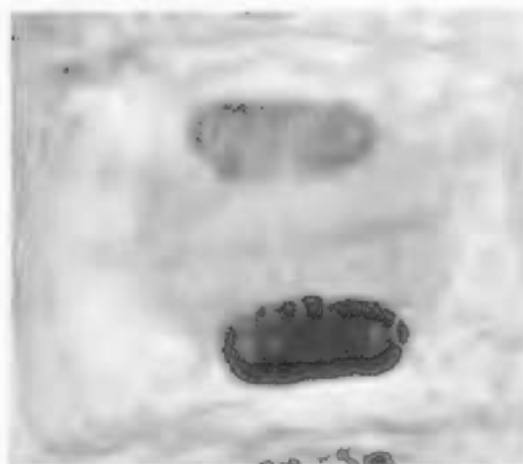


Figure 8-16 In the final phase of mitosis, called telophase, two new daughter cells begin to form. Notice the two distinct groups of chromosomes in the plant cell (left) and in the animal cell (right).

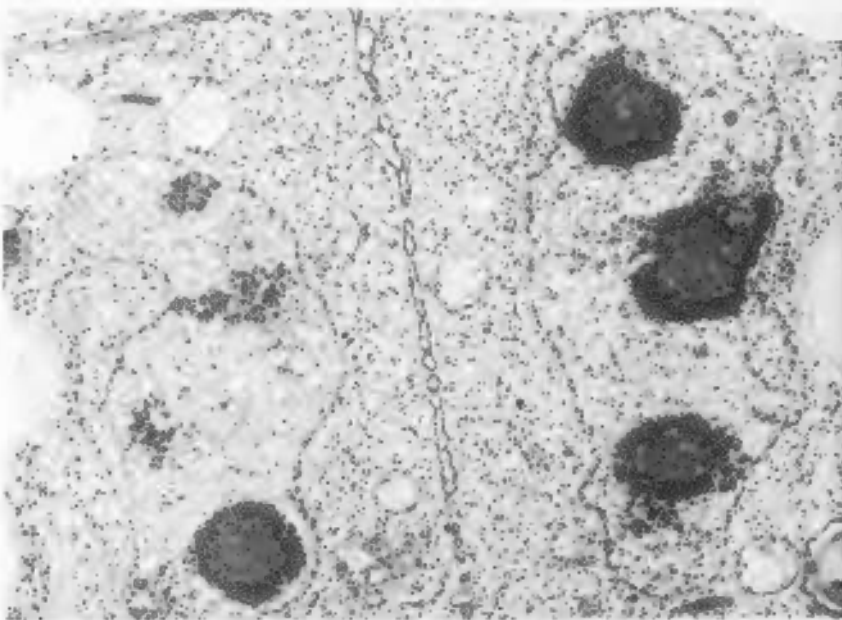
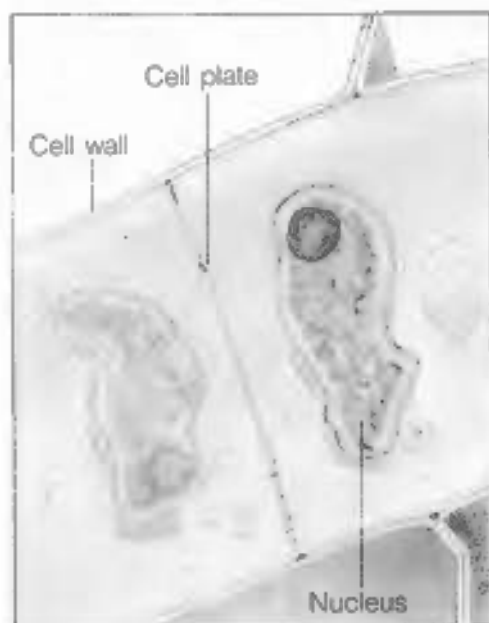
Telophase

Telophase is the final phase of mitosis. The chromosomes, which have been distinct and condensed all during mitosis, now begin to uncoil into a tangle of chromatin. This occurs in the two regions where the nuclei of the daughter cells will form. The nuclear envelope reforms around the chromatin, the spindle begins to break apart, and a nucleolus becomes visible in each daughter nucleus. Mitosis is now complete. However, the process of cell division is not.

Cytokinesis

As a result of mitosis, two nuclei—each with a duplicate set of chromosomes—are formed. Now it remains for the cytoplasm of the cell to divide. This is accomplished as cytokinesis quickly follows mitosis. Cytokinesis, you will recall, is the division of the cytoplasm into two individual cells.

Figure 8-17 Cytokinesis is the division of the cytoplasm and its contents into two individual daughter cells. In plant cells, the cytoplasm is divided by a cell plate. The large dark structures in the electron micrograph are the chromosomes.



A Useful Poison

The meadow saffron, *Colchicum autumnale*, is a flowering plant that grows wild in the meadowlands of England, Ireland, and middle and southern Europe. Its lovely flowers, which range in color from lavender to white, bloom in the fall. But the meadow saffron's flowers are deceiving. Though beautiful, the colorful meadow saffron contains a poison known as colchicine (KAHL-chih-seen).

In the laboratory, however, colchicine is a very useful drug. Colchicine stops cell division, making it important in the study of chromosomes. When colchicine is added to a culture of growing cells, it attaches

to the microtubules in the spindle and causes them to disintegrate. As a result, the spindle is destroyed and mitosis is stopped at metaphase. When the cells are examined under a light microscope, each chromosome is visible as a pair of chromatids that are joined at the centromere.

Laboratory technicians routinely use colchicine because it enables them to count and measure chromosomes. Cell biologists use the drug as a method of studying the assembly and disassembly of microtubules. Scientists were able to find an important use for a very poisonous drug.



Cytokinesis can take place in a number of ways. In most animal cells, the cell membrane moves inward until the cytoplasm is pinched into two nearly equal parts, each part containing its own nucleus and cytoplasmic organelles. In plants, a structure known as the cell plate forms midway between the divided nuclei. The cell plate gradually develops into a separating membrane. A cell wall begins to appear in the cell plate.

8-2

SECTION REVIEW

1. What is mitosis? Cytokinesis?
2. Describe the structure of a chromosome.
3. Name the three main stages of the cell cycle.
4. Briefly describe the three phases of interphase.
5. What are the four phases of mitosis?

PROBLEM

What are the stages of the cell cycle in a plant cell?

MATERIALS (per group)

onion root tips	timer or clock with second hand
safety goggles	2 glass slides
metric ruler	2 medicine droppers
scalpel	toluidine blue
ethanol-acetic acid fixative	probe
3 50-mL beakers	paper towels
glass-marking pencil	coverslip
hydrochloric acid	pencil with eraser
forceps	microscope

PROCEDURE

1. Label the three 50-mL beakers with the glass-marking pencil as follows: fixative, hydrochloric acid, water. Put on your safety goggles and add 10 mL of each liquid to the appropriately labeled beaker. **CAUTION:** *Because acids can burn the skin, handle them with care.* Place the beaker containing the water aside for now.
2. Using the forceps, place the onion root tips in the hydrochloric acid for 4 minutes.
3. After 4 minutes, use the forceps to remove the root tips from the hydrochloric acid. Place them in the fixative for 4 minutes.
4. After 4 minutes, use the forceps to remove the root tips from the fixative and place them on a clean glass slide. Holding the root tips with the forceps, use the scalpel to cut off about 1 mm from each root tip. **CAUTION:** *Be careful when using a scalpel.* Discard the rest of the root tips.
5. Using the forceps, place one root tip on a clean glass slide and then place the glass slide on a paper towel.
6. With a medicine dropper, place a few drops of toluidine blue on the root tip. Allow the

toluidine blue to remain on the root tip for 2 minutes. After 2 minutes, use a paper towel to absorb the excess liquid.

7. Using a clean medicine dropper, place two drops of water on the root tip. Cover it with a coverslip. Use the probe to lower the coverslip over the slide.
8. Place a paper towel over the slide and with the eraser end of the pencil gently press down on the area covered by the coverslip. This will squash the root tip. **CAUTION:** *Do not press so hard as to break the coverslip or the glass slide.*
9. With the microscope, examine the onion root tip under low power to find cells in various stages of the cell cycle. (**Note:** If you cannot clearly distinguish the stages of the cell cycle, repeat steps 5 through 9 using another root tip.)
10. After you have located the various stages of the cell cycle under low power, switch to high power. Draw and label a cell from each stage of the cell cycle. Be sure to identify each stage.

OBSERVATIONS

1. Describe what is happening in each stage of the cell cycle.
2. What stage occurs most frequently?
3. How is interphase different from the other stages?
4. What is the color of the chromosomes? Of other cell structures?

ANALYSIS AND CONCLUSIONS

1. What is the purpose of the toluidine blue?
2. In which area of the onion root tip do most of the cells appear to be undergoing mitosis?
3. How can you tell that mitosis is a continuous process?
4. Do some stages of the cell cycle occur more frequently than others? Identify the stage(s) and explain why.

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

8-1 Cell Growth

- Living things grow because they produce more and more cells.
- As a cell increases in size, its volume increases at a faster rate than its surface area.
- The amount of material entering and leaving a cell and the amount of DNA in the nucleus help to limit the size to which a cell can grow.
- Cell division is the process whereby the cell divides into two daughter cells.
- Cancer is a disorder in which some cells have lost the ability to control their rate of growth.

8-2 Cell Division: Mitosis and Cytokinesis

- Cell division in eukaryotic cells occurs in two main stages: mitosis and cytokinesis.
- Mitosis is the process by which the nucleus of the cell is divided into two nuclei, each with the same number and kinds of chromosomes as the parent cell.
- Cytokinesis is the process by which the cytoplasm divides, forming two distinct cells.

- Chromosomes are cellular structures that contain the genetic information that is passed on from one generation to the next. These structures are made up of chromatin, which is composed of DNA and protein.
- The two identical parts of a chromosome, called chromatids, are attached to each other at a centromere.
- During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells, which repeat the cycle.
- The cell cycle consists of three main stages: mitosis, interphase, and cytokinesis.
- Interphase, the period between cell divisions, is divided into three phases: G₁, S, and G₂.
- Mitosis has four phases: prophase, metaphase, anaphase, and telophase.
- Cytokinesis ends the process of cell division. In animal cells, the cell membrane moves inward until the cytoplasm is pinched in two, each half containing its own nucleus and cytoplasmic organelles. In plant cells, a cell plate forms midway between the divided nuclei, then a cell wall appears in the cell plate.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

8-1 Cell Growth

cell division

8-2 Cell Division: Mitosis and Cytokinesis

mitosis

cytokinesis

chromosome

chromatin

chromatid

centromere

cell cycle

interphase

prophase

centriole

spindle

metaphase

anaphase

telophase

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- Uncontrolled cell division is known as
 - cancer.
 - mitosis.
 - cytokinesis.
 - growth.
- Chromatids are held together by a (an)
 - centriole.
 - centromere.
 - spindle.
 - aster.
- Each chromosome strand is called a (an)
 - centriole.
 - centromere.
 - chromatid.
 - aster.
- A cell has 12 chromosomes. How many chromosomes will each daughter cell have?
 - 24
 - 6
 - 12
 - 4
- The phase of mitosis that is characterized by the lining up of chromosomes along the center of the cell is known as
 - prophase.
 - metaphase.
 - anaphase.
 - telophase.
- During normal mitosis, which occurs first?
 - spindle formation
 - growth and development of daughter cells
 - chromosome duplication
 - cytoplasmic division of the cell
- A cell that is undergoing mitosis is examined with a light microscope. The cell is most likely an animal cell if the
 - chromosome pairs separate from each other.
 - chromosomes twist about each other.
 - nucleoli disappear.
 - centrioles migrate.
- A structure found during plant cell division that is not found during animal cell division is a
 - centromere.
 - cell plate.
 - cell membrane.
 - spindle.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- As a cell increases in size, its volume increases at a faster rate than its surface area.
- As a result of mitosis, a cell having 10 chromosomes gives rise to two cells, each of which contains 20 chromosomes.
- DNA replication occurs during prophase.
- Animal cells contain centrioles.
- Interphase is usually divided into three phases: G₁, S, and G₂.
- Anaphase is the first phase of mitosis.
- During prophase, the centrioles separate from each other and take up positions on the opposite sides of the nucleus.
- In animal cells, a cell plate forms midway between the divided nuclei.

Word Relationships

A. In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

- anaphase, interphase, metaphase, telophase
- chromatid, centromere, chromosome, centriole
- spindle, aster, microtubule, chromosome
- cell division, cytokinesis, mitosis, aster

- B. Replace the underlined definition with the correct vocabulary word.**
5. The structures in the cell that contain the genetic information are not visible in most cells except during mitosis.
 6. The first phase of mitosis begins when the chromosomes become visible.
 7. The meshlike structure that helps move the chromosomes apart develops from the centrioles.
 8. In the final phase of mitosis, the chromosomes are found at opposite poles of the cell.

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. How do living things grow? What are some factors that limit the growth of a cell?
2. Why do cells divide?
3. Distinguish between chromatin, chromosomes, chromatids, and centromeres.
4. List and describe the phases of the cell cycle.
5. What occurs during interphase? How are interphase and the cell cycle related?
6. Identify and describe the phases of mitosis.
7. Distinguish between cell division in an animal cell and cell division in a plant cell.
8. Why is cell division so complicated in eukaryotic organisms?
9. Compare spindles and asters.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Relating facts** The diagram below shows a phase of mitosis. Identify the phase of mitosis and indicate whether the cell is from a rose or a tiger. Give a reason for your answer.



2. **Making calculations** A cell is $4\mu\text{m}$ long, $3\mu\text{m}$ wide, and $3\mu\text{m}$ high. Find the ratio of volume to surface area.
3. **Applying concepts** Is mitosis occurring in your body right now? If so, where? Explain your answer.
4. **Relating concepts** After muscle and nerve cells form in the body, they seldom undergo mitosis. Explain how this affects the human body.
5. **Relating cause and effect** What structure within the cell is most likely to play a major role in the development of generations of cancer cells? Explain your answer.
6. **Using the writing process** Suppose you were small enough to hitch a ride on a chromosome located in a cell that divides by mitosis. Describe what you would see happening during this process.

Electron Microscopist

Electron microscopes use beams of electrons to magnify objects. People who operate electron microscopes to view tiny cell structures are called electron microscopists. They produce photographs called micrographs that allow researchers to learn more about the normal activities of cells.

To become an electron microscopist, the requirements are a high school education and extensive training in the use of an electron microscope.

For information write to the National Society for Histotechnology, P.O. Box 36, Larnham, MD 20706.

Forensic Laboratory Technician

Forensic laboratory technicians use scientific principles and instruments to analyze evidence found at the scene of a crime. They find clues by examining a variety of biological materials that includes hair, blood, fingernails, bones, and tissues. They also study fingerprints, firearms, and bullets. Forensic technicians might be called upon to help reconstruct the scene of a crime or to testify in court.

Most forensic laboratory technicians have a Bachelor's degree with a good background in biology and chemistry.

To receive career information write to the American Academy of Forensic Sciences, 225 S. Academy Blvd., Colorado Springs, CO 80910.

Cell Biologist

Cell biologists examine the structure of cells in plants and animals. They study individual parts of different cells to learn how each part functions and how it is affected by chemical and physical factors. Using microscopes, stains, and other instruments, cell biologists can observe the growth and division of various cells.

Cell biologists usually have medical or Ph.D. degrees. They work in hospitals, universities, and research laboratories.

For information contact the American Society for Cell Biology, 9650 Rockville Pike, Bethesda, MD 20814.

HOW TO**CHOOSE A****TECHNICAL SCHOOL**

Technicians are workers who are trained beyond high school in a specialized field of technology. A technical education mixes theory with practice and usually takes one to three years, depending on the field. Technicians receive either a certificate or an associate degree.

When choosing a technical school, seek reliable evaluations from past graduates and job placement statistics. Although many schools advertise, only the better schools are accredited by the government.

For information write to the National Association of Trade and Technical Schools, 2251 Wisconsin Ave., NW, Washington, DC 20007 and ask for a copy of the Handbook of Trade and Technical Careers and Training.

FROM
THE
AUTHORS

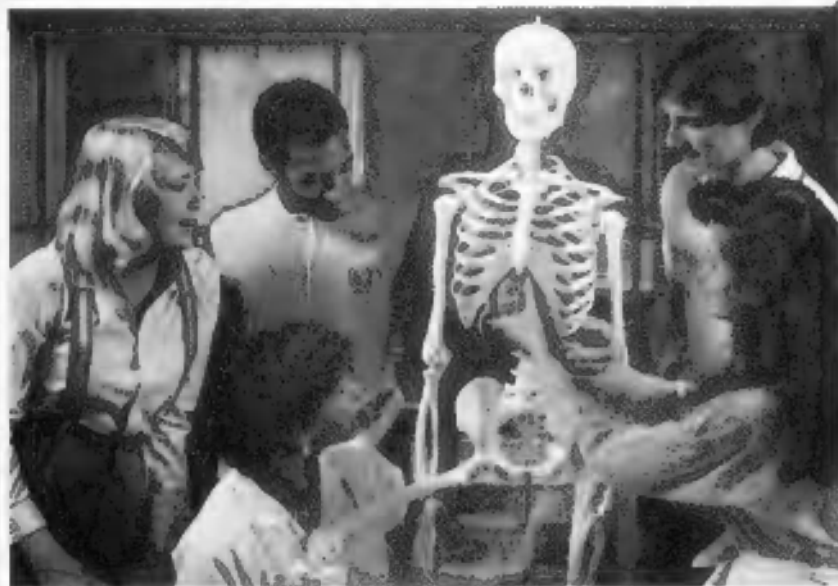


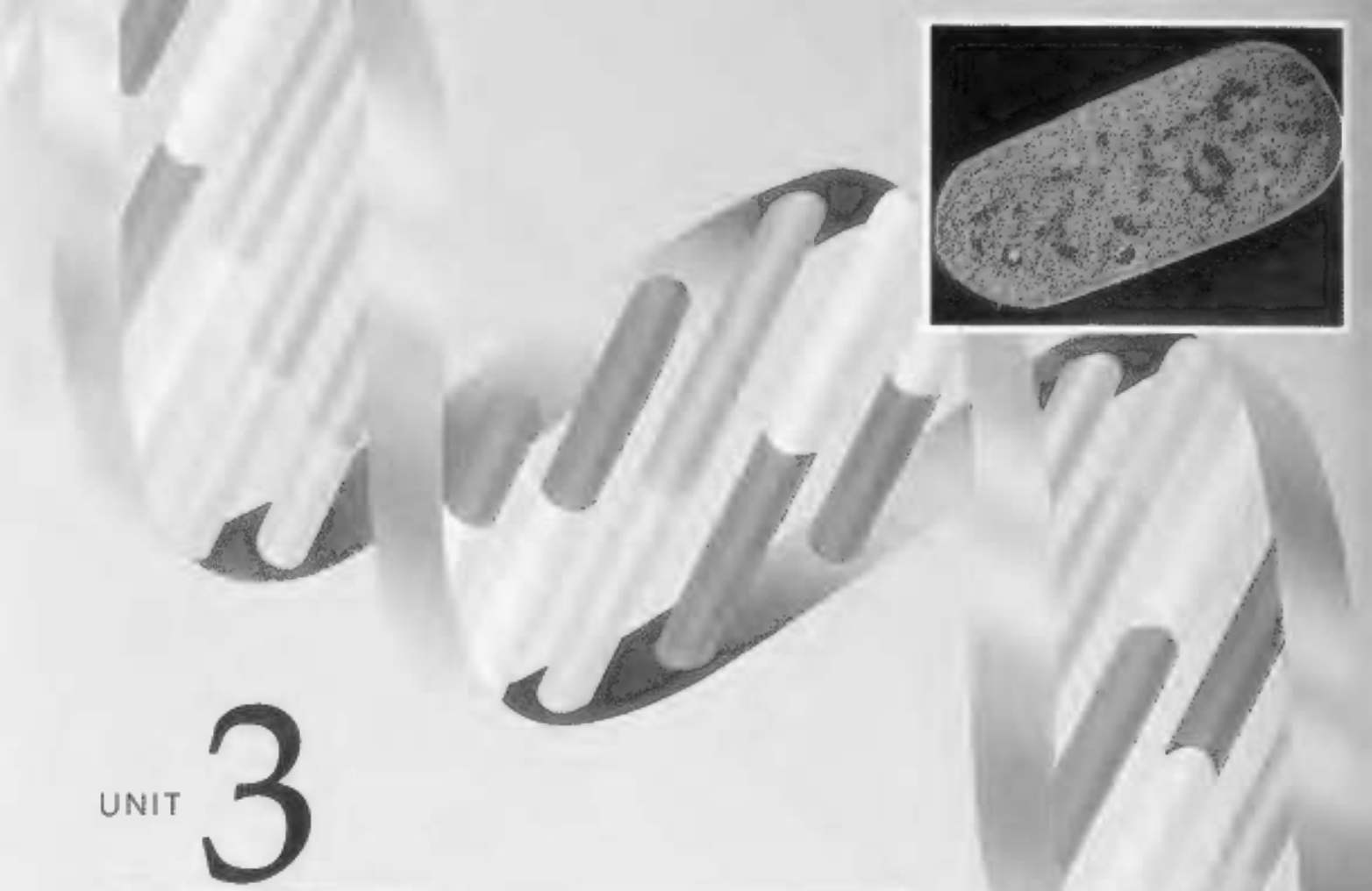
The first time I heard the term DNA mentioned was when I was in junior high. Although our textbook barely mentioned DNA, my science teacher had made a point of keeping up to date. He put up newspaper clippings about the double helix model; told us about the Nobel prize that was shared by Watson, Crick, and Wilkins; and even built a crude model of the molecule. He did his best to let us know that biology didn't stop when our textbook was written.

Way back then (when John F. Kennedy was in his last year in the White House) it was already clear that DNA was the future. The question was not whether DNA was important—it was clear that it was—but how the information in DNA was coded, expressed, and controlled. Three decades later, we know enough to answer many of the questions that seemed so puzzling to me in junior high. I could do better in Mr. Zong's mid-term exam today, but I think it's too late to improve my grade. One thing I can't improve on, however, is the sense he gave me of the future—the feeling that science was changing tomorrow.

Even as they change, things stay the same. It's tempting to think that we've solved all of the big questions, but it would be just as wrong to hold that attitude as it was in 1963. So look around, and pay attention to those newspaper clippings and science magazines in your classroom. No book contains the last word about biology. Tomorrow is up there on the wall.

Ken Miller



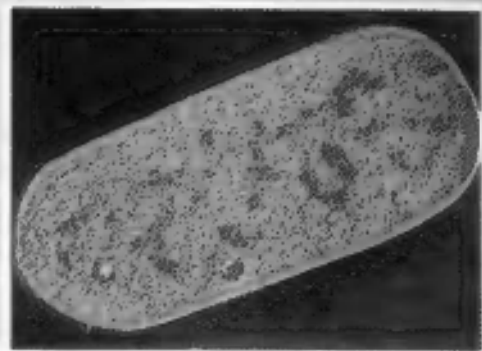


UNIT 3

Continuity of Life

The spiraling molecule called DNA is a common thread that binds all organisms on Earth together. Bacteria and other tiny single-celled organisms contain DNA, as do mushrooms, apple trees, snails, birds, and humans. In fact, all living things require DNA to grow, develop, and carry out the functions of life.

DNA is also necessary for life to continue from one generation to the next. Encoded in the pattern of chemicals within the molecule are all the instructions needed to transform a single fertilized egg cell into a complex, many-celled organism. Some of the most fascinating aspects of biology involve the transmittal of DNA from parents to offspring and the ways in which DNA controls the development of living things.



CHAPTERS

9

Introduction to Genetics

10

Genes and Chromosomes

11

Human Heredity

12

Genetic Engineering



CHAPTER 9

Introduction to Genetics



There are few things as graceful and magnificent as a running horse. A good combination of many inherited traits—fine-boned legs, swiftness, and stamina, for example—helps thoroughbred race horses compete at Churchill Downs in the Kentucky Derby.

Inheritance is something that we are all familiar with; each of us has a biological inheritance. As a child you may have been told that you “inherited” your eyes from your grandfather, your hair from your grandmother, your intelligence from your mother, and your artistic talents from your father. Everyday experience shows us that offspring resemble their parents.

But why do we take after our parents and grandparents? Why do people expect great things from a newborn foal if his father won the Kentucky Derby? Why do the kittens born of a yellow tabby and a black cat have fur colored somewhere between yellow and black? In this chapter you will discover the answers to these questions as you explore the nature of biological inheritance.

9-1 The Work of Gregor Mendel

- Early Ideas About Heredity
- Gregor Mendel
- Genes and Dominance
- Segregation
- Independent Assortment
- A Summary of Mendel's Work

9-2 Applying Mendel's Principles

- Genetics and Probability
- Using the Punnett Square

9-3 Meiosis

- Chromosome Number
- The Phases of Meiosis
- Meiosis and Genetics
- Gamete Formation
- Comparing Mitosis and Meiosis

9-1 The Work of Gregor Mendel

Section Objectives

- Discuss Mendel's experiments.
- Describe dominance, segregation, and independent assortment.

Biological inheritance, or **heredity**, is the key to differences between species. Cats give birth to kittens, dogs produce puppies, and oak trees produce acorns from which, as the saying goes, mighty oaks may grow. Heredity, however, is much more than the way in which a few superficial characteristics are passed from one generation to another. Heredity is at the very center of what makes each species unique, as well as what makes us human. The branch of biology that studies heredity is called **genetics**.

Early Ideas About Heredity

Until the nineteenth century, the most common explanation for the resemblances between parent and offspring was the theory of blending inheritance. People reasoned that because both a male and a female were involved in producing offspring, each parent contributed factors that determined inheritance—factors that were blended in their offspring. The nature of these factors was unknown.

At first, the theory of blending inheritance seemed a reasonable explanation. It is common to see a little bit of both parents in a child. So it seemed fair to say that the characteristics of the mother and father have blended in making the new life. But in the last century biologists began to look at the details of heredity. When they did, they began to develop a very different

Figure 9-1 Why don't the two baby guinea pigs look like each other? Why are they different from their mother? The science of genetics helps us answer questions such as these.



view. The work of the Austrian monk Gregor Mendel was particularly important in changing people's views about how characteristics are passed from one generation to the next.

Gregor Mendel

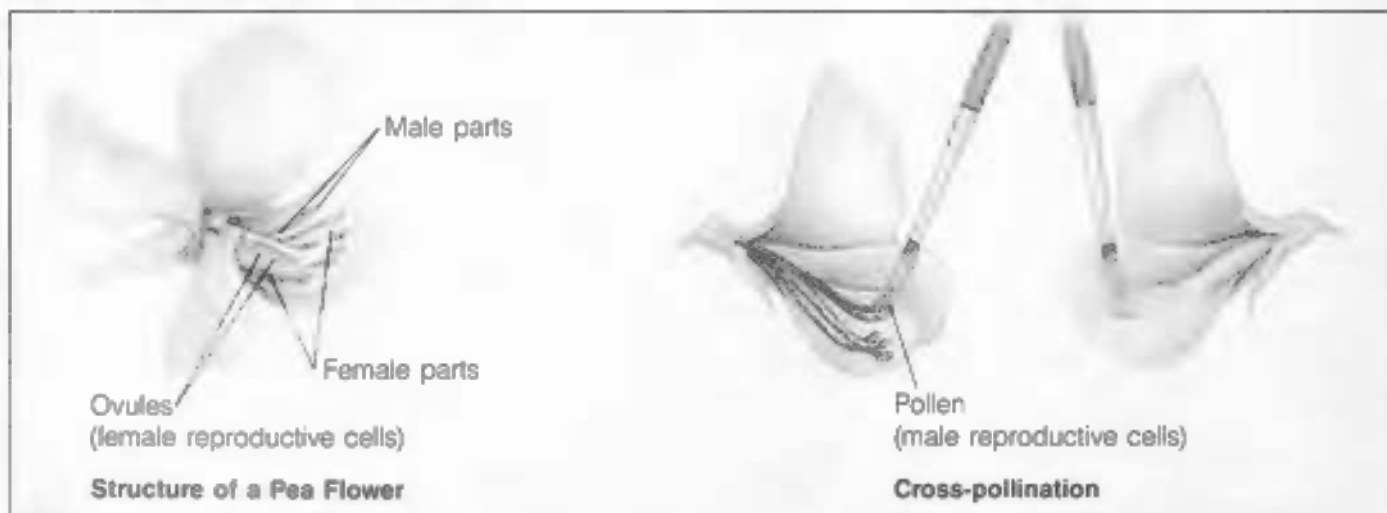
Gregor Mendel was born in 1822 to peasant parents in what is now Czechoslovakia. He did very well in school and entered a monastery in the town of Brno-at the age of 21. Four years later he was ordained a priest. The monastery was a center of scientific learning. In 1851, Mendel was sent to the University of Vienna to study science and mathematics. He returned two years later and spent the next fourteen years working in the monastery and teaching at the high school in Brno.

In addition to his teaching duties, Mendel had charge of the monastery garden. It was in this ordinary garden that he was to do the work that revolutionized biological science.

From his studies in biology, Mendel had gained an understanding of the sexual mechanisms of the pea plant. Pea flowers have both male and female parts. Normally, pollen from the male part of the pea flower fertilizes the female egg cells of the very same flower. Because the pollen produced by the plant fertilizes the egg cells of that very same plant, peas are said to produce seeds by **self-pollination**. Seeds produced by self-pollination inherit all of their characteristics from the single plant that bore them.

Mendel learned that self-pollination could be prevented. He carefully cut the male parts off all the flowers of one plant and the female parts off all the flowers of another plant. He then pollinated the two plants by dusting the pollen from one plant onto the flowers of the other plant. The fertilization of a plant's egg cells by the pollen of another plant is known as **cross-pollination**. Cross-pollination produces seeds that are the offspring of two different plants. With this technique, Mendel was able to cross plants with different characteristics.

Figure 9-2 Mendel used the garden pea in his experiments on heredity. Garden peas usually reproduce by self-pollination because the male and female reproductive parts are tightly enclosed within the flower's petals (left). One method Mendel used to cross-pollinate his pea plants was to cut off the male parts of a flower (thus preventing self-pollination) and then dust the pollen from another plant onto that flower (right).



THE PEA TRAITS STUDIED BY MENDEL

Seed Shape	Seed Color	Seed Coat Color	Pod Shape	Pod Color	Flower Position	Plant Height
 Round	 Yellow	 Gray	 Smooth	 Green	 Axial	 Tall
 Wrinkled	 Green	 White	 Constricted	 Yellow	 Terminal	 Short

Figure 9-3 The seven pea traits studied by Mendel are seed shape, seed color, seed coat color, pod shape, pod color, flower position, and plant height. As you can see, each of these traits has two contrasting characters, or forms.

One of the gifts that Mendel received when he took charge of the monastery garden was a stock of peas developed by earlier gardeners. These peas were **purebred**. This means that if they were allowed to self-pollinate, the purebred peas would produce offspring that were identical to themselves. One line of plants would produce only tall plants, another only short plants. One line would produce only green seeds, another only yellow seeds. These purebred plants were the basis of Mendel's experiments.

In many respects, the most important decision Mendel made was to study just a few isolated **traits**, or characteristics, that could easily be observed. In the case of the peas, one trait was the size of the plant, another the shape of the pod, another the color of the seed. Figure 9-3 shows the seven traits that Mendel studied. By deciding to restrict his observations to just a few such traits, Mendel made his job of measuring the effects of heredity much easier.

Genes and Dominance

What would you do if you were interested in heredity, had several kinds of purebred peas, and also knew how to cause cross-pollination? No, pea soup is not a good answer.

Mendel decided to see what would happen if he crossed pea plants with different characters for the same trait. A character is a form of a trait. For example, the flower-position trait has two characters: axial and terminal. Mendel crossed the tall

THE RESULTS OF MENDEL'S PARENTAL CROSSES

	Seed Shape	Seed Color	Seed Coat Color	Pod Shape	Pod Color	Flower Position	Plant Height
P	Round	Yellow	Gray	Smooth	Green	Axial	Tall
	X	X	X	X	X	X	X
	Wrinkled	Green	White	Constricted	Yellow	Terminal	Short
F ₁							
	Round	Yellow	Gray	Smooth	Green	Axial	Tall

Figure 9-4 When Mendel crossed plants with contrasting characters for the same trait, the resulting offspring had only one of the characters. From the results of these experiments, Mendel concluded that factors that do not blend control the inheritance of traits and that some of these factors are dominant, whereas others are recessive.

plants with the short ones; the plants with yellow seeds with those with green seeds; and so on. From the crosses in his pea plants, Mendel obtained seeds that he then grew into plants. These plants were **hybrids**, or organisms produced by crossing parents with differing characters.

What were those hybrid plants like? Did the characters of the parent plants blend in the offspring? To Mendel's surprise, the plants were not half tall, nor were the seeds they produced half yellow. Instead, all of the offspring had the character of only one of the parents. The plants resulting from his crosses were all tall or produced only yellow seeds. The other character had apparently disappeared.

From this set of experiments, Mendel was able to draw two conclusions. The first is that individual factors, which do not blend with one another, control each trait of a living thing. Mendel used the word *Merkmal* to refer to these factors. *Merkmal* means character in German. Today the factors that control traits are called **genes**. Each of the traits Mendel studied was controlled by one gene that occurred in two contrasting forms. These contrasting forms produced the different characters of each trait. For example, the gene for plant height occurs in a tall form and a short form. The different forms of a gene are now called **alleles** (uh-LEELZ).

The second of Mendel's conclusions is often called the principle of **dominance**: Some factors (alleles) are **dominant**, whereas others are **recessive**. The effects of a dominant allele are seen even if it is present with a contrasting recessive allele. The effects of a recessive allele are not observed when the dominant allele is present. In Mendel's experiments, the tall

and yellow alleles were dominant, whereas the short and green alleles were recessive. Although dominance is seen in the inheritance of many traits, it does not apply to all genes.

Segregation

Mendel was not content to stop his experimentation at this point. He wanted the answer to another question: What happened to the recessive characters? To answer this question, he allowed all seven kinds of hybrid plants to reproduce by self-pollination.

To keep the different groups of seeds and plants clear in his mind, Mendel gave them different names. He referred to the purebred parental plants as the P generation (P for parental). To the first generation of plants produced by cross-pollination, he gave the name F_1 , which stood for first filial generation (from the Latin word *filius*, which means son). If the F_1 plants were crossed among themselves, he called the offspring F_2 , for second filial generation, and so forth.

THE F_1 CROSS The results of the F_1 cross were remarkable. The recessive characters had not disappeared! Some of the F_2 plants produced by each of the F_1 crosses showed the recessive trait. This proved to Mendel that the alleles responsible for the recessive characters had not disappeared. But why did the recessive alleles disappear in the F_1 generation and reappear in the F_2 ? To answer this question, let's take a closer look at one of Mendel's crosses. Keep in mind that the concepts that apply to the crosses involving the trait of plant height also apply to the crosses for the other six traits.

EXPLAINING THE F_1 CROSS To begin with, Mendel assumed that the presence of the dominant tall allele had masked

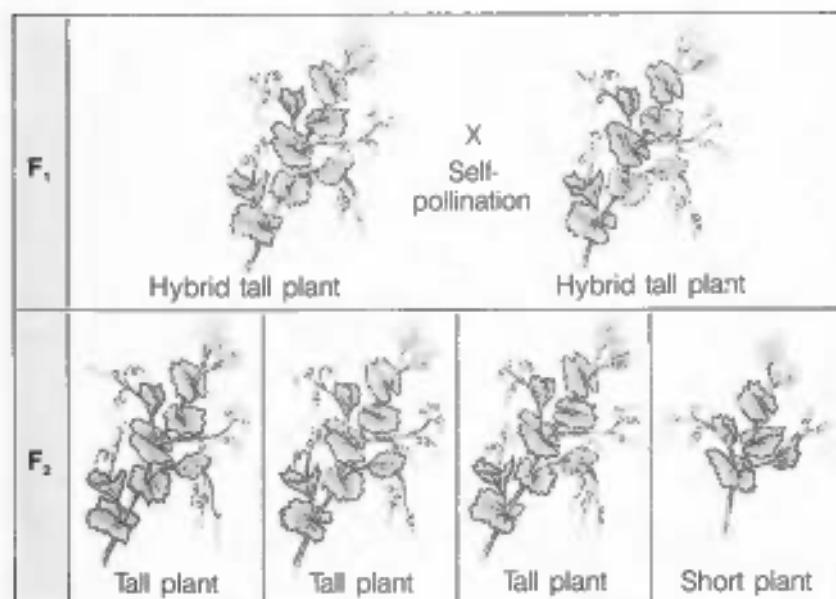


Figure 9-5 When the F_1 hybrid plants were allowed to reproduce by self-pollination, some of the resulting F_2 offspring had the recessive character.

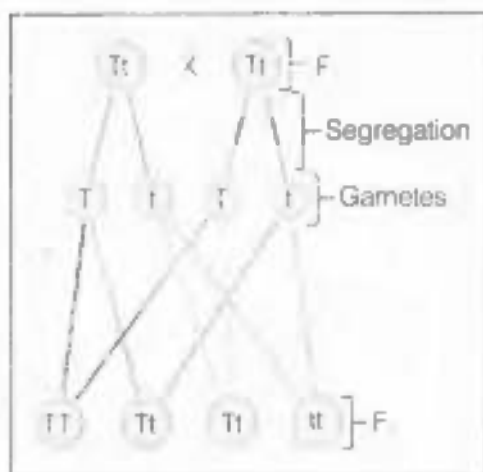


Figure 9-6 Segregation of alleles occurs during gamete formation. The alleles are paired up again when gametes fuse during the process of fertilization.

the recessive short allele in the F_1 generation. But the fact that the recessive allele was not masked in some of the F_2 plants indicated that the short allele had managed to get away from the tall allele. But how did this separation, or **segregation**, of alleles occur? Mendel suggested that during the formation of the reproductive cells (pollen and eggs), the tall and short alleles in the F_1 plants were segregated, or separated, from each other. Did that suggestion make sense?

Perhaps Mendel thought as follows: Let's assume that the F_1 plants have one tall factor from one parent and one short factor from the other parent. (Remember that Mendel did not know about genes and alleles.) Suppose such a plant forms flowers and the two factors are segregated from each other when reproductive cells are made. Each F_1 plant will produce two types of reproductive cells: one that has the tall factor and one that has the short factor. What should be the result when two F_1 plants are crossed?

If segregation occurs the way Mendel thought it did, then the possible gene combinations in the offspring that result from a cross can be determined by drawing a diagram known as a **Punnett square**. Biologists represent a particular gene by using a symbol. The dominant allele is represented by a capital letter. The recessive allele is represented by the corresponding lowercase letter. In this case, T represents the dominant tall allele and t represents the recessive short allele.

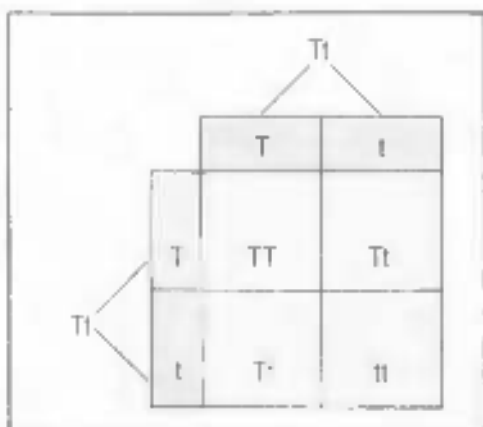
The Punnett square in Figure 9-7 shows the types of reproductive cells, or **gametes** (GAM-eets), produced by each F_1 parent along the top and left-hand side of the square. It also shows each possible gene combination for the F_2 offspring in the four boxes that make up the square.

You can see the probable results of the cross of two F_1 plants from the Punnett square: 1/4 of the F_2 plants have two tall alleles (TT); 2/4, or 1/2, of the F_2 plants have one tall allele and one short allele (Tt), and 1/4 of the F_2 plants have two short alleles (tt). Because tall is dominant over short, 3/4 of the F_2 plants should be tall and 1/4 of the F_2 plants should be short. These numbers are often expressed as ratios. For example, there are 3 tall plants for every 1 short plant in the F_2 generation. Thus the ratio of tall plants to short plants is 3:1. If, of course, Mendel's model of segregation is correct.

Did the data from Mendel's experiments fit his model? Yes. The predicted ratio—3 dominant to 1 recessive—showed up consistently, indicating that Mendel's assumptions about segregation had been correct. For each of his seven crosses, about 3/4 of the plants showed the dominant trait and about 1/4 showed the recessive trait. Segregation did indeed occur according to Mendel's model.

Look again at the Punnett square. You will see that three of the possible combinations result in tall plants. Because all these plants appear tall, we can say that they have the same **phenotype**, or physical characteristics. They do not, however,

Figure 9-7 This Punnett square shows a cross between two hybrid tall (Tt) pea plants.



have the same **genotype**, or genetic makeup. The genotype of 1/3 of the tall plants is TT , whereas the genotype of 2/3 of the tall plants is Tt .

Organisms that have two identical alleles for a particular trait (TT or tt in our example) are said to be **homozygous** (hoh-moh-ZIGH-guhs) (*homo-* means same; *-zygous* refers to alleles). Organisms that have two different alleles for the same trait are **heterozygous** (heht-er-oh-ZIGH-guhs) (*hetero-* means different). In other words, homozygous organisms are purebred for a particular trait and heterozygous organisms are hybrid for a particular trait.

Independent Assortment

After establishing that genes segregate during the formation of gametes (reproductive cells), Mendel began to explore the question of whether they do so independently. In other words, does the gene that controls one trait have anything to do with the gene that controls a different trait? For example, does the gene that determines whether a seed is round or wrinkled in shape have anything to do with the gene for seed color? Must a round seed also be yellow? To answer these questions, Mendel first crossed purebred plants that produced round yellow seeds with purebred plants that produced wrinkled green seeds.

THE TWO-FACTOR CROSS: F_1 In this cross, the two kinds of plants would be symbolized like this:

Round yellow seeds $RRYY$

Wrinkled green seeds $rryy$

Because two traits are involved in this experiment, it is called a two-factor cross. As you examine this cross, keep in mind that you are looking at the kind of seeds the plant produces. (These seeds are not necessarily the same as the seeds from which the plants grew!)

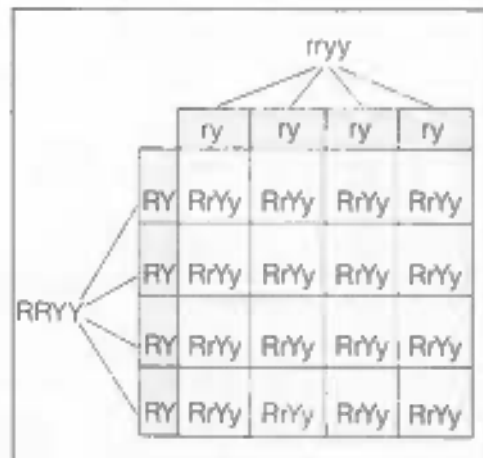
The plant that bears round yellow seeds produces gametes that contain the alleles R and Y , or RY gametes. The plant that bears wrinkled green seeds produces ry gametes. An RY gamete and an ry gamete combine to form a fertilized egg with the genotype $RrYy$. Thus only one kind of plant will show up in the F_1 generation—plants that are heterozygous, or hybrid, for both traits. What is the phenotype of the F_1 plants? That is, what will the seeds produced by the F_1 plants look like? Because we know that round and yellow are dominant traits, we can conclude that the F_1 plants will produce seeds that are round and yellow. Remember that the concept of dominance tells us that the dominant traits will show up in a hybrid, whereas the recessive traits will seem to disappear.

This cross does not indicate whether genes assort, or segregate, independently. However, it provides the hybrid plants



Figure 9-8 Although these plants have different genotypes (TT and Tt), they have the same phenotype (tall).

Figure 9-9 When an individual that is homozygous dominant for two traits is crossed with an individual that is recessive for the same two traits, all of the offspring are heterozygous dominant for those two traits.



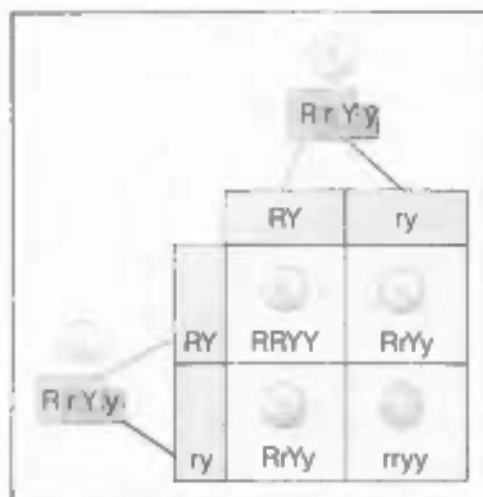


Figure 9-10 If the genes for two traits are connected in some way, only two combinations of the traits are possible in the offspring.

needed for the next cross—the cross of F_1 plants to produce the F_2 generation. The seeds from the F_2 plants will show whether the genes for seed shape and seed color have anything to do with one another. Now for the real experiment.

THE TWO-FACTOR CROSS: F_2 What will happen when F_1 plants are crossed with each other? If the genes for seed shape and color are connected in some way, then the dominant R and Y alleles (which came from one parent) and the recessive r and y alleles (which came from the other parent) will be segregated as matched sets into the gametes. Thus, the gametes could only contain one of two possible gene combinations: RY or ry . As you can see in Figure 9-10, all round seeds will be yellow and all wrinkled seeds will be green.

If the genes are not connected, then they should segregate independently, or undergo **independent assortment**. This produces four possible types of gametes: RY , Ry , rY , and ry . In addition, if the genes assort independently, some of the seeds produced by the F_2 plants will have new combinations of traits—they may be wrinkled and yellow, or round and green.

This two-factor cross is examined in the Punnett square in Figure 9-11. Now that we have four possible gamete types (and sixteen possible offspring) the square is especially useful. If the genes for seed shape and seed color are inherited independently, then the seeds produced by the offspring should be exactly as predicted by the Punnett square:

9/16	yellow round seeds	(315)
3/16	yellow wrinkled seeds	(101)
3/16	green round seeds	(108)
1/16	green wrinkled seeds	(32)

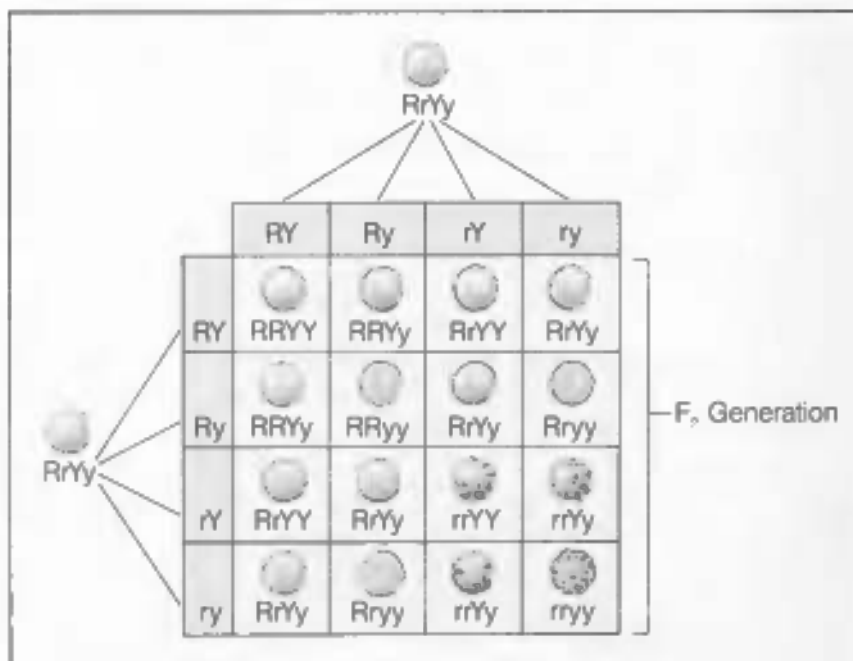


Figure 9-11 If the genes for two traits are not linked, then they will undergo independent assortment. This results in new combinations of the traits. The phenotypic ratio of the offspring that results from crossing individuals that are hybrid for two traits is 9:3:3:1.



Figure 9-12 This young chameleon has obtained half of its genes—and a piggyback ride—from its parent.

Mendel actually carried out this exact experiment, and his results, shown in parentheses, were very close to the 9:3:3:1 ratio that the Punnett square predicts. From these results, Mendel concluded that genes could segregate independently during the formation of gametes. In other words, genes could undergo independent assortment. As we shall see later, there is an important exception to independent assortment. Genes located on the same chromosome are linked and may not undergo independent assortment.

A Summary of Mendel's Work

Mendel's work on the genetics of peas can be summarized in four basic statements:

- **The factors that control heredity are individual units known as genes. In organisms that reproduce sexually, genes are inherited from each parent.**
- **In cases in which an organism possesses two forms of the gene for a single trait, some forms of the gene may be dominant and others may be recessive.**
- **The two forms of each gene are segregated during the formation of reproductive cells.**
- **The genes for different traits may assort independently of one other.**

9-1 SECTION REVIEW

1. What is dominance? Segregation?
2. What is independent assortment?
3. Define the terms genotype and phenotype. To which term does heterozygous refer?
4. Why were purebred peas important for Mendel's experiments?

Section Objectives

- Relate probability to genetics.
- Solve genetics problems using a Punnett square.

9-2 Applying Mendel's Principles

Mendel's careful record keeping and his knowledge of mathematics enabled him to see the patterns of heredity. His paper describing his experiments and conclusions was published in 1866 in the *Proceedings of the Brno Society of Natural Science*. Unfortunately, Mendel's ideas about heredity and his applications of mathematics and statistics to biology were far ahead of their time. Mendel's fellow scientists failed to understand and recognize the importance of his work. In fact, a prominent botanist encouraged Mendel to start working with a different kind of plant and to give up on the hybrid peas. Mendel's pioneering work in genetics remained unappreciated during his lifetime.

In the early 1900s, several scientists working independently rediscovered Mendel's paper. They realized that it correctly described the basic principles of genetics. More than twenty years after his death, Mendel's experiments and conclusions were recognized as important breakthroughs in biology.

Figure 9-13 The mathematical concept of probability allows us to calculate the likelihood that a particular event will occur. What is the probability that the next child in this family will be another girl?



Genetics and Probability

One of the most innovative things Mendel did was to apply the mathematical concept of **probability** to biology. **Probability is the likelihood that a particular event will occur.** Probability is determined by the following formula.

Probability = $\frac{\text{The number of times a particular event occurs}}{\text{The number of opportunities for the event to occur (the number of trials)}}$

Consider, for example, the flipping of a coin. When a coin is flipped, one of two possible events can occur: The coin can land heads up or it can land tails up. The probability of the coin coming up heads is $\frac{1}{2}$, or 1:1. In other words, you will probably get heads (the particular event) one time out of every two times you flip the coin (the trials). And you will probably get tails one time out of every two times you flip the coin. Therefore, if you were to flip the coin 10 times, the most likely outcome would be 5 heads and 5 tails. However, there is a chance that you would wind up with a different outcome—perhaps 4 heads and 6 tails, or 10 heads and 0 tails.

These different outcomes reveal an important rule of probability: You only get the expected ratio for large numbers of trials. The larger the number of trials, the closer you get to the expected ratios. If you were to flip the coin hundreds of times, your final results would be much closer to 1:1. If you were to flip the coin thousands of times, your final results would be even closer to 1:1. With this in mind, why do you think Mendel worked with thousands of pea plants?

Suppose you flipped a coin and it came up heads ten times in a row. What are the chances of getting heads again on your next flip? Because of all the times the coin came up heads, you might think it is more likely that the coin will now come up tails rather than heads. But this is not the case. There is another important rule of probability: Previous events do not affect future outcomes. Each flip of the coin is a separate, independent event. For each flip of the coin, the probability of getting heads is always $1/2$, or $1:1$. It does not matter what happened on previous flips of the coin.

The rules of probability apply to genetics as well as to flipping a coin. Expected genetic ratios may not show up when only a few pea plants (or other organisms) are considered. The larger the number of organisms examined, the closer the numbers will get to the expected values. In addition, genetic ratios do not indicate what the outcome of a single event will be. Because previous events do not affect future outcomes, it cannot be assumed that a particular event will occur because it seems overdue. Despite such limitations, genetic ratios are still very useful because they make it possible to predict the most likely outcome for a large number of events.

Using the Punnett Square

The Punnett square is a handy device for analyzing the results of an experimental cross, and it's a good idea to become familiar with its use. Practice using the Punnett square in the one-factor and two-factor genetics problems that follow.

ONE-FACTOR CROSS In pea plants, tall (T) is dominant over short (t). You have a tall plant. Design a cross to see if this plant is homozygous (TT) or heterozygous (Tt).

Solution:

Cross your tall plant with a short plant. The cross of an organism of unknown genotype and a homozygous recessive individual is called a **test cross**. Figure 9-14 shows how a test cross works.

As you can see in the Punnett squares, if any of the offspring resulting from a test cross shows the recessive phenotype, then the unknown parent must be heterozygous.

TWO-FACTOR CROSS In pea plants, green pods (G) are dominant over yellow pods (g), and smooth pods (N) are dominant over constricted pods (n). A plant heterozygous for both traits ($GgNn$) is crossed with a plant that has yellow constricted pods ($ggnn$). What are the probable genotypic and phenotypic ratios for this cross?

Solution:

Genotypic ratio = $4GgNn:4Ggnn:4ggNn:4ggnn = 4:4:4:4 = 1:1:1:1$
 Phenotypic ratio = 4 green smooth:4 green constricted:4 yellow smooth:4 yellow constricted = $4:4:4:4 = 1:1:1:1$

TT X tt		
	T	T
t	Tt	Tt
t	Tt	Tt

Tt X tt		
	T	t
t	Tt	tt
t	Tt	tt

T = tall t = short

Figure 9-14 A test cross is used to determine the genotype of an individual showing a dominant trait. If any of the offspring resulting from a test cross has the recessive phenotype, then the unknown parent is heterozygous.

Figure 9-15 This Punnett square illustrates a cross between a pea plant that has the genotype $GgNn$ and one that has the genotype $ggnn$.

GgNn X ggnn				
	GN	Gn	gN	gn
gn	GgNn	Ggnn	ggNn	ggnn
gn	GgNn	Ggnn	ggNn	ggnn
gn	GgNn	Ggnn	ggNn	ggnn
gn	GgNn	Ggnn	ggNn	ggnn

G = green g = yellow
 N = smooth n = constricted

Creating a New Breed of Cat

Siamese and Persian cats are two of the most popular kinds of purebred cats. They are also two of the most ancient breeds, with histories that go back several centuries. Siamese cats are slender, with light-colored bodies and dark markings on the face, legs, and tail. Persian cats are stocky and have long luxurious fur. A third breed of cat, the Himalayan, has the distinctive markings of the Siamese and the stocky build and long fur of the Persian. Unlike Siamese and Persian cats, Himalayans have been around for a relatively short time—less than 60 years. And unlike most breeds of cats, the Himalayan is an artificial breed.

The first Himalayan was born in 1935, the product of five years of genetics experiments at Harvard Medical School. The researchers were trying to determine how certain cat traits, such as long fur and Siamese markings, are inherited.

The scientists first crossed Siamese cats with gray, black, or striped Persian cats. The offspring of these crosses all had short hair and were gray, black, or striped in color. When two of the short-haired cats were mated, one of the female offspring had long black fur. This female, when mated to her male parent, produced a long-haired kitten with Siamese markings—the first Himalayan cat.

From their crosses, the scientists determined that short hair was dominant over long hair and that solid or striped colors were dominant over Siamese markings. Although the scientists had created a new type of cat, their role in the new Himalayan breed was over. After all, they had discovered what they had set out to find. Cat breeders in the United States and Britain took over where the scientists had left off. These breeders focused their attention, however, on the effects of other genes, such as those for general body type. By the early 1960s, more than 25 years after the birth of the first Himalayan, the breed was officially recognized by all of the major cat associations in the United States and Britain.



The Himalayan is an artificial breed of cat. It was created during the course of genetics experiments.

9-2 SECTION REVIEW

1. What is probability?
2. What is a test cross?
3. What kind of cross produces a 9:3:3:1 ratio of offspring?
4. A cross of F_1 plants heterozygous for height should produce a ratio of tall to short plants of 3:1. Three seeds from such a cross have been grown and they have produced three tall plants. What are the chances that a fourth seed will produce a short plant?

9-3 Meiosis

The principles of genetics described by Mendel require that organisms inherit a single copy of each gene from each of their parents. These two copies are then segregated from each other during the formation of gametes. An obvious way to test Mendel's ideas would be to see if something similar to segregation takes place during the formation of gametes.

But how are gametes formed? In Chapter 8 you learned about mitosis, a process that involves the separation of chromosomes and the formation of new cells. Could gametes be formed by mitosis?

The answer to this question is no. If gametes were formed by mitosis in the common fruit fly, *Drosophila melanogaster*, each gamete would contain 8 chromosomes—as do the other cells of the fly. When sperm and egg fused in the process of fertilization, the first cell of the offspring would contain 16 (or $8 + 8$) chromosomes. This is twice the number of chromosomes in the cells of the parents. If the number of chromosomes doubled in each generation, before long the cells would contain an unwieldy number of chromosomes.

Chromosome Number

The 8 chromosomes in a *Drosophila* cell can be divided into two sets: One set contains 4 chromosomes from the male parent and the other set contains 4 chromosomes from the female parent. Each chromosome in the male set has a corresponding chromosome in the female set. These corresponding chromosomes are said to be **homologous**. (The chromosomes themselves are called homologs.) A cell that contains both sets of homologous chromosomes (one set from each parent) is said to be **diploid**.

The diploid number is sometimes represented by the symbol $2N$. Thus for *Drosophila* $2N=8$. A diploid cell contains two complete sets of chromosomes and two complete sets of genes.

Section Objectives

- Describe the process of meiosis.
- Compare meiosis and mitosis.

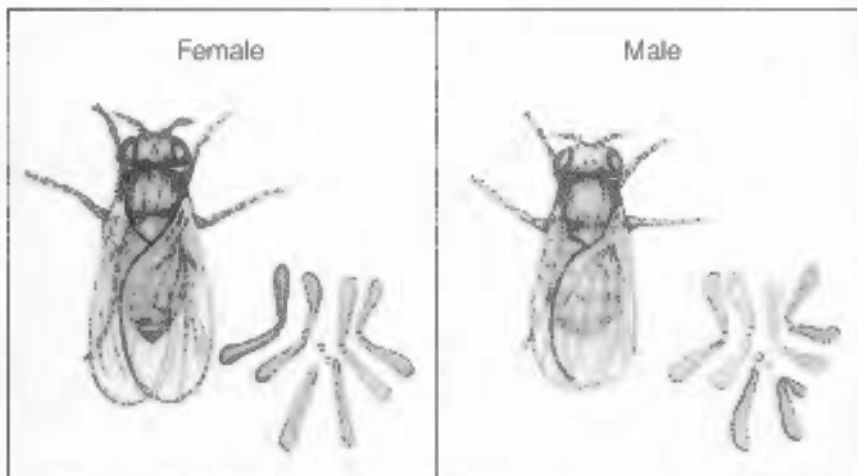
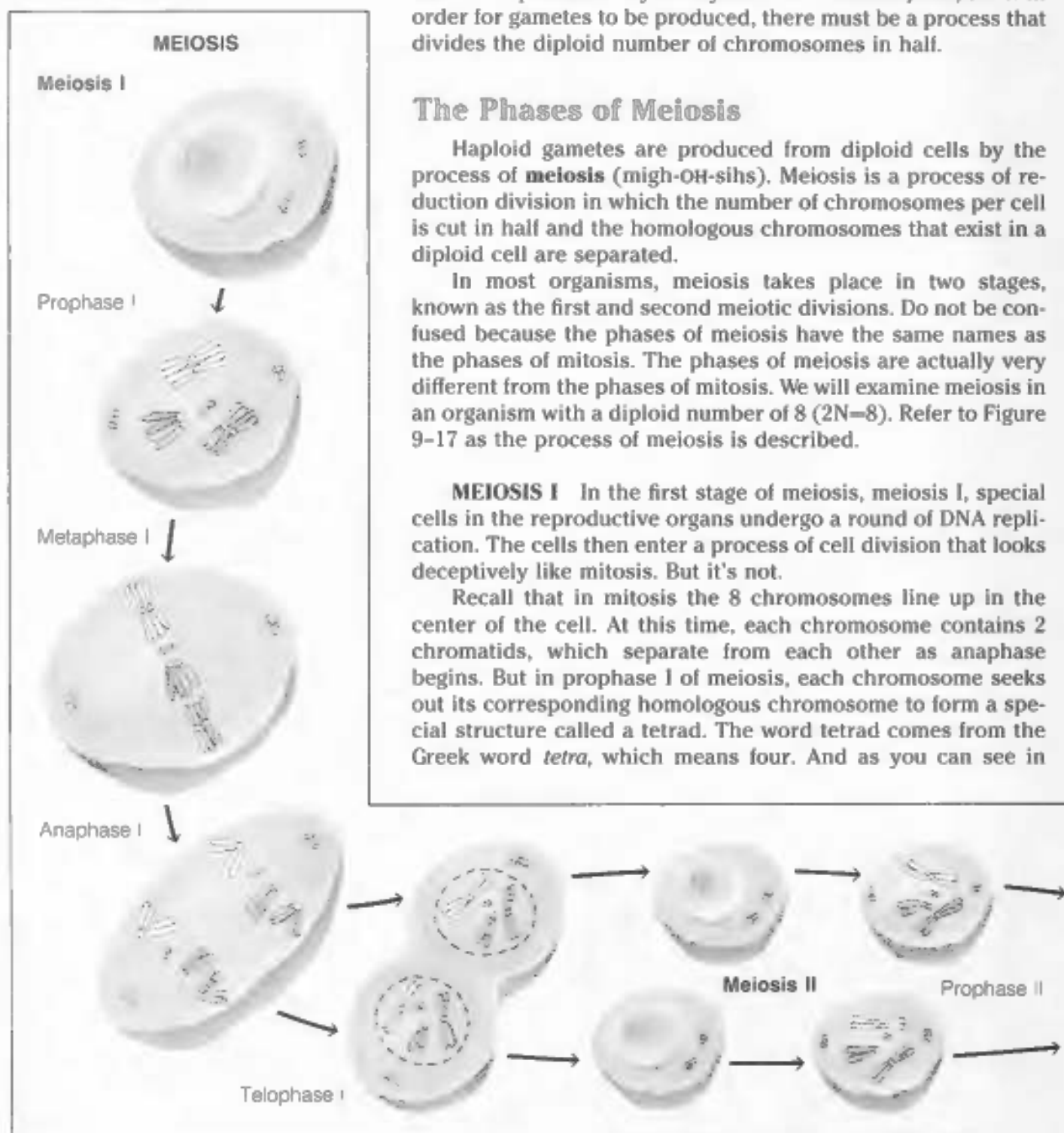


Figure 9-16 Each body cell in a fruit fly contains 8 chromosomes—4 from the male parent and 4 from the female parent (left). This photograph shows the 4 pairs of giant chromosomes of the fruit fly *Drosophila* (right). These giant chromosomes consist of many chromatids attached in parallel.



Figure 9-17 In the process of meiosis, the number of chromosomes per cell is cut in half and homologous chromosomes are separated. Meiosis produces four haploid gamete cells that are genetically different from one another and from the original diploid parent cell.



This agrees with Mendel's idea that all of an organism's cells (except the gametes) contain two alleles for a given trait. Mendel's model of segregation implies that gametes, unlike other cells, should contain only a single set of genes because alleles are separated during the process of gamete formation. This is exactly the case. The gametes of organisms that reproduce sexually contain a single set of chromosomes (and genes). Cells that contain a single set of chromosomes are said to be **haploid** and are represented by the symbol N . For *Drosophila*, $N=4$. In order for gametes to be produced, there must be a process that divides the diploid number of chromosomes in half.

The Phases of Meiosis

Haploid gametes are produced from diploid cells by the process of **meiosis** (migh-OH-sihs). Meiosis is a process of reduction division in which the number of chromosomes per cell is cut in half and the homologous chromosomes that exist in a diploid cell are separated.

In most organisms, meiosis takes place in two stages, known as the first and second meiotic divisions. Do not be confused because the phases of meiosis have the same names as the phases of mitosis. The phases of meiosis are actually very different from the phases of mitosis. We will examine meiosis in an organism with a diploid number of 8 ($2N=8$). Refer to Figure 9-17 as the process of meiosis is described.

MEIOSIS I In the first stage of meiosis, meiosis I, special cells in the reproductive organs undergo a round of DNA replication. The cells then enter a process of cell division that looks deceptively like mitosis. But it's not.

Recall that in mitosis the 8 chromosomes line up in the center of the cell. At this time, each chromosome contains 2 chromatids, which separate from each other as anaphase begins. But in prophase I of meiosis, each chromosome seeks out its corresponding homologous chromosome to form a special structure called a tetrad. The word tetrad comes from the Greek word *tetra*, which means four. And as you can see in

Figure 9-17, there are 4 chromatids in a tetrad. Tetrads, rather than individual chromosomes, line up in the center of the cell during metaphase I of meiosis.

As the homologous chromosomes pair up and form tetrads in meiosis I, they may exchange portions of their chromatids in a process called **crossing-over**. Crossing-over results in the exchange of genes between homologous chromosomes and produces new combinations of genes.

What happens next? The homologous chromosomes separate and two new cells are formed. Although each cell now has 8 chromatids (just as it would after normal mitosis) something is different. Look at Figure 9-17 closely. The two cells no longer have two complete sets of the 4 chromosomes. Instead, the maternal and paternal chromosomes have been shuffled like a deck of cards. The two cells produced by meiosis I have sets of chromosomes (and genes) that are different from each other. These sets are also different from the set in the cell that began the division.

MEIOSIS II The two cells produced by meiosis I now enter meiosis II. Unlike a cell undergoing a second mitotic division, neither cell goes through a round of DNA replication before entering the second meiotic division. Thus each of the cells' chromosomes contains 2 chromatids. During metaphase II of meiosis, 4 chromosomes line up in the center of each cell. In anaphase II, the paired chromatids separate. Each of the four daughter cells produced in meiosis II receives 4 chromatids. The four daughter cells contain the haploid number (N)—4 chromosomes each. The amount of genetic material has been reduced. In addition, the combinations of chromosomes in each gamete have been made at random.

Meiosis and Genetics

As they pass through meiosis, the chromosomes do all the things that Mendel's ideas predicted structures that carry genes would do. Meiosis I results in segregation and independent assortment. During anaphase I of meiosis, the homologous chromosomes separate and are segregated to

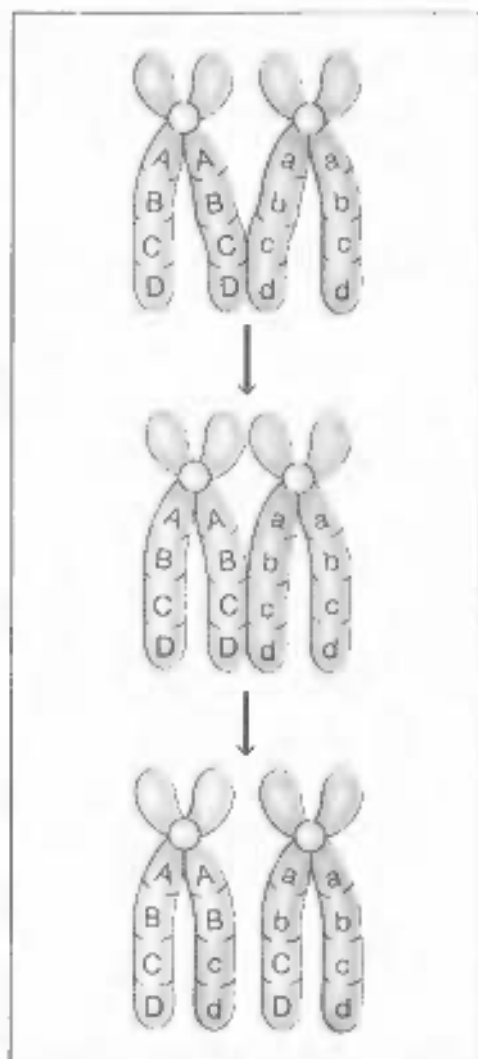
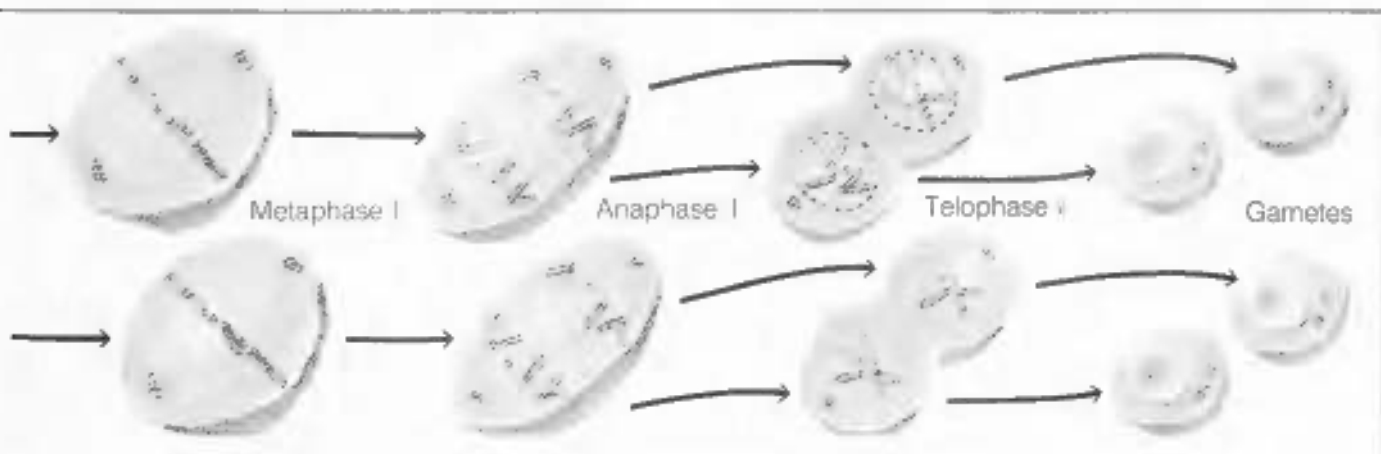


Figure 9-18 During prophase I of meiosis, homologous chromosomes may exchange portions of their chromatids in a process called crossing-over.



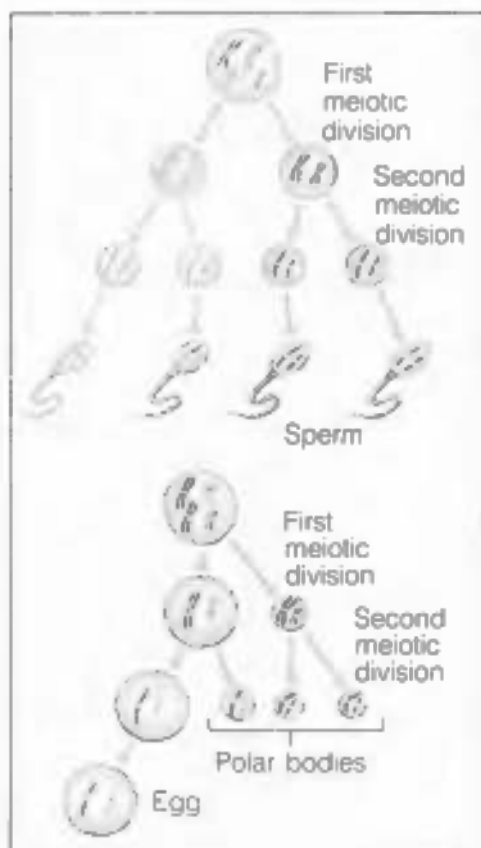


Figure 9-19 In males, meiosis results in four gametes that are the same size as one another. In females, the four cells produced in meiosis are different sizes—three are small and one is large. The large cell is usually the only one of the four female cells that participates in reproduction.

different cells. This also segregates the homologous forms of a gene, or alleles, that are located on these chromosomes. This agrees with Mendel's principles. The chromosomes themselves assort independently during meiosis I. The separation of chromosomes during the first meiotic division is completely random. Which cell receives the maternal copy of a chromosome and which cell receives the paternal copy is strictly a matter of chance.

Gamete Formation

In male animals, the haploid gametes produced by meiosis are called sperm. In higher plants, pollen grains contain haploid sperm cells. In female animals, generally only one of the cells produced by meiosis is used for reproduction. This female gamete is called an egg (animals) or ovule (higher plants). In female animals, the cell divisions at the end of meiosis I and meiosis II are uneven, so that the egg or ovule receives most of the cytoplasm. The other three cells produced in the female during meiosis are known as polar bodies and usually do not participate in reproduction.

Comparing Mitosis and Meiosis

In a way, it's too bad that the words mitosis and meiosis sound so similar and have the same names for their phases because the two processes are very different. Mitosis results in the production of two genetically identical cells. A diploid cell that divides by mitosis gives rise to two diploid daughter cells. The daughter cells have sets of chromosomes (and genes) identical to each other and to the original parent cell.

Meiosis, on the other hand, begins with a diploid cell but produces four haploid cells. These cells are genetically different from the diploid cell and from one another. This is because homologous chromosomes are separated during the first meiotic division and because crossing-over results in the production of new gene combinations on the chromosomes.

9-3 SECTION REVIEW

1. What is meiosis?
2. Define diploid and haploid.
3. In which meiotic division does segregation occur?
4. What are the principal differences between mitosis and meiosis?
5. In human cells, $2N=46$. How many chromosomes would you expect to find in a sperm cell? In an egg cell? In a white blood cell? Explain your answers.

SOLVING GENETICS PROBLEMS

One-Factor Crosses: Sample Problem

In pea plants, red flowers are dominant over white flowers. A heterozygous red flower

is allowed to self-pollinate. What are the probable genotypic and phenotypic ratios in the offspring of this plant?

SOLUTION

R = red
r = white

Rr x Rr



	R	r
R		
r		

	R	r
R	RR	Rr
r	Rr	rr

Step 1 Choose a letter to represent the genes in the cross.

Use a letter whose capital form does not look too similar to its lowercase form. This will make it easier for you to read your finished Punnett square. Except for that requirement, it is not important which letter you select. In this case, let's use *R* for the dominant red allele and *r* for the recessive white allele.

Step 2 Write the genotypes of the parents.

This step is often written as an abbreviation of the cross being studied. The X between the parents' genotypes is read "is crossed with." In this case, *Rr* X *Rr* is read "*Rr* is crossed with *Rr*." Although only one parent is involved in this problem, you must still write it as a cross in which you account for a male parent and a female parent.

Step 3 Determine the possible gametes (reproductive cells) that the parents can produce.

Remember that alleles are segregated during the formation of gametes. Each gamete has 1/2 the number of alleles in the parent.

Step 4 Enter the possible gametes at the top and side of the Punnett square.

Step 5 Complete the Punnett square by writing the alleles from the gametes in the appropriate boxes.

This step represents the process of fertilization. The allele from the gamete above the box and the allele from the gamete to the side of the box are combined inside each of the four boxes. If there is a combination of capital letter and lowercase letter in a box, write the capital letter first. The letters inside the boxes represent the probable genotypes of the offspring resulting from the cross. In this example, 1/4 of the offspring are genotype *RR*, 1/2 are *Rr*, and 1/4 are *rr*.

	R	r
R	RR	Rr
r	Rr	rr

Genotypic ratio = 1:2:1
Phenotypic ratio = 3:1

Step 6 Determine the phenotypes of the offspring.

Remember that phenotype refers to the physical appearance of an organism. The principle of dominance makes it possible to determine the phenotype that corresponds to each genotype inside the Punnett square. In this example, 3/4 of the offspring have red flowers and 1/4 of the offspring have white flowers.

Step 7 Using the results of Steps 5 and 6, answer the problem.

Usually you will be asked to summarize the results of the cross by providing genotypic and phenotypic ratios. When writing such ratios, the numbers for the dominant genotype(s) or phenotype(s) come first. In this example, 1/4 of the offspring are genotype *RR*, 1/2 (or 2/4) are *Rr*, and 1/4 are *rr*. The genotypic ratio is therefore 1/4:2/4:1/4, or 1:2:1. Three fourths of the offspring have red flowers and 1/4 have white flowers. The phenotypic ratio is therefore 3/4:1/4, or 3:1.

Two-Factor Crosses: Sample Problem

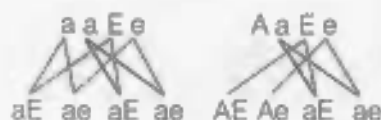
In the fruit fly *Drosophila melanogaster*, wings (*A*) are dominant over a lack of wings (*a*) and red eyes (*E*) are dominant over sepia (brownish) eyes (*e*). A wingless fly that is heterozygous for eye color is crossed with a fly

that is heterozygous for both eye color and presence of wings. What are the genotypic and phenotypic ratios for this cross? What fraction of the offspring from this cross will be wingless and have sepia eyes? What fraction will have the genotype *AaEe*?

SOLUTION

A = wings
a = wingless
E = red
e = sepia

aaEe × *AaEe*



	aE	ae	aE	ae
AE				
Ae				
aE				
ae				

Step 1 Choose letters to represent the genes in the cross.

In this particular problem, the letters to use are given to you. In the event that they are not, follow the same suggestions for choosing letters stated in Step 1 of the One-Factor Cross.

Step 2 Write the genotypes of the parents.

Step 3 Determine the possible gametes that the parents can produce.

Step 4 Enter the possible gametes at the top and side of the Punnett square.

	aE	ae	aE	ae
Ae	AaEe	AaEe	AaEe	AaEe
Ae	AaEe	AaEe	AaEe	AaEe
aE	aaEe	aaEe	aaEe	aaEe
ae	aaEe	aaEe	aaEe	aaEe

Step 5

Complete the Punnett square by writing the alleles from the gametes in the appropriate boxes.

The alleles from the gamete above the box and the alleles from the gamete to the side of the box are combined inside each of the boxes. Write the capital letter first for each pair of alleles. The letters inside each box represent the probable genotypes of the offspring resulting from the cross. In this example, 2/16 of the offspring are *AaEe*, 4/16 are *AaEe*, 2/16 are *AaEe*, 2/16 are *aaEe*, 4/16 are *aaEe*, 2/16 are *aaEe*.

	aE	ae	aE	ae
Ae	 AaEe	 AaEe	 AaEe	 AaEe
Ae	 AaEe	 Aaee	 AaEe	 Aaee
aE	 aaEe	 aaEe	 aaEe	 aaEe
ae	 aaEe	 aaEe	 aaEe	 aaEe

Step 6

Determine the phenotypes of the offspring.

In this example, 6/16 are winged and red-eyed, 2/16 are winged and sepia-eyed, 6/16 are wingless and red-eyed, 2/16 are wingless and sepia-eyed.

Step 7

Using the results of Steps 5 and 6, answer the problem.

Note that in this example, as in many of the genetics problems you will encounter, you are asked for more than just the ratios resulting from the cross. This is one reason why it is important to read genetics problems carefully. In this example, the genotypic ratio is $2/16:4/16:2/16:2/16:4/16:2/16 = 2:4:2:2:4:2 = 1:2:1:1:2:1$. The phenotypic ratio is $6/16:2/16:6/16:2/16 = 6:2:6:2 = 3:1:3:1$. And 4/16, or 1/4, of the offspring have the genotype *AaEe*.

One-Factor Crosses: Practice Problems

1. Pollen from a pea plant with white flowers is used to fertilize the ovules (female gametes) of a heterozygous plant. What are the possible phenotypes in the offspring from this cross?
2. You have a pea plant with red flowers. Design a cross to determine if this plant is homozygous or heterozygous. Use a Punnett square to show all possible crosses.

Two-Factor Crosses: Practice Problems

1. A purebred wingless red-eyed fruit fly is crossed with a purebred winged sepia-eyed fruit fly to produce F_1 flies. The F_1 flies are crossed to produce F_2 flies. What is the phenotypic ratio of the F_2 flies?
2. You have a winged red-eyed fruit fly. Design a cross to determine whether the fly is heterozygous for either or both traits. Use a Punnett square to show all possible crosses.

SIMULATING A ONE-FACTOR CROSS

ANALYSIS AND CONCLUSIONS

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

9-1 The Work of Gregor Mendel

- Mendel's genetic experiments involved the mathematical analysis of the offspring resulting from crosses between pea plants.
- Genes are individual factors that control heredity.
- The different forms of a gene are called alleles. Some alleles are dominant; others are recessive.
- Because of dominance, the effects of the recessive gene are not observed when the dominant gene is present.
- Alleles for the same trait are separated during the process of segregation.
- The genes for different traits may undergo independent assortment.
- An organism's physical characteristics, which reflect its genetic makeup, are its phenotype. An organism's genetic makeup is its genotype.
- Organisms that have two identical alleles for

a particular trait are said to be homozygous, or purebred, for that trait. Organisms that have two different alleles for the same trait are said to be heterozygous, or hybrid, for that trait.

9-2 Applying Mendel's Principles

- Probability is the likelihood that a particular event will occur. The rules of probability apply to genetics.
- Genetics problems can be solved by using a Punnett square.

9-3 Meiosis

- A cell that contains both sets of homologous chromosomes is said to be diploid ($2N$). A cell that contains a single set of chromosomes is said to be haploid (N).
- Meiosis is a form of cell division that results in the formation of haploid gametes. The cells formed in meiosis have different sets of chromosomes from one another and from the diploid mother cell.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

9-1 The Work of Gregor Mendel
heredity
genetics
self-pollination
cross-pollination
purebred
trait

hybrid
gene
allele
dominance
dominant
recessive
segregation
Punnett square

gamete
phenotype
genotype
homozygous
heterozygous
independent
assortment

9-2 Applying Mendel's Principles
probability
test cross

9-3 Meiosis
homologous
diploid
haploid
meiosis
crossing-over

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- Alleles for the same trait are separated from each other during the process of
 - mitosis.
 - meiosis II.
 - cross-pollination.
 - segregation.
- Organisms that have two identical genes for a particular trait are said to be
 - haploid.
 - homozygous.
 - heterozygous.
 - diploid.
- Pea plants usually produce seeds through
 - self-pollination.
 - cross-pollination.
 - mitosis.
 - meiosis.
- Because body cells contain two sets of chromosomes, they are
 - homozygous.
 - heterozygous.
 - haploid.
 - diploid.
- An organism's physical appearance is its
 - genotype.
 - phenotype.
 - heredity.
 - homolog.
- What is the exchange of genes between homologous chromosomes called?
 - tetrad
 - segregation
 - independent assortment
 - crossing-over
- The phenotypic ratio in the offspring resulting from the cross $Tt \times Tt$ is
 - 1:2:1.
 - 3:1.
 - 1:1.
 - 9:3:3:1.
- Some F_2 individuals show the recessive character because of
 - dominance.
 - segregation.
 - crossing-over.
 - independent assortment.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- The fertilization of a plant's ovules (egg cells) by the pollen of another plant is called self-pollination.
- If allowed to self-pollinate, hybrid peas will produce offspring exactly like themselves.
- Meiosis results in haploid cells.
- The effects of a recessive allele are seen in a heterozygous organism.
- The offspring produced by crossing F_1 plants are known as the P generation.
- Reproductive cells are also called gametes.
- Homologous chromosomes pair up during the first stage of mitosis.
- Expected genetic ratios show up only when small numbers of offspring are considered.

Word Relationships

An analogy is a relationship between two pairs of words or phrases generally written in the following manner: $a:b::c:d$. The symbol $:$ is read "is to," and the symbol $::$ is read "as." For example, $cat:animal::rose:plant$ is read "cat is to animal as rose is to plant."

In the analogies that follow, a word or phrase is missing. Complete each analogy by providing the missing word or phrase.

- mitosis:2N::meiosis:_____
- allele:gene::green seeds:_____
- purebred:hybrid::homozygous:_____
- white fur: ff ::phenotype:_____
- egg:ovule::sperm:_____
- A:dominant:: a :_____

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Why is Gregor Mendel sometimes called the "father of genetics"?
2. Describe the process of meiosis.
3. List the four basic principles of genetics that Mendel discovered in his experiments. Briefly describe each of these principles.
4. What is probability? How does probability relate to genetics?
5. How do the cellular events in meiosis account for Mendel's observations?

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** In dogs, short hair is dominant over long hair. Two short-haired dogs are the parents of a litter of eight puppies. Six puppies have short hair and two have long hair. What are the genotypes of the parents?
2. **Applying concepts** Purebred tall plants with round seeds are crossed with purebred short plants with wrinkled seeds. Some of the offspring are then crossed with an unknown plant. The offspring from this second cross are 1/2 tall round and 1/2 tall wrinkled. What are the genotype and phenotype of the unknown plant?
3. **Making inferences** Explain why horse breeders will pay a lot of money to breed one of their horses to a horse that has won the Kentucky Derby.
4. **Making calculations** The probability of two independent events occurring simultaneously is the product of each of their probabilities. For example, if you flip two coins, the chance that both will come up heads is $1/4$ ($= 1/2 \times 1/2$). Suppose that you have ten Ping-Pong balls in a jar, each marked with a numeral from 0 to 9. If you mix them thoroughly and take out one, the chances are 1 in 10 ($1/10$) that you will get a particular numeral. Now suppose you have six such jars. What is your chance of drawing the number 531963?
5. **Making generalizations** In guinea pigs, a rough coat (R) is dominant over a smooth coat (r). A heterozygous guinea pig (Rr) and a homozygous recessive guinea pig (rr) have a total of nine offspring. Each has a smooth coat. Explain these results.
6. **Designing an experiment** In sheep, white wool (A) is dominant over black wool (a). How would you determine the genotype of a white ram, or male sheep?
7. **Using the writing process** In the 1950s, a television series presented an imaginary voyage back in time. Each week a famous person in history was visited. The show was designed to provide insight into the work of the person being interviewed and the time in which he or she lived. You are in charge of producing such a program for today's television viewers. The first person you will visit is Gregor Mendel. Write a script for this program.

	R	r
R	Rr	rr
r	Rr	rr

CHAPTER

10

Genes and Chromosomes



*White tigers have inherited an altered gene for coat color. Because their cells cannot make orange pigment, white tigers are white where normal tigers are orange. Studies of the fruit fly *Drosophila* (inset) have given geneticists insight into how normal genes and altered genes regulate the inheritance of traits.*

In the preceding chapters we set the stage for a detailed discussion of genes and their activities. We have seen that DNA is the genetic material. We know how the genetic code is written into DNA and how that code is translated into protein. We understand many of the things that proteins can do, and we appreciate their importance. We have recently learned how the science of genetics was developed, how the location of genes can be determined, how the chromosome is put together, and the rules that govern the passage of genetic information from one generation to the next. With all of these things behind us, we are like pilots with all of our ground training and study completed. Now we will begin to fly. We will see how the gene actually works!

10-1 The Chromosome Theory of Heredity

- Genes and Chromosomes
- Gene Linkage
- Crossing-Over
- Gene Mapping
- Sex Linkage

10-2 Mutations

- Chromosomal Mutations
- Mutations in Genes

10-3 Regulation of Gene Expression

- Gene Interactions
- Gene Expression in Prokaryotes
- Gene Expression in Eukaryotes

10-1 The Chromosome Theory of Heredity

Section Objectives

- Relate genes to chromosomes.
- Explain how gene linkage and crossing-over affect heredity.
- Describe the patterns of inheritance for sex-linked traits.

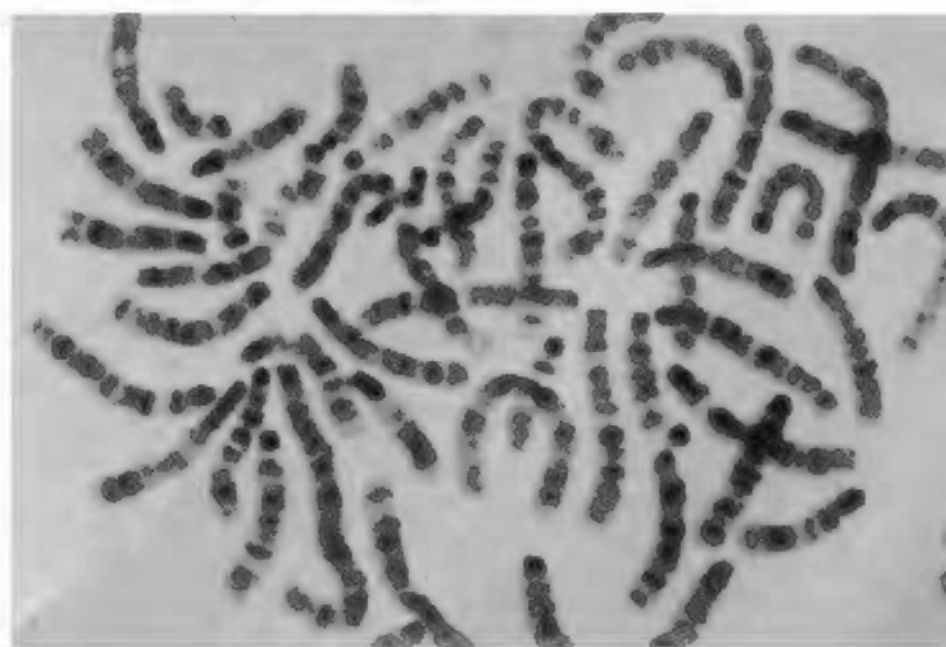
History records Gregor Mendel as the founder of the science of genetics. Yet Mendel's work was incomplete because he never asked an important question that was the logical outcome of his work: Where in the cell are the factors that control heredity? In other words, where are the genes?

We can hardly blame Mendel for this shortcoming. Even if he had been inclined to ask, he would not have been able to search for genes among the bewildering variety of structures and components within cells. Shortly after completing his genetic experiments, Mendel was promoted to abbot, or head of the monastery. His administrative duties kept him too busy to continue his experiments. Fortunately, other scientists who had the time had begun to study cell structures and the processes of cell division. Their observations would prove to have enormous impact on the study of heredity.

Genes and Chromosomes

By the time Mendel's work was rediscovered in 1900, cell biologists had discovered most of the major structures within cells. They had also recorded the sequences of events that

Figure 10-1 These chromosomes are from a mouse cell. Chromosomes, which are located in the nucleus of a cell, are precisely separated during cell division—an indication that they contain something extremely critical to the cell.



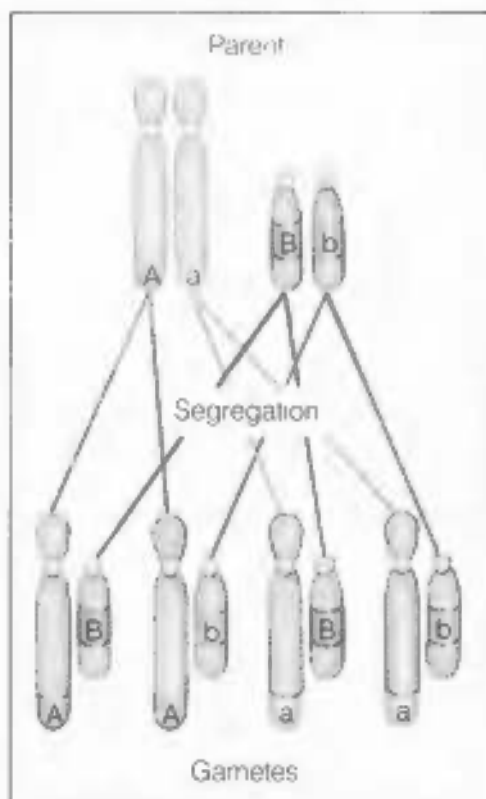


Figure 10-2 According to Mendel's hypothesis, the two factors for each trait are segregated during gamete formation. Thus gametes have only one factor for each trait. This hypothesis is supported by the observations that homologous chromosomes are separated during meiosis and that gametes contain only one of the chromosomes of each homologous pair.

occur during mitosis and meiosis. With this information, it seemed logical that the nucleus was the place for genes to be located. In addition to its large size and central location (which make it look important), the nucleus contains chromosomes—structures that behave in complex and interesting ways during cell divisions. The careful and precise mechanism by which chromosomes are separated during mitosis clearly suggests that they are structures vital to the cell. Could this be because they carry the cell's genes?

Further evidence that genes are located on chromosomes is the behavior of chromosomes during meiosis, the process by which reproductive cells are formed. In meiosis, diploid cells, which have 2 copies of each chromosome, divide to form haploid cells, which have 1 copy of each chromosome. This fits in with Mendel's hypothesis that an organism has 2 factors for each trait and that reproductive cells have only 1 factor for each trait. During the first part of meiosis, homologous chromosomes are separated from each other. This fits in with Mendel's hypothesis that the 2 factors for each trait are segregated, or separated, during the formation of gametes.

Walter Sutton, a young graduate student at Columbia University, arrived at the answer to the question of gene location in 1902. **The factors (genes) described by Mendel are located on chromosomes.** The tools with which Sutton made this discovery were a microscope—which he used to observe chromosomes during sperm formation in grasshoppers—and his own imagination, in which he compared the chromosomes to Mendel's factors. When the numbers and movements of chromosomes were analyzed, it was clear to Sutton that chromosomes behaved exactly as one would expect of the carriers of genetic information.

Sutton's **chromosome theory of heredity** states that genes are located on the chromosomes and each gene occupies a specific place on a chromosome. A gene may exist in several forms, or alleles, and each chromosome contains one allele for each gene.

Gene Linkage

The fact that genes are located on chromosomes is important. Genes on a chromosome are linked together. This means that they are inherited together. In other words, **linked genes** do not undergo independent assortment. Recall Mendel's experiment in which the genes for seed color and seed shape were shown to assort independently. Unlike linked genes, genes that are located on separate chromosomes do, in fact, assort independently during meiosis.

One of the earliest examples of linked genes was discovered in the first part of this century by the American geneticist Thomas Hunt Morgan. Morgan studied the tiny fruit fly, *Drosophila melanogaster*, which can produce a new generation every

four weeks. This short generation time makes *Drosophila* an ideal organism to study because traits in succeeding generations can be observed relatively quickly.

THE EFFECTS OF GENE LINKAGE Morgan crossed pure-bred flies that had gray bodies and normal wings with pure-bred flies that had black bodies and small wings. Because gray (*G*) is dominant over black (*g*), and normal wings (*W*) are dominant over small wings (*w*), all of the F_1 flies should have been gray with normal wings (genotype *GgWw*). That is exactly what Morgan observed.

However, when the F_1 flies (*GgWw*) were crossed with black small-winged flies (*ggww*), Morgan did not observe the expected results. If the principle of independent assortment were true for the *GgWw* $\times$ *ggww* cross, Morgan would have observed 25 percent (1/4) gray normal-winged, 25 percent (1/4) black small-winged, 25 percent (1/4) gray small-winged, and 25 percent (1/4) black normal-winged. Instead, Morgan obtained very different results for the cross.

As you can see in Figure 10-4, Morgan's actual results differed significantly from those predicted. Most gray-bodied flies had normal wings, and most black-bodied flies had small wings. These results indicated that the gene for body color and the gene for wing size were somehow connected, or linked. Morgan concluded that the two genes were linked by a physical bond in such a way that they could not assort independently.

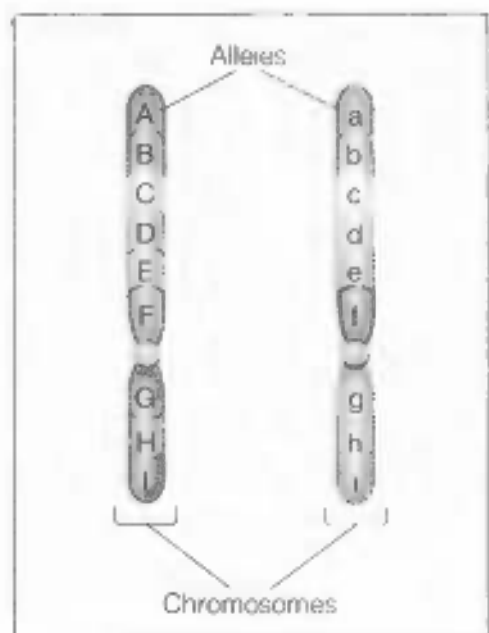
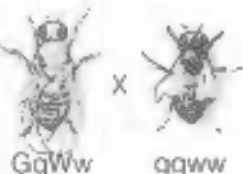


Figure 10-3 According to Sutton's chromosome theory of heredity, genes are located on the chromosomes. Homologous chromosomes have alleles for the same traits. These alleles may be the same on both homologous chromosomes or they may be different.

	GW	Gw	gW	gw	
gw	 <i>GgWw</i>	 <i>Ggww</i>	 <i>ggWw</i>	 <i>ggww</i>	 <i>GgWw</i> <i>ggww</i> G = gray body g = black body W = normal wings w = small wings
gw	 <i>GgWw</i>	 <i>Ggww</i>	 <i>ggWw</i>	 <i>ggww</i>	
gw	 <i>GgWw</i>	 <i>Ggww</i>	 <i>ggWw</i>	 <i>ggww</i>	
gw	 <i>GgWw</i>	 <i>Ggww</i>	 <i>ggWw</i>	 <i>ggww</i>	

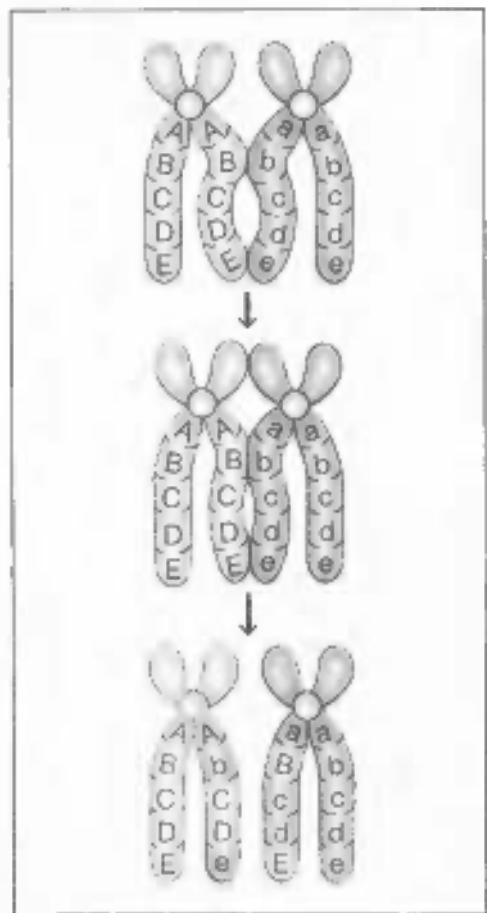
Expected results:	Actual results:
25% (1/4) gray normal	41.5% gray normal
25% black small	41.5% black small
25% black normal	8.5% black normal
25% gray small	8.5% gray small

Figure 10-4 If the principle of independent assortment were true for the genes for body color and wing size in the fruit fly *Drosophila*, the offspring of the cross *GgWw* $\times$ *ggww* would have a 1:1:1:1 phenotypic ratio. Because the actual results did not resemble the expected results, Morgan concluded that the genes for body color and wing size were linked.



Figure 10-5 A cobra has 38 chromosomes. How many linkage groups would this make?

Figure 10-6 During prophase I of meiosis, homologous chromosomes may exchange sections of their chromatids in a process called crossing-over.



LINKAGE GROUPS As Morgan and his associates studied more and more genes, they found that the genes fell into distinct **linkage groups**, or “packages” of genes that always tended to be inherited together. The linkage groups themselves assorted independently, but all the genes on one group were inherited together. The linkage groups, of course, were chromosomes. Because homologous chromosomes contain the same genes, there is one linkage group for every homologous pair of chromosomes. *Drosophila* has four linkage groups. It also has four pairs of chromosomes. Corn has ten linkage groups and ten pairs of chromosomes.

Crossing-Over

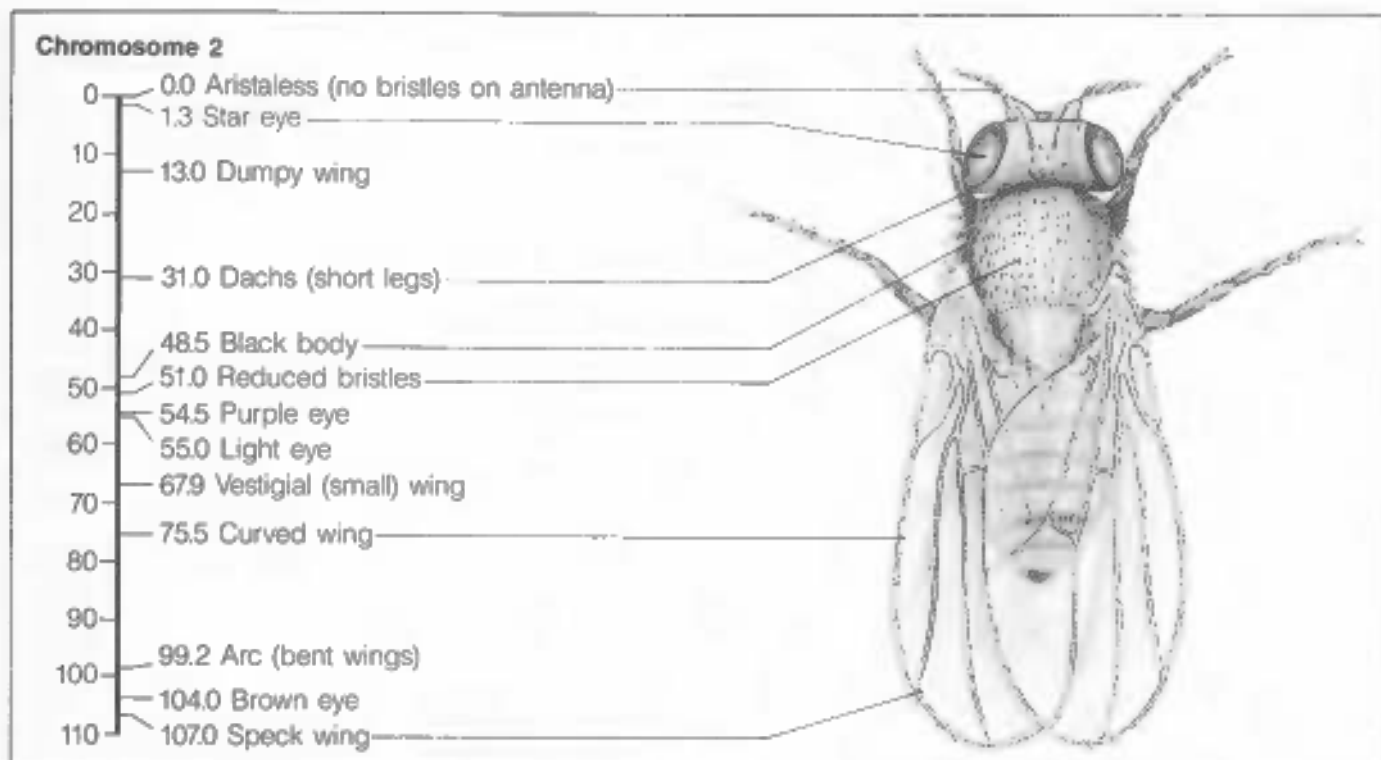
Although the idea of linkage groups explains some of the results of the fruit fly crosses, it does not provide a complete explanation. Look at the results of the test cross between the *GgWw* and *ggww* flies again. Although 83 percent ($41.5\% + 41.5\% = 83\%$) of the flies have gene combinations like their parents, 17 percent have new combinations. The 17 percent are, in the language of geneticists, **recombinants**—individuals with new combinations of genes.

If the genes for body color and wing size are linked, why aren't they linked all the time? Morgan and his associate, Alfred Sturtevant, proposed that the linkages could be broken some of the time. If two homologous chromosomes were positioned side by side, sections of the two chromosomes might cross, break, and reattach. As you can see in Figure 10-6, this process would rearrange the genes on the chromosome and produce new linkage groups. Morgan and Sturtevant called this hypothetical process crossing-over and suggested that it might be the reason for the recombinants in the offspring of the *Drosophila* test cross.

Crossing-over does indeed take place. It occurs during the first meiotic division, when homologous chromosomes are paired. Crossing-over produces new combinations of alleles on each chromosome and thus increases genetic variety.

Gene Mapping

Sturtevant further reasoned that crossing-over occurs at random along the linkage groups, and the distance between two genes determines how often crossing-over occurs between them. If two genes are close together, then crossing-over between them is rare. However, if two genes are far apart, then crossing-over between them is more common. Knowing the frequency with which crossing-over between two genes occurs makes it possible to map the positions of genes on a chromosome. This is precisely what Sturtevant tried to do with the genes in *Drosophila*'s linkage groups. And by 1915, just two years after he had begun, Sturtevant had mapped 85 genes in *Drosophila*.



Morgan and Sturtevant were correct in their ideas about linkage groups, crossing-over, and the formation of gene maps. Today we have detailed maps of *Drosophila* that pinpoint the locations of more than 1500 different genes.

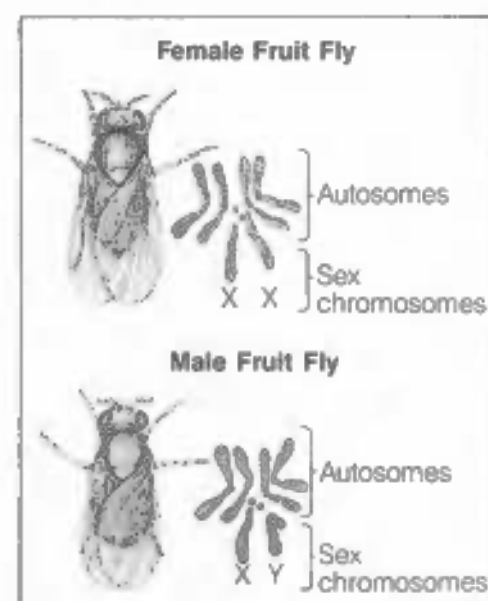
Sex Linkage

There is an exception to the rule that every chromosome has a corresponding homologous chromosome. This exception was discovered in 1905 by American biologist Nettie Stevens. She noticed that the cells of the female mealworm contain “20 large chromosomes, while those of the male contain 19 large ones and 1 small one.” One of the pairs of chromosomes in the male mealworm is not, in the strictest sense of the term, homologous. The 2 chromosomes in the pair have very different shapes. Stevens found the same situation in *Drosophila*. The cells of the female *Drosophila* contain 8 chromosomes that can be arranged in 4 pairs of 2. The cells of the male, however, contain 3 sets of chromosomes that pair up nicely and 2 remaining chromosomes that do not match. One chromosome looks like a member of a pair of chromosomes found in the female, but the other looks completely different. It is small, shaped like a hook, and in no way similar to any of the other 7 chromosomes.

These seemingly mismatched chromosomes are the **sex chromosomes**. The other chromosomes, which are the same in both males and females, are called **autosomes**. The female *Drosophila* has two matching sex chromosomes—**X chromosomes**. The male has two dissimilar sex chromosomes—one X

Figure 10-7 Knowing the frequency with which crossing-over occurs between genes makes it possible to map the positions of genes on chromosomes.

Figure 10-8 A female fruit fly has 2 matching sex chromosomes—X chromosomes. A male fruit fly has sex chromosomes that do not match—1 X chromosome and 1 Y chromosome.



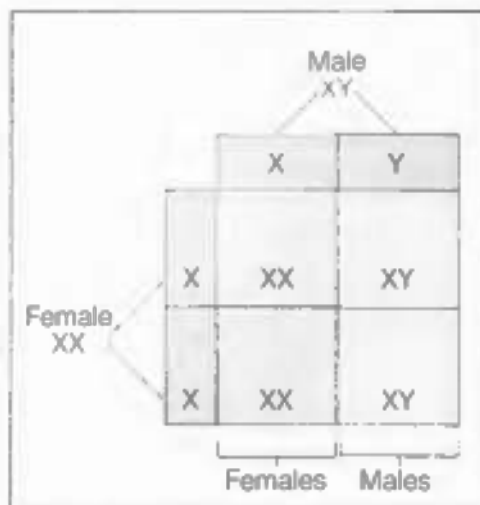


Figure 10-9 In animals such as fruit flies and humans, the sex chromosomes in the male's gametes usually determine the sex of the offspring.

chromosome and one **Y chromosome**. It is the Y chromosome that is small and hook-shaped. If we consider just sex chromosomes, we can refer to the male as XY and the female as XX.

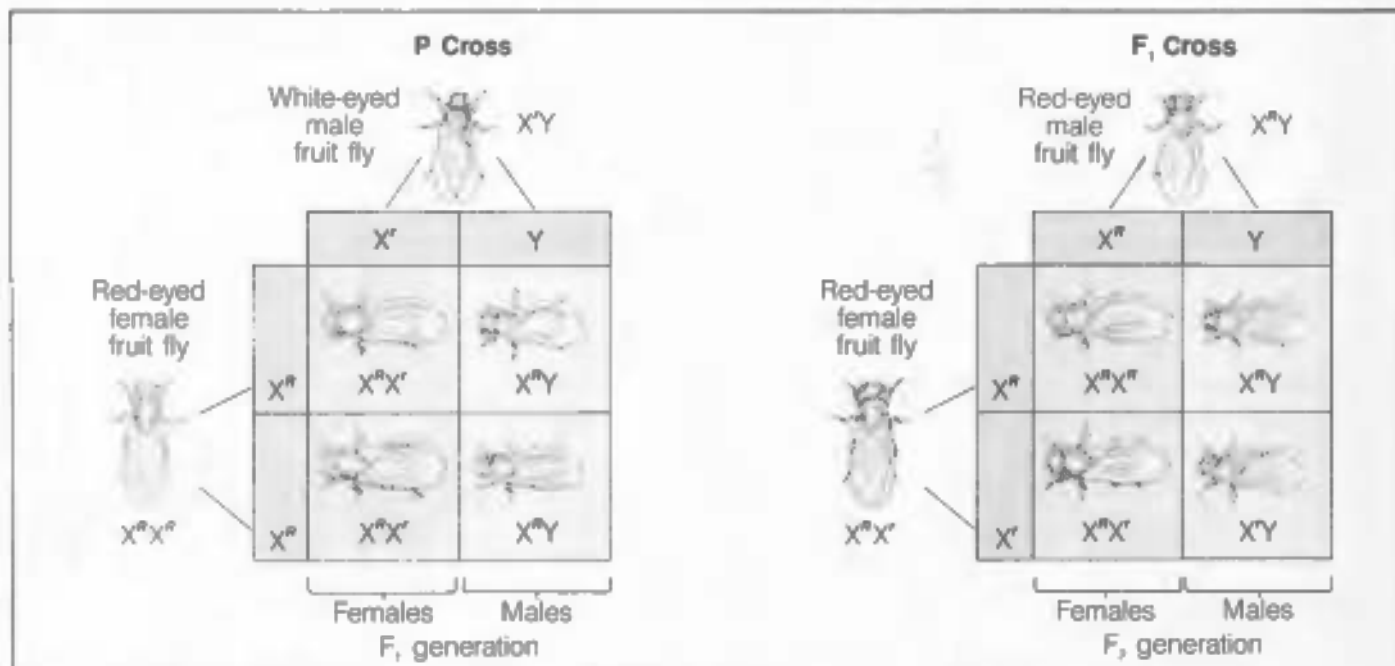
SEX DETERMINATION When female gametes are produced, meiosis separates one of the X chromosomes into each egg cell. In the male, meiosis separates the X and Y chromosomes so that 50 percent of the sperm cells carry a Y chromosome and 50 percent carry an X chromosome. When a Y sperm fertilizes an egg, a male fly (XY) is produced. When an X sperm fertilizes an egg, a female fly (XX) is produced. In a sense, the male is responsible for the sex of its offspring.

Many animals, including humans, follow the same system. We have 22 pairs of autosomes and 1 pair of sex chromosomes: XX in females and XY in males. Because about 50 percent of male sperm have the X chromosome and about 50 percent have the Y, the ratio of males to females is about 50:50, or 1:1.

GENES ON SEX CHROMOSOMES In addition to determining the sex of an individual, the sex chromosomes carry genes that affect other traits. A gene located on one of the sex chromosomes is said to be **sex-linked**. Morgan discovered the first sex-linked gene in his work with *Drosophila*.

Morgan crossed a group of white-eyed male flies with a group of red-eyed female flies. The allele for red eyes (*R*) is dominant over the allele for white eyes (*r*). Just as you might have expected, the hybrid flies of the F_1 generation all had red eyes. See Figure 10-10. Morgan allowed the F_1 flies to interbreed and produce a new generation of flies (the F_2 generation). Mendelian genetics predicts a 3 to 1 ratio of red-eyed flies to white-eyed flies, and that was exactly the ratio Morgan

Figure 10-10 Morgan discovered the first sex-linked gene in experiments with the fruit fly *Drosophila*. The recessive allele, symbolized as X^r , causes white eyes in males—genotype X^rY .



obtained. But Morgan noticed something strange about the F_2 flies. All of the white-eyed flies were male! There was not a single white-eyed female in the bunch.

Why should half of the males but none of the females have white eyes? Could it be that the gene for eye color was on one of the sex chromosomes?

Morgan realized that he could account for his results if the gene for eye color was on the X chromosome. Refer to the Punnett square in Figure 10-10 as you take a closer look at how the F_2 generation is formed.

The female flies produce two kinds of egg cells. One kind of egg cell has the R allele on its X chromosome (we can call those egg cells X^R); the other kind of egg cell has the r allele on its X chromosome (X^r). The male flies make two kinds of sperm cells: One kind of sperm cell has the X chromosome and the other kind of sperm cell has the Y chromosome. The X chromosome has the R allele (X^R) on it. The Y chromosome, however, has neither the r nor the R allele on it.

As you can see from the Punnett square, only one combination of chromosomes will produce a white-eyed fly— X^rY . And every fly with that combination of chromosomes is male.

Morgan tested his hypothesis that the gene for eye color was sex-linked in a famous experiment. He crossed the F_2 white-eyed males (X^rY) with F_1 ($X^R X^r$) females. The Punnett square in Figure 10-11 shows the probable results of the cross if, and only if, the gene for eye color is indeed on the X chromosome. According to the Punnett square, 1/2 of the offspring should have red eyes and 1/2 should have white eyes. In addition, the male offspring should be 1/2 red-eyed and 1/2 white-eyed. And the female offspring should also be 1/2 red-eyed and 1/2 white-eyed. Such results were exactly what Morgan obtained. He had confirmed his idea that the gene for eye color was sex-linked.

Sex-linked genes are not only found in *Drosophila*. They are important in humans as well. As you will see in Chapter 11, several important human genes are located on the X chromosome. Such genes include the genes for color vision and blood clotting. As with the eye color gene in *Drosophila*, the effects of recessive alleles tend to show up more frequently in males than in females.

		White-eyed male fruit fly X^rY	
		X^r	Y
Red-eyed female fruit fly $X^R X^r$	X^R	 $X^R X^r$	 $X^R Y$
	X^r	 $X^r X^r$	 $X^r Y$
		Females	Males

Figure 10-11 The sex-linked X^r allele causes white eyes in females that have a "double dose" of the allele—genotype $X^r X^r$. White-eyed females inherit one X^r allele from their male parent (who must be $X^r Y$) and one from their female parent (who must be either $X^R X^r$ or $X^r X^r$).

10-1 SECTION REVIEW

1. How are genes related to chromosomes?
2. How does crossing-over make genetic mapping possible?
3. What are sex chromosomes? Autosomes?
4. Why are the effects of recessive sex-linked alleles seen more often in males than in females?

Section Objectives

- Describe different kinds of mutations.
- Explain how mutations can affect heredity.

10-2 Mutations

As you will recall from Chapter 7, the processes involved in duplicating genetic information and transmitting it to the next generation are complex and precise. Although mistakes are rare, they do occur. These mistakes are called **mutations**, from a Latin word that means change. Not all mutations are harmful. Many mutations either have no effect or cause slight, harmless changes. And once in a while a mutation may be beneficial to an organism.

Mutations may occur in any cell. Mutations that affect the reproductive cells, or germ cells, are called germ mutations. The variant characters studied in genetics (such as white eyes in *Drosophila* or wrinkled seeds in pea plants) are the result of germ mutations. Mutations that affect the other cells of the body are called somatic (from the Greek word *soma*, which means body) mutations. Because they do not affect the reproductive cells, somatic mutations are not inheritable. Many cancers are caused by somatic mutations. Both somatic and germ mutations can occur at two levels—the level of chromosomes and the level of genes. **Chromosomal mutations involve segments of chromosomes, whole chromosomes, and even entire sets of chromosomes. Gene mutations involve individual genes.**



Figure 10-12 Mutations in genes that regulate development resulted in extra hind legs on this frog.

Chromosomal Mutations

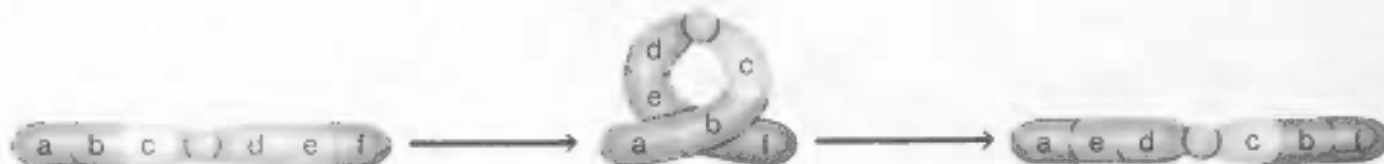
Whenever a **chromosomal mutation** occurs, there is a change in the number or structure of chromosomes. There are four types of chromosomal mutations that involve a change in the structure of a chromosome: deletions, duplications, inversions, and translocations. A deletion involves the loss of part of a chromosome.



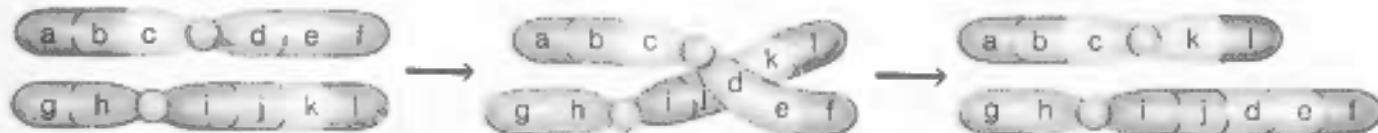
The opposite of a deletion is a duplication, in which a segment of a chromosome is repeated.



When part of a chromosome becomes oriented in the reverse of its usual direction, the result is an inversion.



A translocation occurs when part of one chromosome breaks off and attaches to another, nonhomologous chromosome. In most cases, nonhomologous chromosomes exchange segments, so that two translocations occur at the same time.



Chromosomal mutations that involve whole chromosomes or complete sets of chromosomes result from a process known as **nondisjunction**. Nondisjunction is the failure of homologous chromosomes to separate normally during meiosis. Nondisjunction literally means not coming apart.

When one chromosome is involved, nondisjunction results in an extra copy of a chromosome in one cell and a loss of that chromosome from the other. A number of human disorders that result from nondisjunction will be described in Chapter 11.

Nondisjunction can involve more than one chromosome. When all the homologous chromosomes fail to separate, the result may be a dramatic increase in chromosome number, producing triploid (3N) or tetraploid (4N) organisms. The condition in which an organism has extra sets of chromosomes is called **polyploidy**. Polyploidy is almost always fatal in animals. However, polyploid plants are often larger and hardier than normal plants.

Mutations in Genes

Mutations can occur in individual genes and can seriously affect gene function. Any chemical change that affects the DNA molecule has the potential to produce **gene mutations**. Some gene mutations result from a change involving many nucleotides within a gene; some involve only one nucleotide. The smallest changes, known as **point mutations**, affect no more than a single nucleotide.

Remembering how a DNA base sequence determines the amino acid sequence of a polypeptide, can you predict the possible effects of a point mutation in which one base is substituted for another? Because base substitutions usually affect only a single codon, only one amino acid is affected. In some cases, the sequence of amino acids that the gene codes for may not be changed at all, since different codons may code for the same amino acid. When the point mutation involves the insertion or deletion of a nucleotide, however, the situation may be much more serious. Remember that mRNA is read in groups of three bases. If a single base is inserted or deleted, the groupings are shifted for every codon following the point mutation. Such **frameshift mutations** can completely change the polypeptide product produced by a gene.

Figure 10-13 A frameshift mutation, such as that caused by the addition of a single nucleotide, can greatly change the polypeptide product of a gene (top). This can make it as useless and nonsensical as a sentence in which the deletion of a letter and a frameshift has occurred (bottom).

DNA:	TACGCATGGAATACC
mRNA:	AUG CGU ACC UUA UGG
amino acids:	met - arg - thr - leu - try
DNA:	TATCGCATGGAATAC
mRNA:	AUA GCG UAC CUU AUG
amino acids:	iso - ala - tyr - leu - met

THE	FAT	CAT	ATE	THE	RAT					
THE	F	AT	C	AT	A	TE	T	HE	R	AT
TEF	ATC	ATA	TET	HER	AT					

Manipulating Chromosome Numbers

From Mendel's work we have come to expect that organisms will be diploid ($2N$). In other words, they will have two sets of chromosomes—one set inherited from each parent. However, plants with the “wrong” number of sets of chromosomes do exist. And, interestingly enough, these plants are extremely useful in agricultural research.

For example, a plant with only one set of chromosomes shows the effects of all its genes, including potentially desirable recessive genes. A plant with only one set of chromosomes is obtained by taking cells formed in meiosis and growing them under special conditions. However, plants with only one set of chromosomes cannot reproduce sexually because meiosis cannot occur normally in their cells. If these plants show a desirable characteristic, they can be made into diploid plants by treating them with the drug colchicine. Colchicine prevents spindle formation during mitosis and thus causes the number of chromosomes in a cell to double. The diploid plants produced by treatment with colchicine are purebred for the desired traits and can reproduce normally.



By manipulating chromosome numbers with colchicine, it was possible to produce high-protein Triticale.

Colchicine can also be used to change the number of sets of chromosomes in a naturally occurring plant. For example, colchicine has been used to create

strawberry and blueberry plants that are polyploid, or have more than two sets of chromosomes. Polyploid plants produce larger fruit than plants with the normal number of sets of chromosomes. The ability to change the number of sets of chromosomes makes it possible to cross plants that have different diploid numbers. The high-protein grain *Triticale* was created by crossing wheat ($2N=42$) and rye ($2N=14$). The plants grown from the hybrid seeds were sterile; they could not produce offspring. However,

when the hybrid plants were treated with colchicine, the chromosome number was doubled and meiosis could occur normally. Thus the second-generation plants were fertile.

Manipulating chromosome numbers is useful in studying plant genetics. It is also a technique that allows researchers to create new and potentially better crops.

10-2 SECTION REVIEW

1. What is a somatic mutation? How does it differ from a germ mutation?
2. Compare a chromosomal mutation and a gene mutation.
3. How does nondisjunction result in chromosomal mutations?

10-3 Regulation of Gene Expression

Like the individual cells of a large organism, individual genes do not function in isolation. The expression and activities of genes, like those of cells, are regulated and controlled, thereby enabling a complex genetic system to function smoothly. As biologists have intensified their studies of gene activity, it has become clear that interactions between different genes and between genes and their environment are critically important.

This section focuses on some of the ways in which genes are regulated by conditions within cells. However, genes are also influenced by environmental conditions such as temperature and light.

Gene Interactions

Dominance is the simplest example of how genes interact with each other. In Chapter 9, you learned that the effects of the dominant allele are seen even when the recessive allele is present. But what causes dominance?

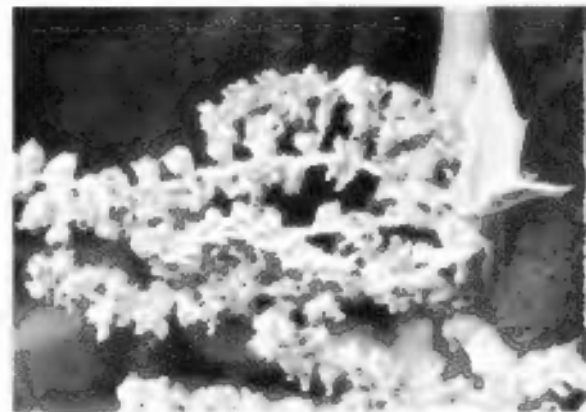
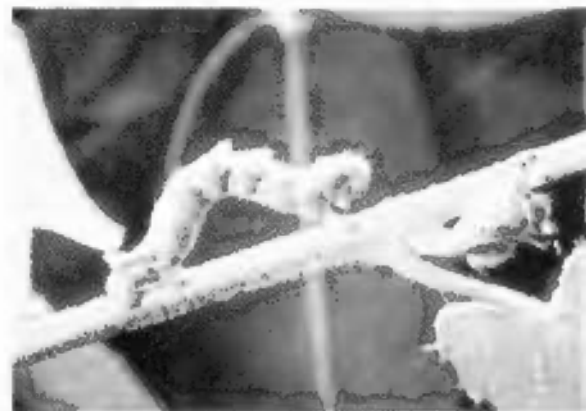
Remember that a gene is a section of DNA, and DNA codes for a polypeptide, or string of amino acids. In many cases, the dominant allele codes for a polypeptide that works, whereas the recessive allele codes for a polypeptide that does not work. For example, suppose that the allele *B* codes for an enzyme that makes a black pigment in a mouse's fur and allele *b* codes for a defective enzyme that cannot make the pigment. A mouse that has the genotype *bb* will have white fur because it lacks the enzyme that makes the black pigment. But a mouse that has the genotype *BB* or *Bb* will have black fur because it possesses the enzyme that makes the black pigment. Although each cell in the *Bb* animal has just one copy of the functioning allele, that single copy can code for thousands of mRNA molecules. And each mRNA molecule can code for thousands of enzymes. This is the reason the *B* allele is dominant over the *b* allele.

INCOMPLETE DOMINANCE In 1760 the German scientist Josef Kölreuter reported on experiments in which he crossed white carnations (*rr*) with red carnations (*RR*). Kölreuter found that all of the offspring from his crosses had pink flowers (*Rr*). In other words, the hybrids had a phenotype that was intermediate between those of the parents. At first glance, it might appear as if the parents' genes had blended together. But when Kölreuter crossed his pink *F*₁ hybrids with each other to form an *F*₂ generation, the parents' phenotypes reappeared. In the *F*₂ generation, 1/4 of the plants had red flowers, 1/2 had pink flowers, and 1/4 had white flowers. (This 1:2:1 ratio should be familiar to you from Mendel's crosses.)

Section Objectives

- Discuss gene interactions that influence gene expression.
- Explain how an operon is turned on and off.
- Describe introns and exons.

Figure 10-14 For some organisms, such as these caterpillars, gene expression is regulated by chemicals in the food they eat. Each caterpillar of this species has the genetic ability to develop either the twiglike or the flowerlike form. However, caterpillars that eat gray-green oak twigs look like twigs (top). And caterpillars that eat fuzzy gold oak flowers look like flowers (bottom).



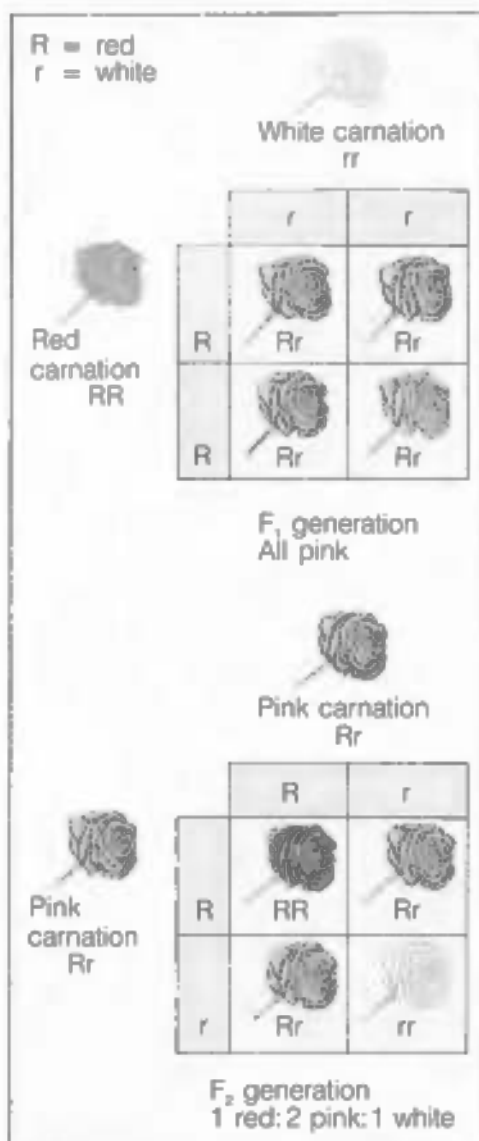


Figure 10–15 Flower color in carnations is an example of incomplete dominance. The heterozygous phenotype, pink, is somewhere in between the homozygous phenotypes, red and white.

In carnations, the *R* allele, which codes for an enzyme that makes red pigment, is incompletely dominant over the *r* allele, which codes for a defective enzyme that cannot make pigment. In **incomplete dominance** the active allele does not compensate for the inactive allele, and the heterozygous phenotype is somewhere in between the homozygous phenotypes.

CODOMINANCE Many genes display **codominance**, a condition in which both alleles of a gene are expressed. In other words, both alleles are active. (Remember that in incomplete dominance only one of the alleles is active.) Codominant alleles are written as capital letters with subscripts (for example, *B*₁ and *B*₂) or superscripts (for example, *R* and *R'*).

Codominance is seen in many organisms. For example, red hair (*H^R*) is codominant with white hair (*H^W*) in cattle. Cattle that have the genotype *H^RH^W* are roan, or pinkish brown, in color because their coats are a mixture of red and white hairs. Much the same thing happens in certain varieties of chickens. Black feathers (*F^B*) are codominant with white feathers (*F^W*). Erminette chickens (*F^BF^W*) are speckled black and white.

POLYGENIC INHERITANCE It would be a great mistake to assume that all traits are produced by single genes. Many traits are produced by the interaction of many genes. Traits controlled by two or more genes are said to be **polygenic** (*poly*-means many). For example, at least three enzymes—each of which is produced by a different gene—are involved in making the reddish-brown pigment in the eyes of fruit flies. Different combinations of enzymes (which may be present in the normal form or altered or absent due to a mutation) produce different eye colors. More complicated traits, such as the shape of your nose or the color and markings on an animal's coat, are the result of interactions between large numbers of genes.

Gene Expression in Prokaryotes

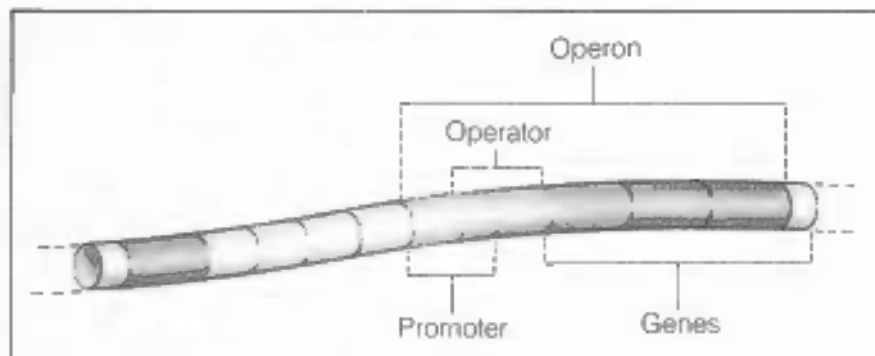
In Chapter 7 you learned that individual genes on a chromosome serve as a template, or pattern, for the production of mRNA. In turn, mRNA serves as the instructions for the production of a protein (polypeptide). The genes of a single organism cannot all be activated at the same time. A cell that activated all of its genes at once would make a great many molecules that it did not need and would waste energy and raw materials in doing so. However, when the cell does need the product of a gene, it must be able to produce that product quickly and in adequate amounts.

When the product of a gene (a specific protein) is being actively produced by a cell, we say that the gene is being expressed. Within a single organism, some genes are rarely expressed, some are constantly expressed, and some are expressed for a time and then turned off. But how does a cell

"know" when to make a protein and when not to make it? In other words, how does a cell "know" which genes to turn on and which to turn off?

THE OPERON The mechanisms by which genes are turned on and off are quite complex. In this section we will examine one way genes are regulated in prokaryotes (organisms without a nucleus). This particular mechanism was discovered by the French scientists François Jacob and Jacques Monod in 1961. They noticed that genes that work together are often clustered together on a small area of a prokaryote's chromosome. Jacob and Monod also determined that there are regions on a chromosome that lie near these gene clusters but that do not code for the production of proteins. These regions are, however, involved in the regulation and expression of nearby gene clusters. These regions and the gene cluster they regulate are called an **operon** because they operate together.

An operon consists of the following parts: a cluster of genes that work together; a region of the chromosome near the cluster of genes called the **operator**; and a region of the chromosome next to the operator called the **promoter**. As you can see in Figure 10-17, the operator and promoter regions overlap slightly.



The gene cluster in the operon that Jacob and Monod studied produces enzymes that break down lactose, a sugar that bacteria can use as a food source. Bacteria do not produce these lactose-breaking enzymes in large amounts unless lactose is present. In other words, the very presence of lactose induces the production of the enzymes necessary to break down lactose for use as food. In this operon system, lactose is called the **inducer** because it induces the production of enzymes.

In order to make the enzymes, RNA polymerase must move along the genes on the chromosome, producing mRNA in the process. Before the RNA polymerase can get to the desired genes, it must first attach to the promoter region near the genes. We might think of the promoter as a "Start Here!" instruction to RNA polymerase. Once the RNA polymerase attaches to the promoter, it can move along the chromosome, past



Figure 10-16 In certain varieties of chickens, black and white feather colors are caused by codominant alleles. Thus the heterozygous phenotype, speckled black and white, is a result of the expression of both alleles.

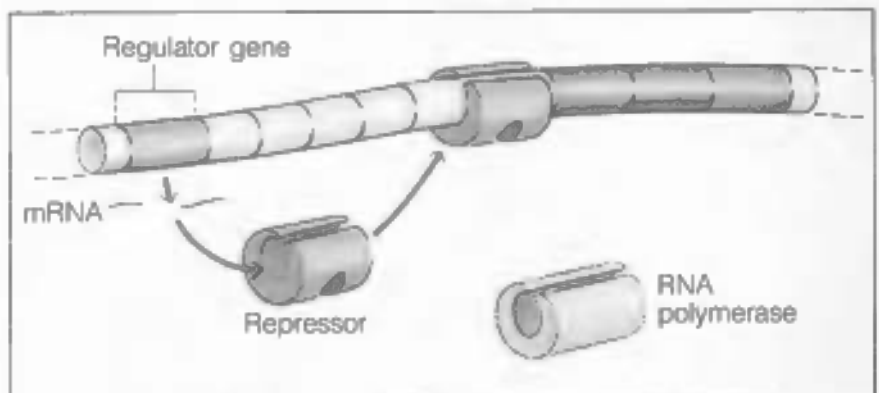
Figure 10-17 Some genes in prokaryotes are regulated by an operon. An operon consists of several sections of DNA that are operated together. The operon studied by Jacob and Monod, which breaks down the sugar lactose, consists of a promoter, an operator, and a cluster of genes that code for lactose-metabolizing enzymes.

the operator region, to the genes. When the RNA polymerase reaches the genes, it can produce mRNA, which “instructs” the ribosomes to make the enzymes. When this process is taking place, we say the genes are activated, or being expressed. The enzymes coded for by the genes can then perform their task in the cell—in this case, breaking down the inducer lactose.

Remember that Jacob and Monod observed that the enzymes coded for by the genes in the operon were not produced in the absence of the inducer (lactose). Does this mean that the cell has a way to turn the operon off? Indeed it does.

THE REPRESSOR The cell produces a special protein called a **repressor**. When the repressor nears the operator region of an operon, it attaches itself to the operator so that it sits between the promoter and the genes. The repressor’s position blocks the access of RNA polymerase to the genes. Like the guard outside a locked factory, the repressor prevents the workers (RNA polymerase) from getting to their jobs (making mRNA). In other words, the repressor turns the genes of the operon off.

Figure 10-18 The genes in this operon are turned off when a protein called the repressor binds to the operator and thus prevents the transcription of mRNA.



You might wonder how the repressor “knows” which operon to attach to and thereby turn off. The actual mechanism is quite elegant and specific. Each repressor is shaped to fit a specific region of DNA on the chromosome. It can attach only to the specific operator on the operon it regulates. Thus each repressor turns off a specific operon.

GENE ACTIVATION You now know that a gene cluster is part of an operon that includes an operator and a promoter. And you also know that the genes are turned off when the repressor binds to the operator. But there is more to the story. How is the operon turned back on when it is needed?

When the inducer enters the cell, it binds to the repressor. And something quite remarkable happens: The repressor changes shape and can no longer bind to the operator. The repressor actually falls off the operator.

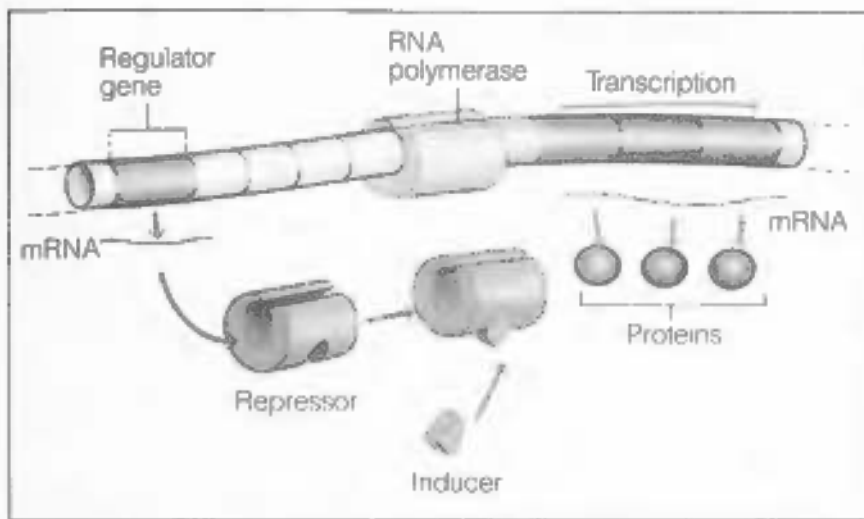


Figure 10-19 The genes in this operon are turned on when lactose (the inducer) binds to the repressor and causes it to fall off the operator. This allows RNA polymerase to bind to the promoter, move across the operator, and transcribe mRNA from the cluster of genes. The operon system ensures that genes are activated only when their products are needed. In this case, the lactose-metabolizing enzymes are produced only when lactose is present.

When the repressor falls off the operator, the RNA polymerase can bind to the promoter, move across to the genes, and produce messenger RNA. The mRNA codes for the enzymes that are used to break down the inducer. When the cell runs out of the inducer, the repressor can bind to the operator again, and the operon is turned off. The complete system is automatic and self-regulating. The presence of the inducer causes the cell to make the enzymes needed to use it. And when the inducer disappears, the enzymes are no longer made.

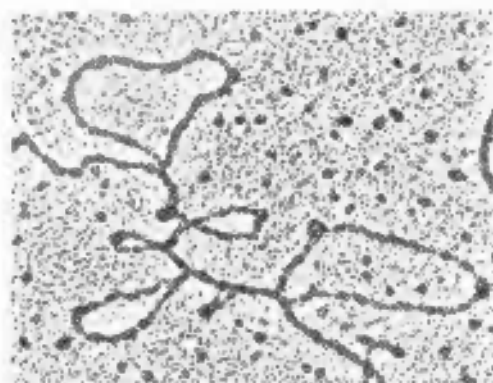
The repressor-operon system provides us with one model of how a group of genes can be regulated so that they are expressed only when they are needed. A number of other gene-regulation systems in prokaryotes have been identified. Some of these gene systems use repressors in a manner similar to that just described. Others use proteins that enhance the rate of transcription. In other systems, regulation occurs at the level of protein synthesis. Regardless of the actual system involved, the result is the same: Cells are able to turn their genes on and off, using the genes only when needed.

Gene Expression in Eukaryotes

The cells of eukaryotes contain a nucleus and membrane-enclosed organelles. Gene regulation in eukaryotes is more complex than in prokaryotes. Increased understanding of control systems in eukaryotes indicates that there are several systems of gene regulation. One system involves a substance called an inducer. Like the inducer in the operon system, inducers in eukaryotes induce, or cause, the activation of genes. In eukaryotes, inducers bind directly to DNA and either start or increase transcription of particular genes.

In 1976 Philip Sharp and Susan Berget discovered that mRNA produced during transcription may be altered before it is used to make protein (polypeptide) during translation. You may recall that during transcription, the base sequence in a

Figure 10-20 The sequence of bases on the mRNA for this egg-white protein does not exactly match that of its corresponding gene. The DNA sequences that are not complementary to the mRNA appear as loops called introns.



Single strand of DNA

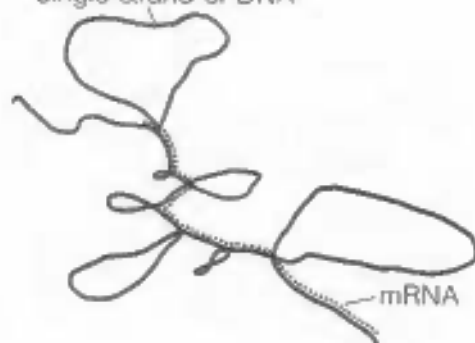


Figure 10-21 RNA polymerase transcribes an entire gene, introns and exons alike. Before the transcribed RNA, or pre-mRNA, can leave the nucleus and code for protein, the introns must be removed and a chemical "cap" and "tail" must be attached.

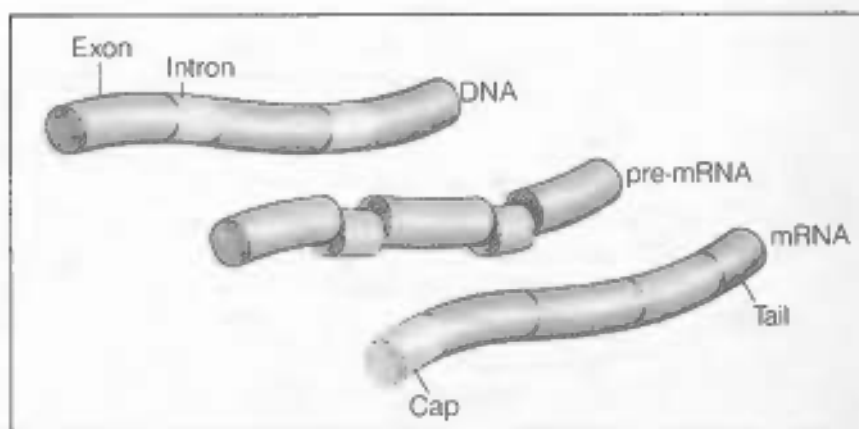
gene is transcribed into the complementary base sequence on mRNA. Most scientists assumed that a sequence of bases on mRNA was exactly complementary to a DNA sequence for a gene.

Sharp and Berget carefully compared the mRNA of a protein with a piece of DNA containing the gene for that protein. They expected to find an exact pairing between the bases on the gene and the bases on the mRNA that helps produce the protein. Instead, they discovered that the DNA fragment contained large sequences that were not complementary to the base sequence on the mRNA. What was going on?

Sharp and Berget quickly realized that the presence of DNA sequences that are not complementary to mRNA sequences implies that the gene is in "pieces." In other words, DNA sequences that code for protein (the gene pieces) are separated by DNA sequences that do not code for protein. Today we know that many eukaryotic genes contain sequences that are complementary to mRNA and sequences that are not. The sequences that are complementary code for protein. These "expressed" sequences are called **exons**. The segments that are not complementary do not code for protein. These "intervening" sequences are called **introns**.

When RNA polymerase moves along a gene, it transcribes the entire gene. This means that the RNA produced by transcription, or pre-mRNA, contains introns. Before the cell can produce protein, the pre-mRNA must be processed into functional mRNA. During this processing, the introns on the pre-mRNA are removed and the exons are spliced back together. In addition, a chemical "cap" and "tail" are attached to the RNA. At this point, the pre-mRNA can be called mRNA.

The conversion of pre-mRNA into mRNA has further significance because of the fact that the processing takes place entirely within the nucleus. This means that mRNA must complete its processing before it is allowed to leave the nucleus. There may be some kind of a molecular watchman at the gate of the nucleus that allows only processed molecules to leave. Such a system would regulate gene expression by preventing the protein products of a gene from being produced.



Jumping Genes



In the 1940s a young scientist named Barbara McClintock began to study certain genes in corn. She was particularly interested in why certain kernels of corn developed a spotty, or speckled, appearance. She knew that the color of each seed

was genetically determined and that all of the cells in the coating of the seed had the same genetic makeup (genotype). Yet the speckled colors indicated that genes were being suddenly and unpredictably switched on and off in one cell or another. She could find only one reasonable explanation for this observation: There are special controlling elements that can be transposed or move from one place to another around the chromosome. These transposable elements, which are sometimes called jumping genes, can insert themselves into different parts of the chromosome and

turn the genes near them on or off.

McClintock's theory of transposable elements was far ahead of its time, and found little support. But McClintock patiently continued her studies, providing experimental proof and documentation that she was right about these moving genes. Finally, in 1975, the techniques of molecular biology had advanced to the point where scientists could actually look for jumping genes. And scientists found jumping genes in bacteria, insects, mammals (including humans), and corn.

Jumping genes may play a role in gene regulation in some organisms, such as corn. They also are involved in the formation of certain proteins that show a great number of variations, such as antibodies—proteins that defend the body against disease-causing organisms. More jumping genes are discovered every day, and it will be a long time before scientists are able to explain all of their different functions.

McClintock has lived to see the importance of her discovery appreciated and is now the recipient of many honors, including the highest prize that can be awarded to a scientist, the Nobel prize (in 1983).

10-3 SECTION REVIEW

1. Compare incomplete dominance and codominance.
2. What is a polygenic trait?
3. Suppose the gene that codes for a repressor was deleted. What effect would this have on the operon?
4. "Mutations in introns are less likely to affect phenotype than mutations in exons." Defend or refute this statement.

PROBLEM

How can rates of crossing-over be used to map chromosomes?

MATERIALS (per group)

wooden stick from a frozen-dessert bar
metric ruler
pen
sheet of unlined paper

PROCEDURE

- Using a pen and a ruler, draw a vertical line 15 cm long in the center of a clean sheet of unlined paper. Make a small horizontal mark at the bottom of the line. Measuring from the bottom of the line, add horizontal marks at 1 cm, 3 cm, 6 cm, 10 cm, and 15 cm.
- Label each horizontal mark alphabetically (A through F), starting from the bottom.
- The vertical line on the paper represents a chromosome that has six genes on it—A, B, C, D, E, and F. This chromosome's homologous chromosome is represented by the colored edge of the wooden stick.
- Adjust the sheet of paper so that its bottom edge is about 15 cm from the edge of your lab table or desk. Move your chair back so that the front edge of your seat is about 30 cm from the edge of your lab table or desk.
- Toss the wooden stick, underhand, toward the vertical line until the stick lands across the line. The landing of the stick across the line represents crossing-over.
- When crossing-over occurs, look at the colored edge of the stick to determine which genes have been separated. Make a tally mark in the appropriate place in the data table for each gene that has become separated from gene A. For example, if the colored edge of the stick lands between D and E, make tally marks for genes E and F because they have been separated from gene A as a result of crossing-over.
- Toss the stick and tally the results until crossing-over has occurred 100 times.
- Count up the number of tally marks for each of the five genes. In the appropriate place in your data table, record the number of times each gene was separated from gene A.
- Calculate the frequency of crossing-over by dividing the number of times each gene was separated from gene A by 100. Record the results of your calculations.
- Calculate the location of each gene by multiplying the frequency of its crossing-over by 15 and rounding off to the nearest integer. Record the calculated gene locations.

OBSERVATIONS

Genes Separated from Gene A	Times Separated from Gene A		Frequency of Crossing-over	Gene Locations	
	Tally	Number		Calculated	Actual
B					1
C					3
D					6
E					10
F					15

- Did every toss result in crossing-over?
- Which genes became separated from gene A most frequently? Most infrequently?

ANALYSIS AND CONCLUSIONS

- What is the relationship between the frequency of gene separation due to crossing-over and the distance between genes?
- Are your calculated gene locations exactly the same as the actual gene locations? If so, discuss why the experiment went as expected. If not, discuss possible sources of error.
- How can the frequencies of crossing-over be used to map chromosomes?

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

10-1 The Chromosome Theory of Heredity

- Genes are located on the chromosomes.
- Genes that are located on the same chromosome tend to be inherited together.
- Gene linkages may be broken by crossing-over. The farther apart genes are located on a chromosome, the more likely that they will be separated by a cross-over event.
- Sex-linked genes are located on the sex chromosomes.

10-2 Mutations

- Mutations are changes in the genetic material. There are two kinds of mutations. Chro-

somal mutations involve segments of chromosomes, whole chromosomes, or entire sets of chromosomes. Gene mutations involve individual genes.

10-3 Regulation of Gene Expression

- Interactions between genes affect gene expression.
- Genes can be turned on when they are needed and turned off when they are not.
- Many genes contain sequences that are not expressed. These sequences are removed when the RNA transcribed from DNA is made into mRNA.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

10-1 The Chromosome Theory of Heredity

chromosome theory of heredity
linked genes
linkage group
recombinant
sex chromosome
autosome
X chromosome
Y chromosome
sex-linked

10-2 Mutations

mutation
chromosomal mutation
nondisjunction
polyploidy
gene mutation
point mutation
frameshift mutation

10-3 Regulation of Gene Expression

incomplete dominance
codominance
polygenic
operon
operator
promoter
inducer
repressor
exon
intron

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- An organism has an extra copy of a chromosome in all its cells. This is an example of
 - polyploidy.
 - a chromosomal mutation.
 - a gene mutation.
 - a somatic mutation.
- Both alleles are expressed in
 - codominance.
 - nondisjunction.
 - polyploidy.
 - dominance.
- The expressed allele does not make up for the inactive allele in
 - polyploidy.
 - translocation.
 - codominance.
 - incomplete dominance.
- Which kind of mutation would result if an extra nucleotide were inserted into a gene?
 - germ
 - frameshift
 - chromosomal
 - deletion
- Traits that are caused by the interaction of many genes are said to be
 - polyploid.
 - linked.
 - polygenic.
 - autosomal.
- The gene product is not produced when the repressor binds to
 - the operator.
 - RNA polymerase.
 - lactose.
 - the enzyme gene.
- A point mutation can best be classified as a
 - chromosomal mutation.
 - germ mutation.
 - deletion mutation.
 - gene mutation.
- Gene linkages may be broken by
 - nondisjunction.
 - duplication.
 - crossing-over.
 - polyploidy.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- Crossing-over is more likely to occur between genes that are close together.
- A somatic mutation affects sperm cells or egg cells and can be inherited.
- The effects of recessive sex-linked alleles are seen more often in males.
- Changes in DNA are called mutations.
- Segments of nonhomologous chromosomes are exchanged in crossing-over.
- Sex-linked genes are located on the autosomes.
- Polyploidy is the condition of having extra sets of chromosomes.
- A point mutation affects a single nucleotide.

Word Relationships

A. In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

- inversion, translocation, duplication, nondisjunction
- operator, promoter, repressor, inducer
- dominance, codominance, incomplete dominance, polygenic inheritance
- gene mutation, point mutation, frameshift mutation, chromosomal mutation

B. Give the vocabulary word whose meaning is opposite that of the following words.

- | | |
|-------------------|---------------------|
| 5. sex chromosome | 7. somatic mutation |
| 6. crossing-over | 8. intron |

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

- | | |
|--|---|
| 1. List and describe the four types of chromosomal mutations that result in a change in the structure of a chromosome. | 3. Describe two ways genes are regulated in eukaryotes. |
| 2. Explain why the operon is turned on when the inducer is present and turned off in the absence of the inducer. | 4. What is a linkage group? What kind of evidence suggests that linkage groups are the same as chromosomes? |

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

- | | |
|---|--|
| 1. Making predictions Would a mutation in an intron affect gene expression? Explain. | 4. Applying concepts Two of the genes that Mendel studied are located on the same chromosome. Despite this, they show independent assortment in test crosses. What can you conclude about their relative positions on the chromosome? |
| 2. Relating concepts How are crossing-over and linkage related to gene mapping? | 5. Using the writing process Pretend you are the sex-linked gene for colorblindness. Describe the effects you have on each generation as you are passed down through two generations. |
| 3. Problem solving Examine the data for the crosses in cats shown below. How are the black and yellow coat colors inherited? (<i>Hint:</i> Male cats are XY and female cats are XX.) Using a Punnett square, predict the results of a cross involving a black male and a tortoise-shell female. | |

Parents	Offspring
black male X yellow female	$\frac{1}{2}$ yellow males $\frac{1}{2}$ tortoise-shell (black and yellow) females
yellow male X black female	$\frac{1}{2}$ black males $\frac{1}{2}$ tortoise-shell females
yellow male X tortoise-shell female	$\frac{1}{4}$ black males $\frac{1}{4}$ yellow males $\frac{1}{4}$ yellow females $\frac{1}{4}$ tortoise-shell females

CHAPTER 11

Human Heredity



In humans, as in all living things, traits such as sex and skin color are inherited.

Of all the organisms in the world, there is one that we find particularly fascinating. This organism is not, however, an ideal one for the study of genetics. Why? The reasons are many. It is composed of approximately 10^{14} (100 million million) cells. Its generation time (about 20 years) is much too long. It cannot be kept in the laboratory for study. It produces too few offspring for good statistics. It cannot be used in test crosses. And its genetic system contains nearly 100,000 genes. Despite these disadvantages, biologists have studied the genetics of this single organism, *Homo sapiens*, for more than 80 years. The reason for so much scientific interest is clear: Of all the organisms on Earth, it is ourselves we long to know the best. In this chapter, you will discover how some human traits are inherited and how some inherited disorders can be cured or prevented.

11-1 "It Runs in the Family"

- The Human Organism
- Human Traits

11-2 The Inheritance of Human Traits

- Human Blood Groups
- Huntington Disease
- Sickle Cell Anemia
- Polygenic Traits

11-3 Sex-Linked Inheritance

- Sex Determination
- Sex-Linked Genetic Disorders
- Sex-Influenced Traits

11-4 Diagnosis of Genetic Disorders

- A Chromosomal Abnormality—Down Syndrome
- Prenatal Diagnosis
- Ethical Considerations

11-1 "It Runs in the Family"

Section Objectives

- 1 Explain how human traits are inherited.
- 2 Distinguish between sex chromosomes and autosomes.
- 3 Discuss the influence of the environment on gene expression.

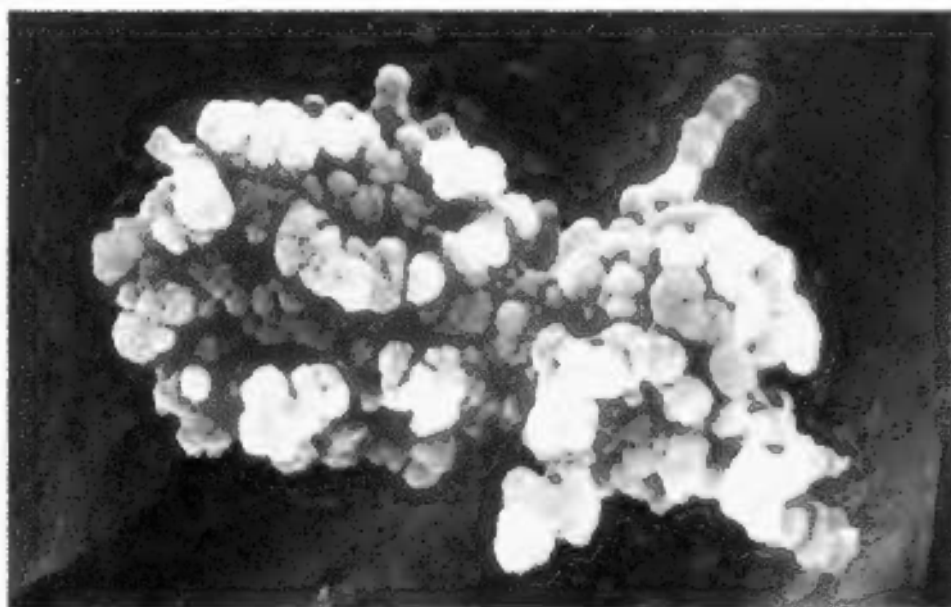
How many times have you overheard two people discussing whether a newborn baby looks more like its mother or its father? People have always discussed such things. But when those of us who study biology engage in such discussions, we make an important assumption: Human children inherit characteristics from their parents as a result of gene interactions.

The principles of genetics that we have already discussed apply to humans. **Many human traits are inherited by the action of dominant and recessive genes, although other traits are determined through more complicated gene interactions.** Although the study of human genetics is difficult, it is one of the most important fields in biology. For we are interested in finding out as much as possible about ourselves, including the role that heredity plays in determining who and what we are and how some of the disorders and conditions that we inherit can be cured or prevented.

The Human Organism

The study of ourselves logically begins with a discussion of human chromosomes. Recall that a diploid cell has two sets of homologous chromosomes. A human diploid cell contains 46 chromosomes arranged in 23 pairs. These 46 chromosomes

Figure 11-1 Each human chromosome contains a specific set of genetic instructions that is passed on from parent to child. The human chromosome in this electron micrograph has been magnified approximately 20,000 times.



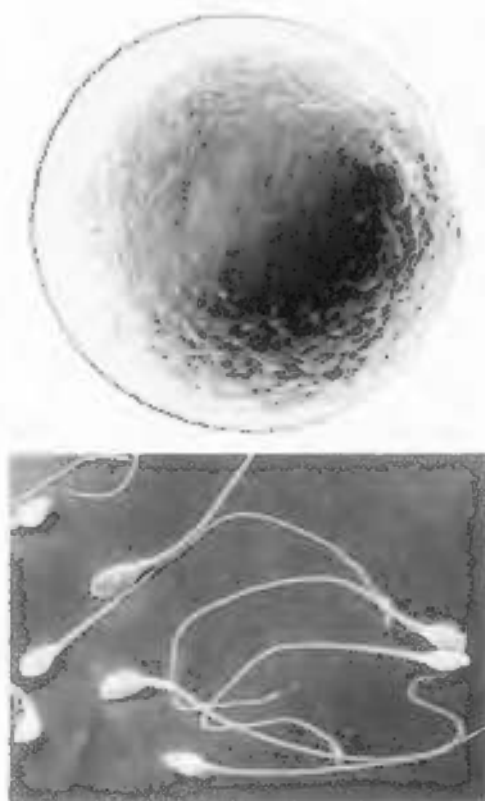


Figure 11-2 In humans, the egg (top) and the sperm (bottom) contain 23 chromosomes each. During fertilization, these gametes unite to produce a zygote that contains 46 chromosomes.

contain 6 billion nucleotide pairs of DNA—6 billion individual characters of the genetic code. To get an idea of how long a complete human DNA sequence actually is, consider the following: In this textbook, there are approximately 3000 letters on each page. If a complete human DNA sequence were to be written in the same-size type as this textbook, it would comprise a book more than 1 million pages long!

As you will recall from Chapter 9, the principles of genetics described by Mendel require that organisms inherit a single copy of each gene from each parent. In humans, the **gametes**, or reproductive cells, contain a single copy of each gene. Gametes (sperm and eggs) are formed in the reproductive organs by the process of meiosis. Each egg cell and each sperm cell contain 23 chromosomes, or the haploid number of chromosomes. During fertilization, sperm and egg unite and a **zygote** (ZIGH-goht), or fertilized egg, is produced. The zygote contains 46 chromosomes (23 pairs), or the diploid number of chromosomes characteristic of the organism.

Of the 46 chromosomes found in a human diploid cell, two are the sex chromosomes, X and Y. The remaining 44 chromosomes are the autosomes. The inheritance of dominant and recessive human genes carried on any of the 44 autosomes follows Mendel's principles. Human genes carried on the sex chromosomes are sex-linked.

The simplest patterns of inheritance occur in traits that are influenced by a single gene. Fortunately, many such genes have now been described. Human genetics is advancing so rapidly that scarcely a week goes by without a new human gene being reported and mapped.

Human Traits

You will recall from Chapter 10 that the phenotype of an organism is only partly determined by its genotype. There are some traits that are strongly influenced by environmental, or nongenetic, factors. Environmental factors include nutrition and exercise. For example, recent studies show that improvements in infant and childhood nutrition in the twentieth century in the United States and Europe have greatly increased

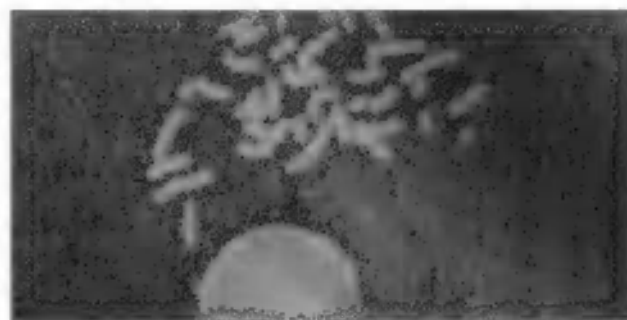
Figure 11-3 Notice the difference in the heights of these teenagers. Although the genes for height are inherited, the trait is strongly influenced by environmental factors, such as diet.



How Do We Map Human Genes?

Preparing a human genetic map presents special challenges. As we saw in Chapter 10, crossing-over is the key to gene mapping in most organisms: Crossovers rarely occur between nearby genes but are common between distant genes. It is possible to map human genes in this way, but the need to gather crossover data from several generations has made human gene mapping slow and tedious. In the last few years, however, several breakthroughs have made it possible to map human genes much more rapidly.

One of the most exciting new techniques was developed by Jeanne Lawrence and Robert Singer at the University of Massachusetts Medical School. Their technique attaches a fluorescent label to pieces of DNA complementary to a particular gene. Once the labeled DNA fragments are mixed with a chromosome



Two tiny yellow spots mark the location of the genes of the Epstein-Barr virus.

preparation, they attach to the DNA of the gene in question by a chemical bond known as a hydrogen bond. This action produces an intense fluorescent label at the place on the chromosome where the gene is located. The Lawrence-Singer technique is just one more tool in an increasingly powerful workshop for exploring the human genetic system.

the average height of these populations over the nineteenth-century averages. Famine-stricken countries, however, were found to produce a generation with stunted growth.

Although it is important to consider the influence of the environment on the expression of some genes, it must be understood that environmental effects on gene expression are not inherited; genes are. Genes that are denied a proper environment in which to reach full expression in one generation can, in a proper environment, achieve full potential in a later generation.

11-1 SECTION REVIEW

1. How are human traits inherited?
2. What is a gamete? A zygote?
3. How many chromosomes are in a human diploid cell? A human haploid cell?
4. Distinguish between sex chromosomes and autosomes.
5. How does the environment influence gene expression?

Section Objectives

- Identify two human traits that are determined by multiple alleles.
- Explain how Huntington disease and sickle cell anemia are inherited.
- Distinguish between traits determined by multiple alleles and polygenic traits.

11-2 The Inheritance of Human Traits

At the writing of this textbook, more than 1000 human genes have been described and studied. Listing all of these genes would serve no purpose, but it is useful and interesting to examine a few cases in which particular genes affect us in very significant, and often dramatic, ways.

Human Blood Groups

Multiple alleles are three or more alleles of the same gene that code for a single trait. ABO and Rh blood groups are determined by multiple alleles. A number of other human traits are determined by multiple alleles.

ABO BLOOD GROUPS In 1900, the Austrian physician Karl Landsteiner discovered that human blood could be classified into four general groups, or types, known today as the Landsteiner blood groups. These four blood types are determined by the presence or absence of specific chemical substances in the blood.

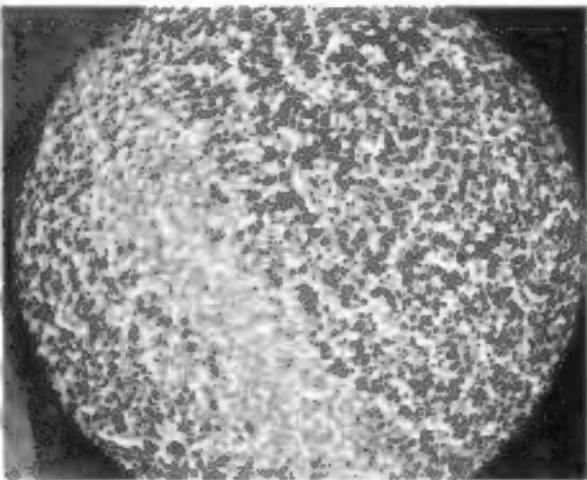
Landsteiner observed that when he mixed together the red blood cells from different people, the red blood cells agglutinated, or clumped together. After doing extensive research, Landsteiner determined that the red blood cells contained two antigens, A and B. Antigens are molecules that can be recognized by the immune system.

The presence or absence of these antigens (A and B) produces four possible blood types: A, B, AB, and O. A person with type A blood has red blood cells that contain antigen A but not antigen B. A person with type B blood has red blood cells that contain antigen B but not antigen A. A person with type AB blood has both antigen A and antigen B. And a person with type O blood has neither antigen A nor antigen B.

The ABO blood groups are of particular importance in blood transfusions. A transfusion of the wrong blood type can cause a violent, often fatal, reaction in the body as the immune system responds to the presence of an antigen not found on its own cells. For example, if type B blood is given to a person with type A or type O blood, a reaction will occur against the red blood cells containing the B antigen. Because people with type AB blood have both antigens on their red blood cells, they can receive blood from any of the four types.

The Landsteiner, or ABO, blood groups are determined by a single gene with three possible alleles: I^A , I^B , or i . Figure 11-5 illustrates the relationship of these alleles to the blood group phenotype. Because the I^A and I^B alleles are both expressed when they occur together, they are said to be codominant.

Figure 11-4 This photomicrograph shows the agglutination, or clumping, of human red blood cells that can occur when blood of two different types is mixed.



Rh BLOOD GROUPS In addition to the ABO antigens, there is another antigen on the red blood cells that determines the success or failure of transfusions. It is the Rh antigen (named after the rhesus monkey in which the antigen was first discovered by Landsteiner and Alexander Wiener). People who have the Rh antigen on their red blood cells are said to be Rh positive (Rh^+). People who do not have the Rh antigen on their red blood cells are said to be Rh negative (Rh^-). It is interesting to note that although the Rh blood groups are commonly referred to as either positive or negative, there are actually more than two alleles that determine these blood groups. In fact, there are eight common alleles and many that are rarer.

In blood banks, the ABO and Rh blood groups are often expressed together in symbols such as AB^- or O^+ . The gene for the Rh antigen, however, displays simple dominance. Genotype $Rh^+ Rh^+$ and $Rh^- Rh^+$ produces the Rh positive phenotype. Only the double recessive genotype $Rh^- Rh^-$ produces Rh negative blood.

Huntington Disease

Many of the tens of thousands of human genes are so essential to the normal functioning of cells and tissues that we do not notice them unless something goes wrong and a genetic disease results. **Huntington disease, which is produced by a single dominant allele (H), is an example of a genetic disease.** People who have this disease show no symptoms until they are in their thirties or forties, when the gradual damage to their nervous system begins. As you will recall from Chapter 10, the effects of a dominant allele are expressed even when the recessive allele is present. So people who have the dominant allele for Huntington disease have the disease and suffer painful progressive loss of muscle control and mental function until death occurs.

Until very recently, the only way people knew if they carried the gene for Huntington disease was the appearance of the disease later in their lives. Thus many Huntington disease sufferers had children who inherited the gene for this disease.

Sickle Cell Anemia

In 1904, Doctor James Herrick noticed an unusual ailment afflicting one of his young patients. His patient, a 20-year-old black college student, had been complaining of weakness and dizzy spells and had open sores on his legs. The Chicago physician examined the student's blood cells under a microscope and discovered that many of the red blood cells were bent and twisted into shapes that resembled sickles (farm tools used to cut grain). The normal shape of a red blood cell is that of a round, flattened disk. Doctor Herrick guessed correctly that these unusually shaped cells were the cause of his patient's

Genotypes	Phenotypes
ii	O
$I^A I^A, I^A i$	A
$I^B I^B, I^B i$	B
$I^A I^B$	AB

Figure 11-5 This chart illustrates the relationship between genotype and phenotype for each of the ABO blood groups. What are the possible genotypes of a person with phenotype B blood?

Figure 11-6 This photograph shows a rhesus monkey, the type of monkey after which the Rh blood group was named.



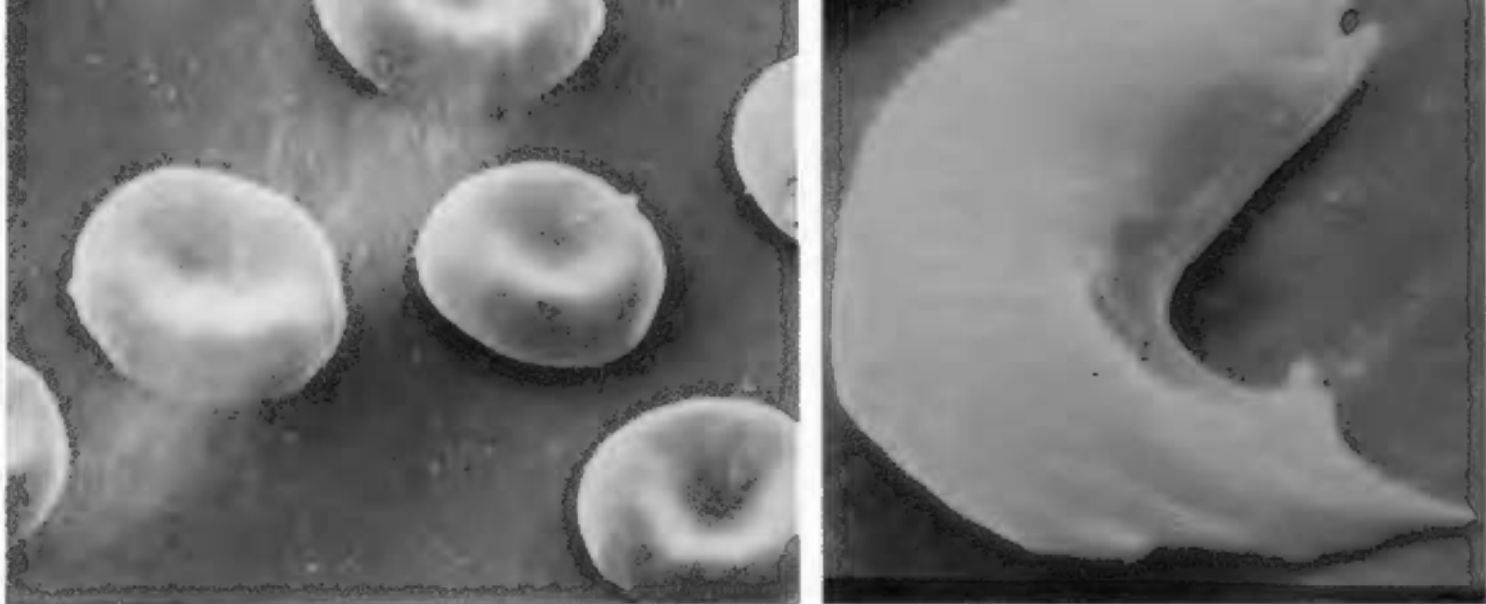
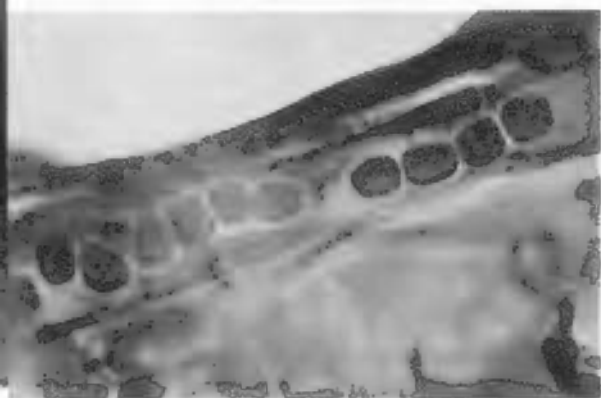


Figure 11-7 These scanning electron micrographs show human red blood cells that contain normal hemoglobin (left) and a red blood cell that contains the abnormal hemoglobin characteristic of sickle cell anemia (right). The red blood cells have been magnified approximately 10,000 times.

Figure 11-8 Capillaries, which are the narrowest blood vessels, are so small that they permit only one red blood cell at a time to pass through. What happens to sickle-shaped red blood cells as they move through the capillaries?



problems, and he gave the disease the name by which we know it today—sickle cell anemia.

THE CAUSE OF SICKLE CELL ANEMIA Sickle cell anemia is caused by a change in one of the polypeptides found in hemoglobin. Hemoglobin is the protein that carries oxygen in red blood cells.

When a person who has sickle cell anemia is deprived of oxygen (from heavy exercise, holding one's breath, or even nervousness or anxiety), the hemoglobin molecules join together and form fibers. These fibers cause the red blood cells to undergo the dramatic changes in shape that Doctor Herrick observed. The sickle-shaped red blood cells are more rigid and tend to become stuck in the capillaries, the narrowest blood vessels in the body. See Figure 11-8. As a result, the movement of blood through these vessels is stopped and damage to cells and tissues occurs. Serious injury or death may result.

THE GENETICS OF SICKLE CELL ANEMIA The gene for normal hemoglobin (A) is codominant with the sickle cell gene (S). People who are heterozygous (AS) are said to be sickle cell carriers. Because roughly half of the hemoglobin molecules in the blood of carriers is normal, these people suffer few ill effects of the disorder. People who are homozygous (SS) are said to be sickle cell sufferers. Because all of their hemoglobin molecules are affected by the sickle cell gene, these people are more severely afflicted by the disease.

THE MOLECULAR BASIS OF SICKLE CELL ANEMIA The gene for sickle cell hemoglobin differs from the gene for normal hemoglobin by a single nucleotide. Why does this seemingly small difference cause so much trouble?

The substitution of one nucleotide in the gene results in the substitution of a different amino acid in the sickle cell

hemoglobin protein. This change makes hemoglobin less soluble in water. Most of the time the condition does not present a problem. But when the body is under even minor stress, the hemoglobin in a large proportion of red blood cells will come out of solution as crystals. This crystallization of hemoglobin causes the sickle-shaped cells to appear, accompanied by their medical consequences.

THE DISTRIBUTION OF SICKLE CELL ANEMIA In the United States, people of African ancestry are the most common carriers of the sickle cell trait. In the rest of the world, sickle cell anemia is found in the tropical regions of Africa and Asia. Approximately 10 percent of Americans of African ancestry and as many as 40 percent of the population in some parts of Africa carry the trait. Why is sickle cell anemia so common in some regions and virtually unknown in others (such as Northern Europe and Asia)?

The answer to this question provides us with a surprising lesson in evolution. People who are heterozygous for sickle cell anemia (AS) are partially resistant to malaria, a serious disease that affects the red blood cells. The sickle cell hemoglobin offers this resistance because the malaria parasite, which lives within the red blood cell, can be killed when hemoglobin molecules crystallize out of solution. People who are homozygous for normal hemoglobin (AA), on the other hand, have no resistance to malaria.

The incidence of sickle cell anemia parallels the incidence of malaria throughout the tropical areas of the world. The sickle cell trait probably developed in many people throughout the world as a single mutation, or change in genetic material. That mutation conferred an advantage wherever malaria was common, and thus it was favored by natural selection. Sickle cell anemia has persisted wherever it has helped its carriers survive malaria.

	A	S
A	AA	AS
S	AS	SS

A = gene for normal hemoglobin
S = gene for sickle cell hemoglobin

Figure 11-9 This Punnett square shows the cross between a person who is heterozygous for sickle cell anemia and a person who is homozygous for normal hemoglobin. What are the possible genotypes of their offspring?

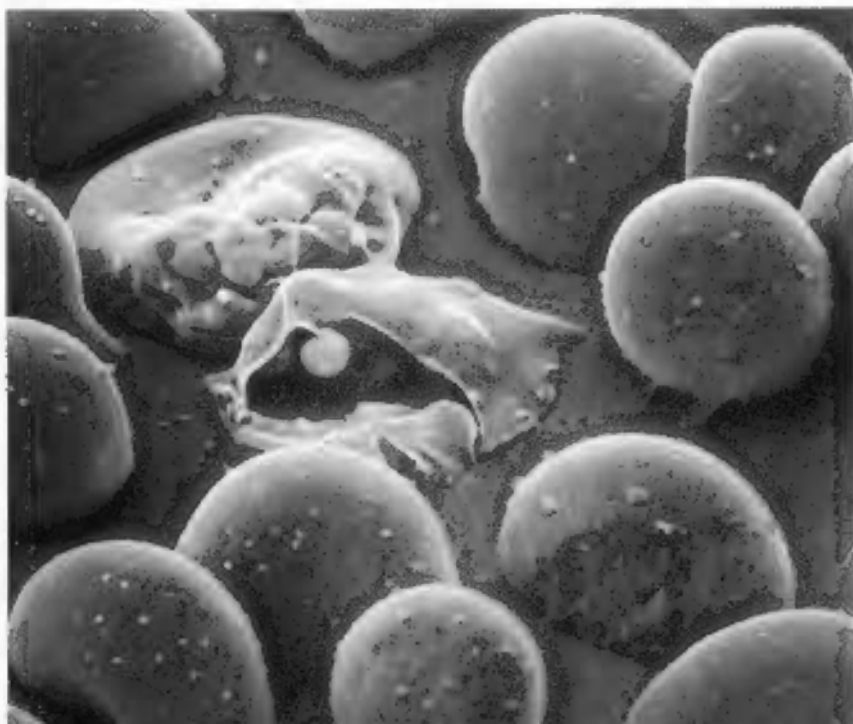


Figure 11-10 Two of the red blood cells in this scanning electron micrograph have been invaded by the parasite that causes malaria. People who are heterozygous for sickle cell anemia are partially resistant to malaria.

Figure 11-11 The color of human skin ranges from very light to very dark, depending upon the amount of melanin (dark pigment) present in the skin cells. Very dark-skinned people have alleles that code for production of melanin at all the gene positions for skin color. In very light-skinned people fewer of these positions are occupied by alleles that code for melanin production.



Polygenic Traits

Human traits that are controlled by a number of genes are called **polygenic** (pahl-uh-JEHN-ihk) **traits**. Examples of polygenic human traits include height, body weight, and skin color.

Unlike the simple skin pigmentation system of many animals, which allows a single gene to determine color, the human skin pigmentation system is rather complex. In humans, at least four different genes control skin color, and several of these genes may have multiple alleles. This means that the inheritance of skin color in our species can be somewhat unpredictable. And because skin color is a polygenic trait, children of the same mother and father may have quite different patterns of skin color—each pattern determined by which combination of genes they have inherited from their parents.

The color of human skin ranges from very dark to very light, depending upon the amount of melanin, a dark-colored pigment, present in skin cells. Very dark-skinned people have alleles that code for the production of melanin at all their gene positions for skin color. Light-skinned people, on the other hand, have alleles that code for the production of melanin at fewer gene positions for skin color. The range of human skin color, spread across the globe with no clear dividing line, is an illustration of what a wonderfully diverse species we are.

11-2 SECTION REVIEW

1. List several human traits determined by multiple alleles.
2. How is Huntington disease inherited?
3. What is sickle cell anemia?
4. What are polygenic traits? Give two examples of polygenic traits.
5. If a man with type O blood marries a woman with type AB blood, what are the possible genotypes of their offspring?

11-3 Sex-Linked Inheritance

As you will recall from Chapter 10, genes that are located on the sex chromosomes of an organism are inherited in a sex-linked pattern. As in many organisms, the sex in humans is determined by the X and Y chromosomes. In females, meiosis produces egg cells that contain one X chromosome and 22 autosomes. In males, meiosis produces sperm cells of which half contain one Y chromosome and 22 autosomes and the other half contain one X chromosome and 22 autosomes.

The sex of a person is determined by whether an egg cell is fertilized by an X-carrying sperm or a Y-carrying sperm. Males are normally 46XY, meaning that they have a total of 46 chromosomes, including an X chromosome and a Y chromosome. Females are normally 46XX.

Sex Determination

How do the X and Y chromosomes determine whether the sex of the zygote will be male or female? In *Drosophila* (fruit flies), which also have an XY system of sex determination, geneticists have found that sex is determined by the number of X chromosomes. A fruit fly that has a single X chromosome is male, regardless of whether it has a Y chromosome. A fruit fly that has two X chromosomes is female, regardless of whether a Y chromosome is present. This is not so in humans.

THE HUMAN XY SYSTEM Although meiosis is a precise mechanism that separates the two sex chromosomes of a diploid cell into single chromosomes of haploid gamete cells, errors sometimes do take place. The most common of these errors is nondisjunction. **Nondisjunction is the failure of chromosomes to separate properly during one of the stages of meiosis.** See Figure 11-12.

Nondisjunction can produce gametes that contain either two sex chromosomes or no sex chromosomes—a direct contrast to the normal condition of one sex chromosome. When one of these gametes joins with a normal gamete during fertilization, the result is a person with an abnormal number of sex chromosomes.

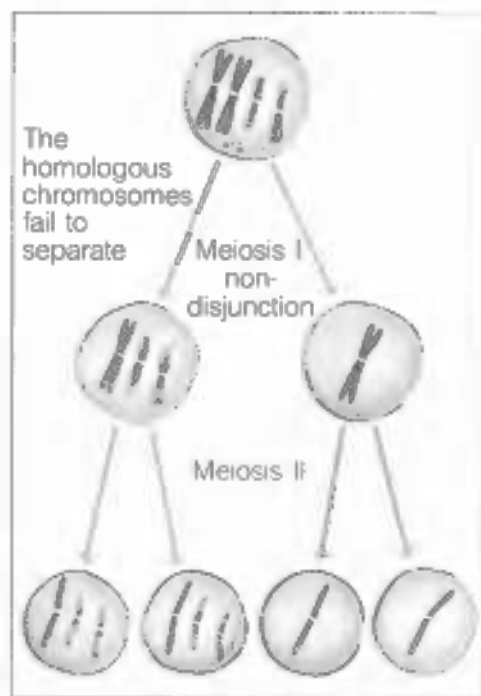
NONDISJUNCTION DISORDERS Roughly 1 birth in 1000 is affected by an abnormality involving nondisjunction of the sex chromosomes. The most common abnormalities are Turner syndrome and Klinefelter syndrome.

People who have Turner syndrome are female in appearance but their female sex organs do not develop at puberty and they are sterile, or unable to have children. Turner syndrome is abbreviated 45X or 45XO, where O denotes the absence of a second sex chromosome. People with Klinefelter syndrome are

Section Objectives

- Describe how sex is determined in humans.
- List two conditions of nondisjunction of sex chromosomes.
- Identify some human sex-linked traits.
- Compare sex-linked and sex-influenced traits.

Figure 11-12 When homologous chromosomes fail to separate during meiosis, nondisjunction results.



Zeroing in on the Maleness Gene

Disorders such as Turner syndrome and Klinefelter syndrome make it clear that maleness is determined by a gene on the Y chromosome. But how would one go about finding that gene? The crucial first steps have now been taken by David Page, a young researcher at the Massachusetts Institute of Technology (MIT). As he studied human sex determination, Page learned that doctors had been treating a number of male patients whose genotypes were 46XX. In every case, these people were found to have portions of the Y chromosome attached to one of their X chromosomes. Page reasoned that these portions must contain the gene for male determination.



Each human has traits that result from the expression of inherited genes. Today, scientists are studying the genetic makeup of X and Y chromosomes to learn how maleness and femaleness are determined.

By analyzing the Y-chromosome portions, Page and his associates found that a single identical piece of the Y chromosome, about 100,000 DNA bases in length, was present in every one of the XX males. Investigators in many laboratories are now concentrating on the structure of this 100,000-base region. Surprisingly, a section of this region is almost identical to a normal fragment found on the X chromosome. No one is certain why the X and Y chromosomes should have a nearly identical fragment, but every new piece of information brings us that much closer to understanding one of the most fundamental of all human differences—maleness and femaleness.

male in appearance, and they, too, are sterile. The abbreviation for Klinefelter syndrome is 47XXY.

It is interesting to note that there have been no reported instances of babies being born without an X chromosome. Embryos without an X chromosome do not seem to develop properly because, as we will soon discover, the X chromosome contains a number of genes that are vital for normal development.

What can we learn from these abnormalities of the sex chromosomes? First, an X chromosome is absolutely essential for survival. Second, sex seems to be determined by the presence or absence of a Y chromosome and not by the number of X chromosomes. For example, there have been reported cases of people who have genotypes 48XXXY and 49XXXXY and are male in appearance.

After years of uncertainty, the reason for the genetic importance of the Y chromosome is finally becoming clear: The Y chromosome contains a gene that switches on the male pattern of growth during embryological development. If this gene is absent, the embryo follows a female pattern of growth.

Sex-Linked Genetic Disorders

Genes that are carried on either the X or the Y chromosome are said to be **sex-linked**. In humans, the small Y chromosome carries very few genes. The much larger X chromosome contains a number of genes that are vital to proper growth and development. And as you just read, it seems to be impossible for humans to develop without the genes of the X chromosome.

It is particularly easy to spot recessive defects in genes located on the X chromosome because the genes are expressed more commonly in males than in females. What is the reason for this? Recall that males have one X chromosome. Thus all X-linked genes are expressed in males, even if they are recessive. In order for a recessive gene to be expressed in females, there must be two copies of it, one on each of the two X chromosomes. If one of the X chromosomes contains a dominant gene, it will mask the expression of the recessive gene.

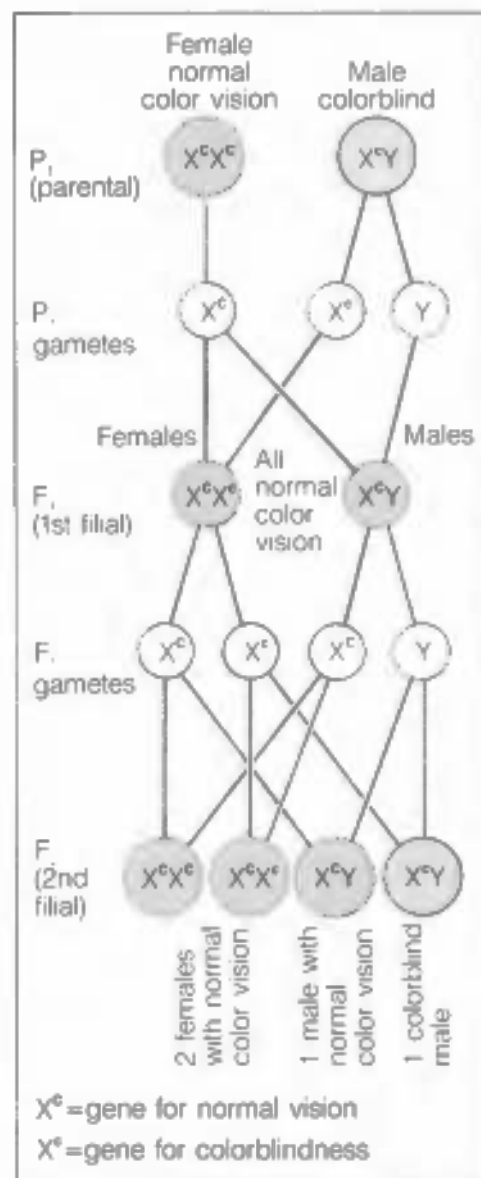
COLORBLINDNESS Colorblindness is a recessive disorder in which a person cannot distinguish between certain colors. **Most types of colorblindness are caused by sex-linked genes located on the X chromosome.** The genes for colorblindness render people unable to make some of the pigments in the eye necessary for color vision.

The most common type of colorblindness is red-green colorblindness. People afflicted with this trait have difficulty distinguishing the lighter shades of red and green. The frequency of this type of colorblindness varies among different populations. In most Caucasian populations, about 8 percent of the males are affected but only about 1 percent of the females are.

In humans, color vision depends on the varying sensitivity of three groups of specialized nerve cells (cones) in the retina of the eye. One group is sensitive to blue light, one to red light, and one to green light. Colors of any given shade excite a specific level of activity from each of the three groups of nerve cells. We will learn more about color vision in Chapter 37.

Because the gene for color vision is carried on the X chromosome, the dominant allele for normal color vision is represented as X^C and the recessive allele for red-green colorblindness is represented as X^c . Homozygous ($X^C X^C$) and heterozygous ($X^C X^c$) females have normal color vision. A female who is heterozygous for colorblindness is said to be a carrier because she carries the recessive allele but does not express it. Although she is not colorblind, she is capable of

Figure 11-13 Colorblindness is an example of a sex-linked trait. In this cross, a female with normal color vision marries a colorblind male (P_1 generation). What are the phenotypes of the offspring in the F_2 generation?



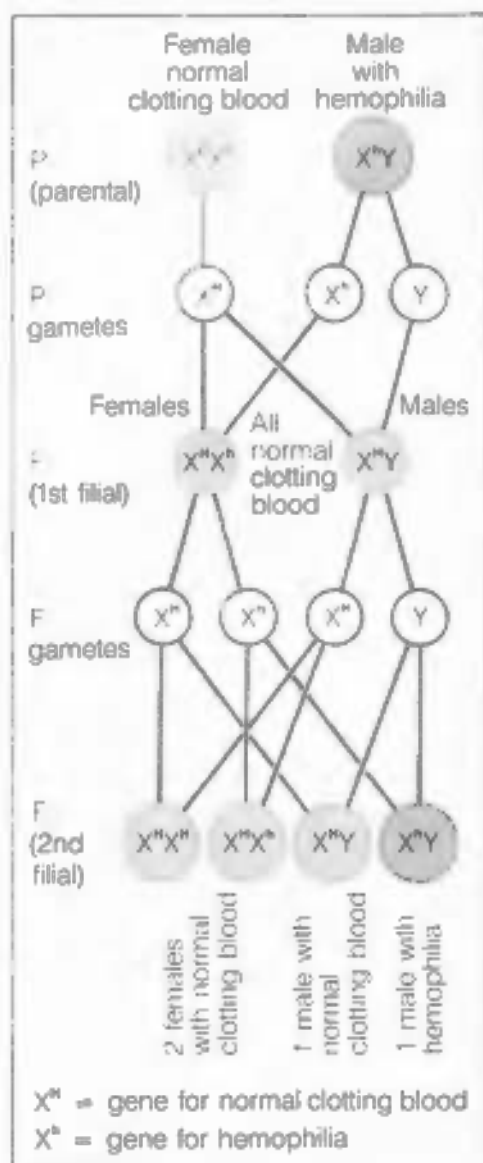


Figure 11-14 Hemophilia is an example of a sex-linked trait that results in the blood not clotting normally. In this cross, a female with normal-clotting blood marries a male with hemophilia. What are the genotypes of their offspring?

Figure 11-15 Male pattern baldness is a sex-influenced trait. The expression of this trait is thought to be enhanced by the presence of male sex hormones.

passing on the gene for colorblindness to her offspring. Only homozygous recessive females ($X^c X^c$) are colorblind. Because males have only one X chromosome, they are either colorblind ($X^c Y$) or have normal color vision ($X^C Y$).

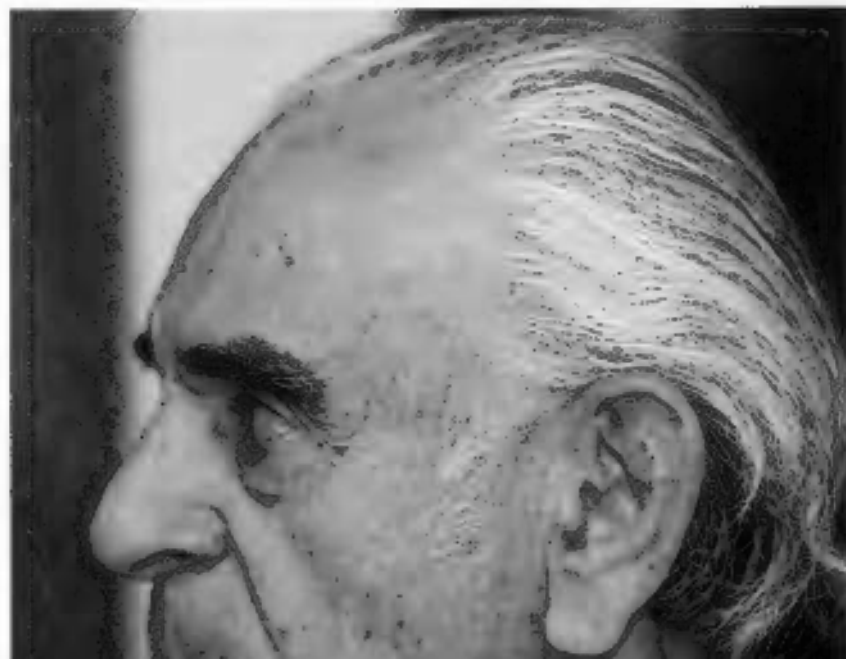
HEMOPHILIA Another recessive gene on the X chromosome produces a disorder called hemophilia (hee-moh-FIH-lee-uh), or "bleeder's disease." Hemophilia is a disorder in which the protein antihemophilic factor (AHF) necessary for normal blood clotting is missing. Not only is hemophilia a rarer disorder than colorblindness, affecting only about 1 male in 10,000 and only about 1 female in 100,000,000, it is also a more serious disorder.

People who have hemophilia can bleed to death from even the smallest cut. Internal bleeding (hemorrhaging) can occur from the slightest bump or bruise. In recent years, people who have hemophilia have been successfully treated by removing the AHF from donated blood and injecting it into their blood. Although this procedure is inconvenient and dangerous, since it makes people who have hemophilia susceptible to certain diseases carried in the blood, the use of AHF relieves the most serious effects of the disease.

MUSCULAR DYSTROPHY Muscular dystrophy (DIHS-truh-fee) is an inherited disease that results in the progressive wasting away of skeletal muscle. People who have this disease as young children seldom survive past early adulthood. The most common form of this disease, Duchenne muscular dystrophy, is caused by a gene carried on the X chromosome.

Sex-Influenced Traits

Many traits that may seem to be sex-linked, such as male pattern baldness, are actually caused by genes located on autosomes, not on sex chromosomes. Why then is baldness so much more common in men than it is in women? Male pattern



baldness is a **sex-influenced trait**. A **sex-influenced trait** is a trait that is caused by a gene whose expression differs in males and females.

Many genetic studies indicate that baldness is controlled by a single gene with two alleles, one for normal hair (B) and one for baldness (b). Men and women who have the genotype BB have normal hair, whereas those relatively rare people who have the genotype bb (two baldness alleles) tend to be bald, whether they are male or female. The difference between the sexes occurs in the heterozygous condition, Bb. Males who are heterozygous tend to be bald, whereas females do not. We are not certain how the sex of a person influences the expression of these genes, although it is possible that the male sex hormones may provide an answer.

11-3 SECTION REVIEW

1. How is sex determined in humans?
2. Describe two conditions that are caused by nondisjunction of the sex chromosomes.
3. What are some examples of sex-linked traits?
4. Distinguish between sex-linked and sex-influenced traits.

11-4 Diagnosis of Genetic Disorders

Humans have been aware of genetic disorders throughout history. For centuries, religious and ethnic laws and customs have reflected a clear understanding on the part of people of the genetic nature of certain disorders. For years, physicians have longed for a way to detect and treat genetic disorders. Today, for some disorders detection is as simple as an examination of a person's chromosomes.

A Chromosomal Abnormality— Down Syndrome

You have just learned about several examples of chromosomal abnormalities. Failures of meiosis, including nondisjunction, cause abnormal combinations of chromosomes to be produced, including those responsible for Turner syndrome and Klinefelter syndrome. Nondisjunction affects autosomes, too.

An example of nondisjunction of autosomes is a condition known as Down syndrome (trisomy 21). In Down syndrome, there is an extra copy of chromosome 21. The presence of this

Section Objectives

- Describe how Down syndrome is inherited.
- Identify two methods of detecting genetic disorders during pregnancy.

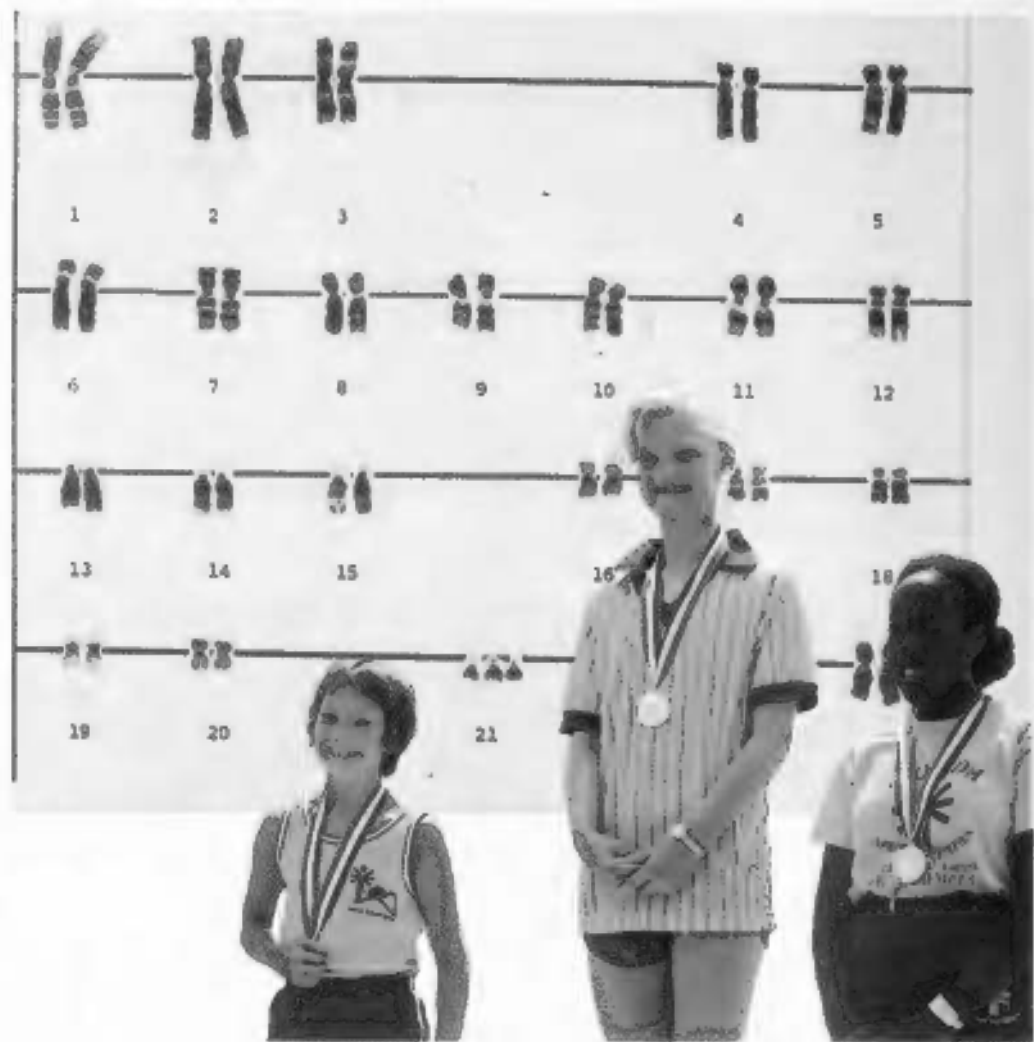


Figure 11–16 Down syndrome results from the nondisjunction of chromosome 21. Although people with Down syndrome are physically challenged, they can live normal, active lives.

extra chromosome can be detected in a careful examination of cells under the light microscope.

Down syndrome results in mental retardation that ranges from mild to severe. It is also characterized by an increased susceptibility to many diseases. In the United States, 1 baby in 800 is born with Down syndrome.

It is not clear why an extra copy of one chromosome should cause so much trouble, but scientists have recently discovered rare cases of Down syndrome in which only 46 chromosomes are present. In each of these cases, a small portion of chromosome 21 is attached to another chromosome. Scientists assume that this small portion must contain the genes that cause Down syndrome. A number of other genetic disorders are also produced by chromosomal abnormalities. Like Down syndrome, they too can be diagnosed by microscopic examination of chromosomes.

Prenatal Diagnosis

Down syndrome and other genetic disorders can now be diagnosed before birth by analyzing cells from the developing embryo. One technique, which is known as **amniocentesis**

(am-nee-oh-sehn-TEE-sihs), requires the removal of a small amount of fluid from the sac surrounding the embryo. Cells from the fluid are carefully grown in the laboratory for a few days, treated with a chemical that prevents cell division, and then carefully broken and examined. A karyotype (KAR-ee-uh-tighp), which is a display of all the chromosomes in a cell nucleus, is then prepared to make certain that the chromosomes of the developing embryo are normal.

Chorionic villus biopsy (kor-ee-AHN-ihk VIH-uh-s BIGH-ahp-see), a new alternative to amniocentesis, is a method in which a sample of embryonic cells is removed directly from the membrane surrounding the embryo. Results are obtained more rapidly from this technique than from amniocentesis.

Both amniocentesis and chorionic villus biopsy make it possible to detect Down syndrome and other chromosomal abnormalities. Both techniques are also considered safe for the mother and the developing baby. Scientists are now developing procedures that can detect other genetic disorders. Some of these procedures test for biochemical abnormalities in the embryonic cells, whereas others test for the presence of certain DNA sequences that are characteristic of particular defective genes. The rapid advance of these techniques has made it possible to detect more than 100 genetic disorders from embryonic cells.

Ethical Considerations

Although it is impossible to doubt the effectiveness of prenatal (taking place before birth) diagnosis of genetic disorders, the rapid development of genetic screening techniques is forcing a new set of moral and ethical questions on society. As a society, how should we react to the news that a particular infant will be born with a serious or fatal genetic disorder? Do we favor a society in which such infants are not allowed to develop, or one in which every possible effort is made to preserve all human lives?

Biology has given us great gifts of knowledge and understanding, but it cannot tell us what is proper in such difficult cases. Answers to ethical questions do not come from the laboratory but from the great resources of the human spirit.

11-4 SECTION REVIEW

1. What is Down syndrome?
2. What is amniocentesis? Chorionic villus biopsy?
3. How is a karyotype useful in determining genetic disorders?

PROBLEM

What are some patterns of human heredity?

MATERIALS (per student)

sheet of paper pencil mirror

PROCEDURE

1. Copy the data table onto the sheet of paper.
2. In the column labeled Trait, circle your phenotype for each trait listed. A description of the dominant allele for each trait follows.
Tongue rolling (R) is the ability to roll the tongue up at the edges.
Widow's peak (W) is a hairline that forms a V in the center of the forehead.
Free earlobes (F) are those that hang below the point of attachment to the head.
Dimples (D) are indentations on the cheeks.
Freckles (F) are brownish spots on the skin.
3. Transfer the data from your data table onto the chalkboard, where your teacher has constructed a chart to collect class data.
4. After your classmates have recorded their data on the chalkboard, record the information in

the appropriate place in your data table.

5. To determine the percentage of students demonstrating each trait, divide the number of students who have the trait by the total number of students in the class and then multiply this number by 100. Record the data in the appropriate place in your data table.

OBSERVATIONS

1. For each trait, which occurs more frequently: the dominant or recessive allele?
2. Which trait is the most common in your class? The least common?
3. What is the ratio of the percentages for each of the traits?

ANALYSIS AND CONCLUSIONS

1. Do dominant traits occur more often than recessive traits? Explain your answer.
2. What would happen to your results if you were to perform this investigation with five other classes and recorded their data?

Trait		Number of Students Demonstrating Dominant Phenotype	Number of Students Demonstrating Recessive Phenotype	Percentage Demonstrating Dominant Phenotype	Percentage Demonstrating Recessive Phenotype
Dominant	Recessive				
Tongue roller (R)	Nonroller (r)				
Widow's peak (W)	Straight hairline (w)				
Free earlobes (E)	Attached earlobes (e)				
Dimples (D)	No dimples (d)				
Freckles (F)	No freckles (f)				

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

11-1 "It Runs in the Family"

- Many human traits are inherited by the action of dominant and recessive genes, although other traits are determined through more complicated gene interactions.
- Each gamete (sperm cell or egg cell) contains 23 chromosomes.
- During fertilization, sperm and egg unite and a zygote is produced that contains 46 chromosomes.
- Of the 46 chromosomes found in the human diploid cell, 2 are the sex chromosomes (X and Y) and the remaining 44 are called autosomes.

11-2 The Inheritance of Human Traits

- Multiple alleles are three or more alleles of the same gene that code for a single trait. ABO and Rh blood groups are determined by multiple alleles.
- Sickle cell anemia is a disorder that causes the normally disk-shaped red blood cells to become sickle-shaped. The gene for normal

hemoglobin is codominant with the sickle cell gene.

- Polygenic traits are traits that are controlled by a number of genes.

11-3 Sex-Linked Inheritance

- Nondisjunction is the failure of chromosomes to separate during one of the stages of meiosis.
- Genes that are carried on either the X or the Y chromosome are said to be sex-linked.
- A sex-influenced trait is a trait that is caused by a gene whose expression differs in males and females.

11-4 Diagnosis of Genetic Disorders

- Down syndrome is an example of a condition caused by the nondisjunction of autosomes.
- Many genetic disorders can now be diagnosed before birth because of such genetic screening techniques as amniocentesis and chorionic villus biopsy.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

11-1 "It Runs in the Family"

gamete
zygote

11-2 The Inheritance of Human Traits

multiple allele
polygenic trait

11-3 Sex-Linked Inheritance

sex-linked
sex-influenced

11-4 Diagnosis of Genetic Disorders

amniocentesis
chorionic villus
biopsy

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. An example of a trait that is determined by multiple alleles is
 - a. Huntington disease.
 - b. ABO blood groups.
 - c. Down syndrome.
 - d. hemophilia.
2. Three brothers have blood types A, B, and O. What are the chances that the parents of these three will produce a fourth child whose blood type is AB?
 - a. 0 percent
 - b. 25 percent
 - c. 50 percent
 - d. 100 percent
3. A disorder that results from a change in an amino acid in the hemoglobin molecule is
 - a. sickle cell anemia.
 - b. hemophilia.
 - c. Down syndrome.
 - d. Turner syndrome.
4. Which is an example of a polygenic trait?
 - a. skin color
 - b. hemophilia
 - c. ABO blood groups
 - d. Huntington disease
5. Which parental pair could produce a colorblind female?
 - a. homozygous normal vision mother and colorblind father
 - b. colorblind mother and normal vision father
 - c. heterozygous normal vision mother and normal vision father
 - d. heterozygous normal vision mother and colorblind father
6. Which is an example of a sex-influenced trait?
 - a. Down syndrome
 - b. colorblindness
 - c. male pattern baldness
 - d. skin color
7. What is the total number of chromosomes in a diploid cell of a person with Down syndrome?
 - a. 22
 - b. 23
 - c. 44
 - d. 47
8. Which of the following techniques is directly associated with the diagnoses of certain genetic disorders by the examination of chromosomes?
 - a. blood typing
 - b. karyotyping
 - c. chemical screening
 - d. microsurgery

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. During fertilization, sperm and egg unite and produce a gamete.
2. A person with type A blood has red blood cells that contain antigen B.
3. A genotype Rh^+Rh^- will produce the Rh negative phenotype.
4. People who are heterozygous for sickle cell anemia are partially resistant to malaria.
5. Based on the pattern of inheritance of sex-linked traits, if a male has hemophilia, he has one gene for this trait on the sex chromosomes in each of his diploid cells.
6. The dominant allele for normal color vision is represented as X^c .
7. In Down syndrome, there is an extra copy of chromosome 16.
8. Chorionic villus biopsy is a genetic screening technique in which a small amount of fluid is removed from the sac surrounding the developing embryo.

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Why are humans not considered good organisms for genetic studies?
2. Explain why type O blood is sometimes referred to as the universal donor. Is this true in the case of O⁺ blood?
3. What is the cause of sickle cell anemia?
4. Why is it easy to believe that the sickle cell trait may have arisen independently in several places throughout the world?
5. What is the evolutionary connection between the incidences of sickle cell anemia and the incidences of malaria?
6. Why are there more colorblind males than there are colorblind females?
7. What evidence suggests that an X chromosome is essential for normal development? Is the same true of the Y chromosome?
8. The genes for red-green colorblindness and hemophilia are located on the X chromosome. How might you determine whether these genes are closely linked?
9. How would you determine whether a human gene was sex-linked?

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** Cystic fibrosis (CF) is caused by an autosomal recessive gene and is a fatal disorder that affects people of European ancestry. CF is characterized by a production of thick mucus that clogs the lungs and parts of the digestive system, making it difficult to breathe or eat. Suppose two people without a history of CF in their immediate families have a child with CF. They would like to have another child, but they are concerned about whether the second child will have CF. Can you help them predict the chances of having a second child with CF?
2. **Making diagrams** Polydactyly is a human characteristic in which a person has extra digits (fingers or toes) on his or her hands or feet. The trait for polydactyly is dominant over the trait for five digits on the hands and/or feet. Suppose a man who is heterozygous for this trait marries a woman with the normal number of digits. What are the possible genotypes and phenotypes of their offspring? Draw a Punnett square showing the possible results of this cross.
3. **Relating concepts** Nine of ten children in a family are right-handed. Right-handedness is a dominant trait. Assume that this trait is controlled by a pair of genes.
 - a. What is the genotype of a left-handed child?
 - b. What are the possible genotypes of the right-handed children?
 - c. What are the possible genotypes of the parents?
 - d. Could these parents have produced only right-handed children? Explain.
 - e. If these parents had produced only one child, would this child have been left- or right-handed? Explain your answer.
4. **Making inferences** Discuss the impact of genetic screening techniques on society.
5. **Using the writing process** Your career ambition is to be a science reporter. You are sent by your school newspaper to interview a physician who works with human genetic disorders. Prepare a script of the questions you would like answered.

CHAPTER 12

Genetic Engineering



In mythology, the chimera is a fire-breathing monster that is part lion, part goat, and part serpent. In genetics, the word chimera refers to a piece of DNA (or even an entire organism) that is made up of DNA from different sources.

In Greek mythology, the chimera was a frightening beast with the head of a lion, the body of a goat, and the tail of a serpent. The idea of combining the characteristics of many animals into one, however, did not originate with the Greeks. The Sphinx of Egypt and the winged lions of Assyria are just two examples of composite monsters that predate the Greek myths. Although we do not take these stories seriously today, it is ironic to note that biology has progressed to the point where these old myths have been dusted off. Today the word chimera has a different meaning: It refers to fragments of DNA from two organisms that have been joined to make a single DNA molecule. Although these DNA chimeras have not yet merged the serpent, the goat, and the lion, they have carried human genes into mice, produced plants that glow in the dark, and made it possible to design new organisms to suit human needs.

12-1 Modifying the Living World

- Breeding Strategies
- Mutations: Producing New Kinds of Organisms

12-2 Genetic Engineering: Technology and Heredity

- The Techniques of Genetic Engineering
- Engineering New Organisms

12-3 The New Human Genetics

- Analyzing Human DNA
- DNA Fingerprinting
- Sequencing the Human Genome
- Genetic Engineering of Humans
- Ethical Issues

12-1 Modifying the Living World

Section Objectives

- Describe breeding strategies that have been used to modify living things.
- Explain how mutations in organisms can be useful to humans.

We humans are rarely, if ever, satisfied with the world around us. We are always trying to improve it. Humans are not content with merely altering the course of a river, building cities, or sailing the seas. For thousands of years we've been trying to do something equally remarkable: to make "better" living things.

Breeding Strategies

Farmers and ranchers throughout the world have long tried to improve the organisms with which they work. By selecting the most productive plants or animals to produce the next generation, people have found that the productivity of a domesticated species can gradually be increased. Such an increase in productivity results from using breeding strategies such as selective breeding and two special forms of selective breeding: inbreeding and hybridization.

SELECTIVE BREEDING The oldest and most obvious way of improving a species is by **selective breeding**, or selecting a few individuals to serve as parents for the next generation. By crossing only those individual plants or animals that have a

Figure 12-1 The small horse is a full-grown miniature horse. Miniature horses, which are 86 centimeters high at the shoulder (or less), are the product of selective breeding. First produced in the mid-1700s, they were originally intended to pull ore carts in the low, narrow passages of mines. However, they were soon adopted as exotic pets by wealthy families.

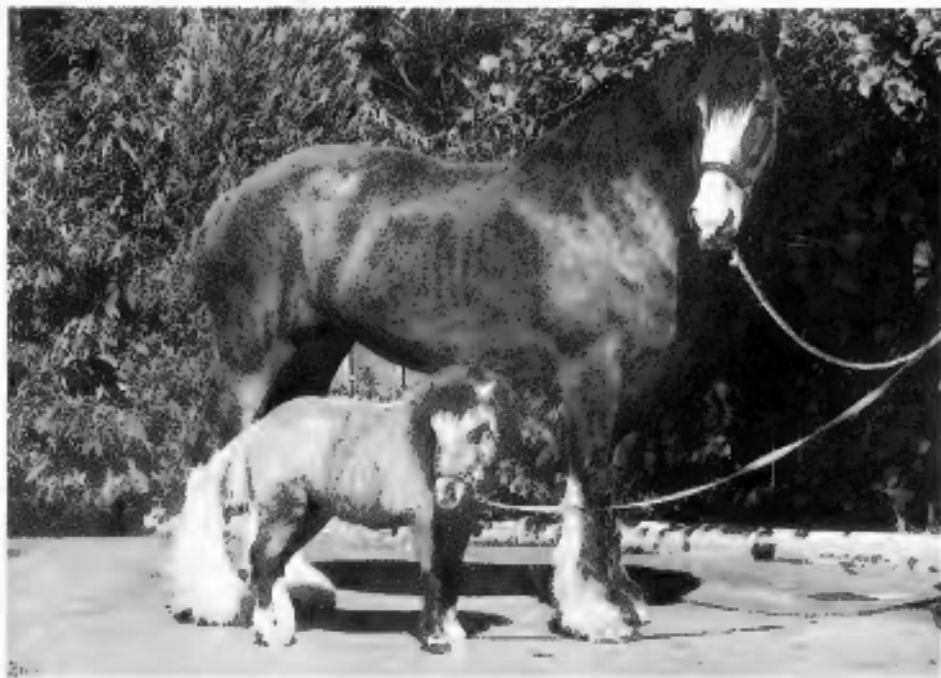




Figure 12-2 Selective breeding has produced domestic animals such as pigs (top) that are very different from their wild ancestors (bottom).

desired characteristic, the breeder can improve the yield of a crop plant, increase the milk production of cattle, or develop flowers of a particular color. Most present-day crop plants were first developed by selective breeding.

Luther Burbank of California (1849–1926) was perhaps the world's foremost selective breeder. Burbank produced more than 250 new varieties of fruit by selective breeding, but his work also extended to other plants, including the daisy and the famous Burbank Potato.

INBREEDING Once a breeder has successfully produced an organism with a useful set of characteristics, the next concern is to maintain a stock of similar organisms. The most direct method is **inbreeding**, or crossing individuals with similar characteristics so that those characteristics will appear in their offspring. Often the individuals crossed in inbreeding are closely related. The many varieties of purebred dogs—including German shepherds, toy poodles, and Great Danes—are maintained by inbreeding. Puppies are considered purebreds only if both their parents are registered members of the same breed.

Although inbreeding is useful in retaining a certain set of characteristics, it does have its risks. Because most of the members of an inbred line are genetically similar, the chances that recessive genetic defects will show up after repeated inbreeding become much greater. Problems in many dog breeds, including deformities in the joints and progressive blindness in German shepherds and golden retrievers, have resulted from repeated inbreeding.

HYBRIDIZATION One of the most useful of the breeder's techniques is **hybridization**, a cross between dissimilar individuals. Hybridization often involves crossing members of different (but related) species. Hybrids, the individuals produced by such crosses, are often hardier than either of the parents. This phenomenon is known as hybrid vigor. All breeds of corn that are grown commercially are hybrids, and every year corn breeders produce new hybrids that combine such basic characteristics as disease resistance, yield per acre, and nutritional value. Modern hybrid corn produces as much as ten times the crop per acre of older varieties of corn.

Mutations: Producing New Kinds of Organisms

As useful as selective breeding is, it is confined to characteristics that already exist in the population. But as you may recall from earlier chapters, mutations, which are inheritable changes in DNA, can sometimes produce organisms with new characteristics. If the new characteristics are desirable, breeders can use selective breeding to produce an entire population possessing these characteristics.



Figure 12-3 Inbreeding has resulted in an increased susceptibility to diseases and deformities in cheetahs (bottom), dogs, and other organisms. Fortunately for this golden retriever puppy (top), which was bred by Ken Miller, its ancestors have been certified to be free of certain inherited defects. The puppy can be expected to lead a happy—and healthy—life.

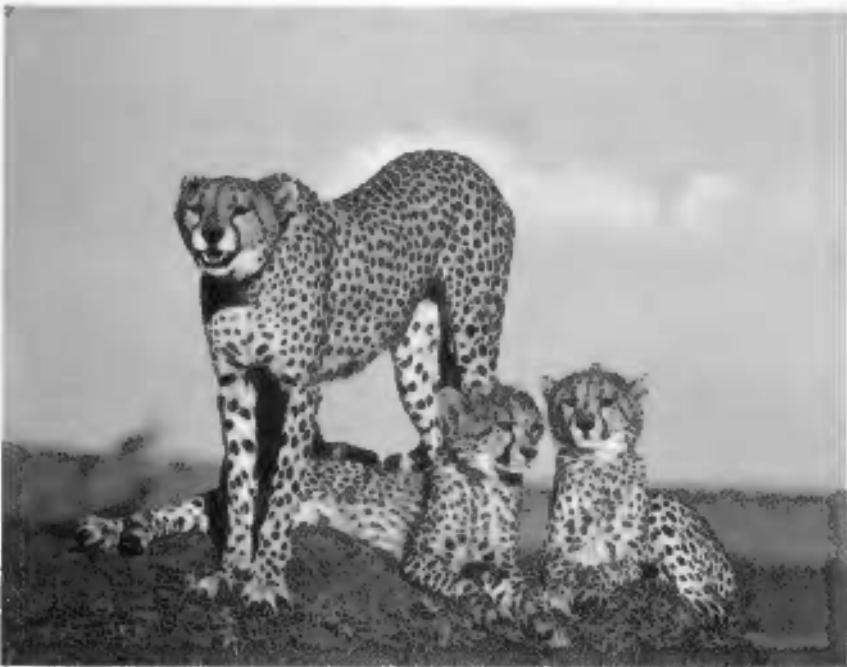


Figure 12-4 Seedless oranges and hairless mice are the result of mutations.

Of course, a breeder may not want to wait for a beneficial mutation to appear naturally. In such a case, a breeder may decide to artificially increase the chances of mutations occurring in a group of organisms. This can be done with agents or substances known as **mutagens**. Mutagens, which include radiation and chemicals, cause mutations. Many mutations are harmful; but with luck and perseverance, a few mutants (individuals with mutations) with desirable characteristics not found in the original population may be produced.

Mutagenesis, or using mutagens to increase the mutation rate, is particularly useful with bacteria. Their small size enables millions of organisms to undergo mutagenesis at the same time, thereby increasing the chances of producing a useful mutant. Using this technique, scientists have been able to develop hundreds of useful bacterial strains. It has even been possible to produce bacteria that can digest oil and are thus useful in cleaning up oil spills.



Uniformity or Diversity?

Why would any sensible person want to raise a breed of cows that produces less milk than other breeds? Or a breed of sheep that has coarser wool than other breeds?

At one time, the goals of livestock breeders were plain: to produce animals that yielded high-quality products, were highly productive, and completely predictable. Uniformity was particularly important. It is easier and less expensive to raise large numbers of animals if all the individuals have the same needs and growing times.

However there is a problem associated with the improvements that result from uniformity in domestic animals. Modern breeds are homogeneous; that is, the genes of individuals are almost identical. Although genetic similarity is good in terms of raising livestock and producing animal products of uniformly high quality, it is potentially disastrous in the long run. Similar animals are similarly vulnerable to changes in their environment. For example, a single disease could wipe out an entire herd or flock of

genetically similar animals. (In a group of genetically diverse animals, the same disease might kill only susceptible individuals. The resistant individuals could go on to produce resistant offspring.)

This is where the old-fashioned breeds come in. Although the productivity of old-fashioned breeds is lower than that of modern breeds, they have greater genetic diversity. They are vital to modern agriculture because they serve as banks of genes that may be useful in livestock at a future date.

So here's the dilemma for breeders: The breeding

strategies for preserving genetic diversity are opposite those for producing commercially feasible livestock. To preserve genetic diversity, breeders must ensure that as many individuals as possible breed and pass on their genes to the next generation. Selective breeding—allowing only the best individuals to produce the next generation—automatically breeds out many genes. And these may be precisely the genes that are needed in the future.



Although belted Galloway cattle are not as productive as modern breeds, they contain a wealth of potentially useful genes, such as those for the ability to thrive on poor-quality food.

12-1 SECTION REVIEW

1. What is selective breeding? Inbreeding? Hybridization?
2. What are some advantages of breeding strategies?
3. Why might breeders want to cause mutations in plants?
4. Many human societies have laws preventing close blood relatives from marrying. How are these restrictions related to the practice of inbreeding?

12-2 Genetic Engineering: Technology and Heredity

Ultimately, the selection techniques that humans use to generate new breeds of plants and animals affect DNA, the molecule that carries genetic information. Hybridization, inbreeding, and mutagenesis are, after all, indirect techniques designed to alter the DNA of a particular organism.

In the last two decades molecular biologists have developed a powerful new set of techniques that affect DNA directly. For the first time biologists can engineer a set of genetic changes directly into an organism's DNA. Appropriately enough, this new form of manipulation is called **genetic engineering**.

The Techniques of Genetic Engineering

Genetic engineering could not have come about without the development of a technology to support the process. The Wright Brothers could not have built an airplane without the existence of a small gasoline engine and lightweight metal tubing. Such equipment was actually developed for the automobile and the bicycle; but once available, it was adapted to the needs of a flying machine. The story of genetic engineering is much the same.

Imagine for a moment the tools you would need to take a gene from one organism and place it into another. First, you would need a way to carefully cut the DNA containing the gene away from the genes surrounding it. Second, you would have to find a way to combine that gene with a piece of DNA from the recipient organism; that is, the organism that will receive the DNA. Third, you would have to insert the combined DNA into the new organism. Finally, it would be useful to have a way to read the sequences of nucleotide bases in the gene in order to analyze the genes that you are manipulating. Each of these tools is now available, making it possible to insert a gene from one organism into another.

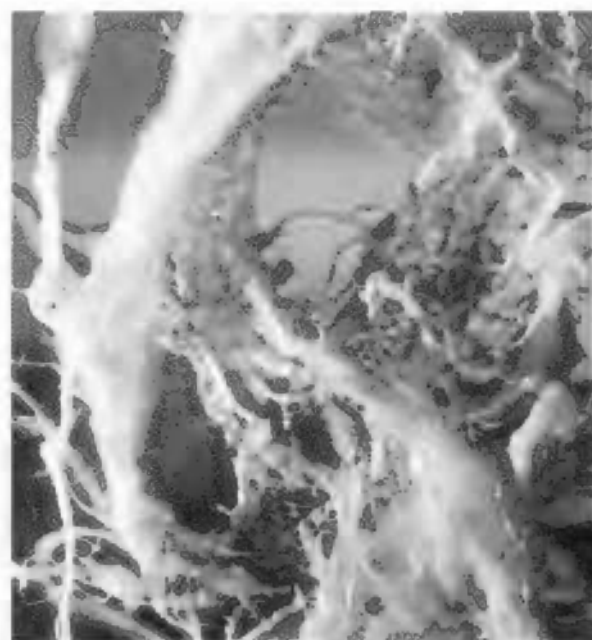
RESTRICTION ENZYMES Genes can be cut at specific DNA sequences by proteins known as **restriction enzymes**. More than 75 different kinds of restriction enzymes are known, and each one "recognizes" and cuts DNA at a particular sequence. The cutting sites of three typical restriction enzymes are shown in Figure 12-6 on page 252. Each one of the restriction enzymes shown "recognizes" a site of four to six nucleotide pairs and then makes a cut across both strands of DNA.

The accuracy of these enzymes is breathtaking. They will not cut any sequence other than the one they recognize, even if five out of six bases are identical to their recognition site. Restriction enzymes make it possible to cut DNA into fragments that can be isolated, separated, and analyzed.

Section Objectives

- Describe how DNA is isolated, cut, spliced, and handled.
- Explain how DNA is used to transform cells and organisms.

Figure 12-5 These strands of artificial DNA were synthesized from DNA extracted from animal cells. The techniques of genetic engineering allow scientists to manipulate and change DNA directly.



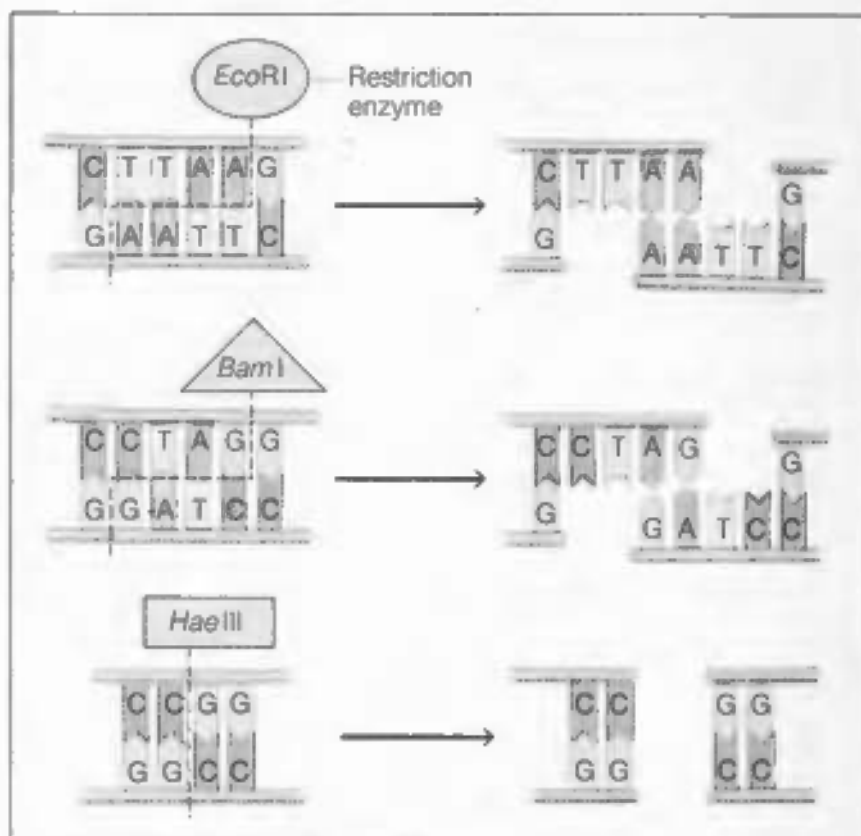


Figure 12-6 Different restriction enzymes “recognize” different sequences of bases on DNA molecules. Each restriction enzyme cuts DNA at the sites at which its recognition sequence occurs.

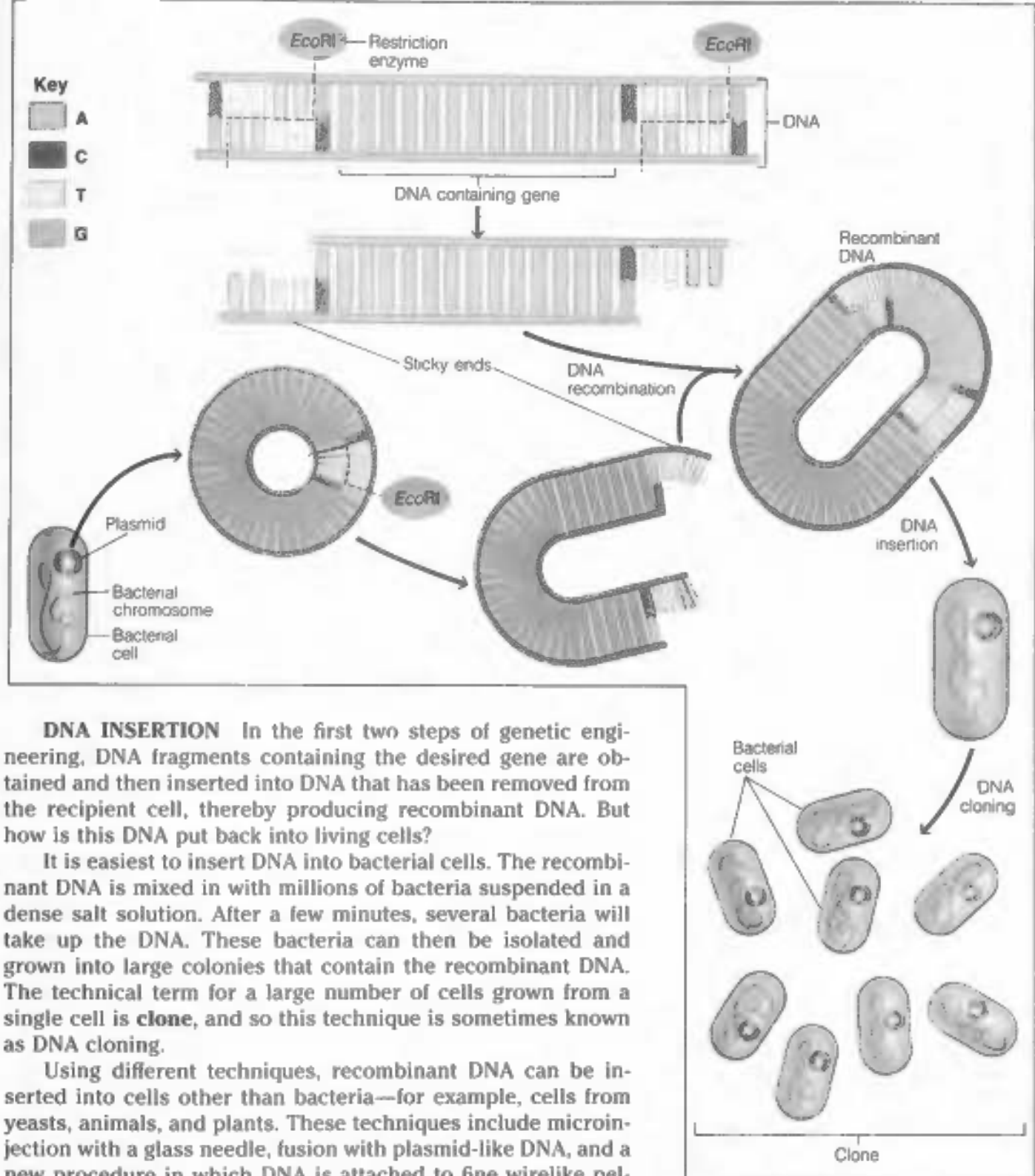
Figure 12-7 Plasmids are small circular pieces of bacterial DNA.



DNA RECOMBINATION DNA fragments cannot function all by themselves. They must become part of the genetic material of living cells before the gene they contain can be activated. In the second step of genetic engineering, DNA fragments are made into part of the recipient cell’s genetic material. This is done by combining DNA fragments with DNA from the recipient cell.

For example, DNA fragments may be combined with bacterial DNA so that they can later be inserted into a bacterial cell. Bacteria often contain small circular DNA molecules known as **plasmids** in addition to their chromosomes. These plasmids can be removed from bacterial cells and cut with the same restriction enzyme used to produce the DNA fragments. The cuts made by the restriction enzyme produce matching “sticky ends” on the DNA fragments and the cut plasmids. These sticky ends are the sites at which a DNA fragment and a plasmid can be joined end to end, thereby forming a new plasmid that contains a piece of foreign DNA. See Figure 12-8.

Like the mythical chimera (kigh-MIHR-ah), which you read about in the chapter opener, the combined DNA formed by fusing a DNA fragment and a plasmid consists of parts from different kinds of organisms. In genetic engineering, molecules of combined DNA are known as **chimeras** because they are produced by combining DNA from different species. Combined DNA is also known as **recombinant DNA**, since DNA from two sources has been recombined to produce it.



DNA INSERTION In the first two steps of genetic engineering, DNA fragments containing the desired gene are obtained and then inserted into DNA that has been removed from the recipient cell, thereby producing recombinant DNA. But how is this DNA put back into living cells?

It is easiest to insert DNA into bacterial cells. The recombinant DNA is mixed in with millions of bacteria suspended in a dense salt solution. After a few minutes, several bacteria will take up the DNA. These bacteria can then be isolated and grown into large colonies that contain the recombinant DNA. The technical term for a large number of cells grown from a single cell is **clone**, and so this technique is sometimes known as DNA cloning.

Using different techniques, recombinant DNA can be inserted into cells other than bacteria—for example, cells from yeasts, animals, and plants. These techniques include microinjection with a glass needle, fusion with plasmid-like DNA, and a new procedure in which DNA is attached to fine wirelike pellets that are then shot into cells with a microscopic gun.

DNA SEQUENCING Sequencing a piece of DNA, or reading the sequence of DNA bases along its length, can now be accomplished. Only one of the two strands of the DNA double helix is used in the process of DNA sequencing. However, many copies of this one strand are needed. These multiple copies can be produced through the process of DNA cloning.

Figure 12-8 In genetic engineering, foreign genes are inserted into plasmids. The altered plasmids are then used to carry the foreign genes into a bacterial cell.

DNA Sequencing

1. A radioactive label is attached to the "front" end of each strand of DNA.
2. The strands of DNA are divided among four test tubes. Each test tube undergoes a different chemical treatment. These treatments selectively break the chemical bonds between one of the DNA bases and the part of the DNA strand that follows that base. For example, the chemical added to test tube 1 breaks the DNA strand wherever adenine (A) occurs. Because only some of the bonds between adenine and the rest of the DNA strand are broken, the DNA is split into pieces of different lengths, some of which include the radioactive label.

3. The DNA pieces are carefully injected into a gel. A process called electrophoresis is used to separate these fragments. In electrophoresis, an electric field is used to separate substances by moving them through a gel. In this case, the pieces are separated according to their length because smaller pieces of DNA move faster than larger pieces. After a while, the DNA fragments appear as radioactive bands in the gel. The pattern of the bands reveals the order of the bases in the original strand of DNA. The DNA sequence can literally be read off the gel!

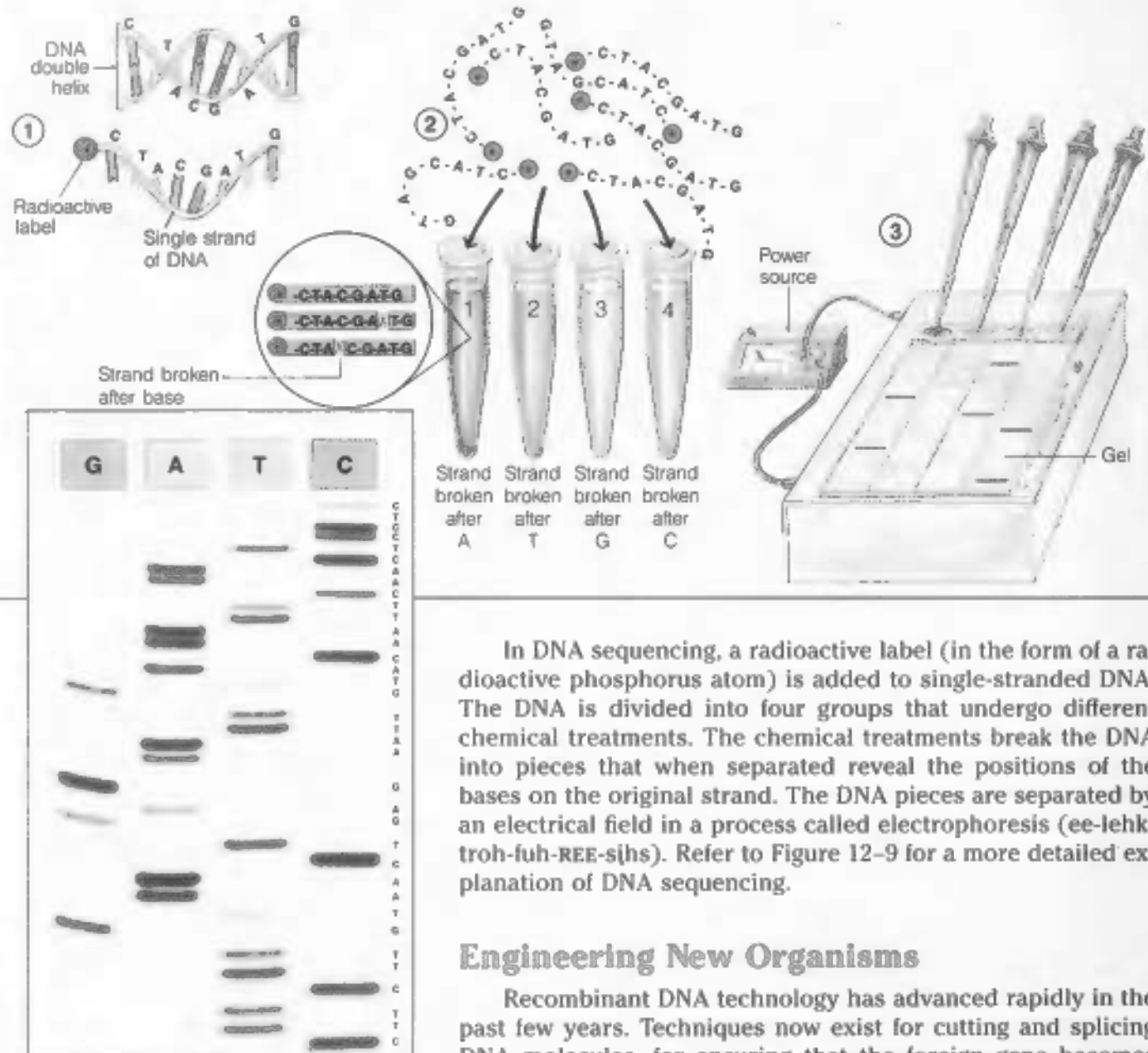


Figure 12-9 In DNA sequencing, DNA is treated to produce pieces that are then separated by electrophoresis. The bands on the gel that result from this process reveal the sequence of the bases in DNA (inset).

In DNA sequencing, a radioactive label (in the form of a radioactive phosphorus atom) is added to single-stranded DNA. The DNA is divided into four groups that undergo different chemical treatments. The chemical treatments break the DNA into pieces that when separated reveal the positions of the bases on the original strand. The DNA pieces are separated by an electrical field in a process called electrophoresis (ee-lehktroh-fuh-REE-sihz). Refer to Figure 12-9 for a more detailed explanation of DNA sequencing.

Engineering New Organisms

Recombinant DNA technology has advanced rapidly in the past few years. Techniques now exist for cutting and splicing DNA molecules, for ensuring that the foreign gene becomes part of the chromosome of the recipient cell, and for controlling the gene once it has been inserted. Organisms that contain such foreign genes are said to be **transgenic**.

GENETIC ENGINEERING IN BACTERIA When a gene coding for a human protein is properly inserted into bacteria, the recombinant cells can be used to produce large amounts of

the protein quickly and inexpensively. As recently as ten years ago, human growth hormone, a protein needed for normal growth and development, was rare and extremely costly. (It could only be obtained in small amounts from cadavers, or dead bodies used for scientific purposes.) Thus people who do not produce normal amounts of this hormone themselves could not always be guaranteed a supply. Genetically engineered bacteria that contain the human growth hormone gene now produce large quantities of this protein, making it plentiful enough to treat everyone who needs it. Other genetically engineered bacteria produce human insulin (another hormone) and interferon, a protein that blocks the growth of viruses and may be useful in cancer treatment.

GENETIC ENGINEERING IN PLANTS DNA can be injected into plant cells directly or attached to plasmids of certain species of bacteria that infect plant cells. Plant cell biologists have developed techniques that enable a complete transgenic plant to be grown from the cells containing recombinant DNA. The goals of genetic engineering in plants include the production of plants that manufacture natural insecticides and the production of plants that contain genes that enable them to produce their own nitrogen nutrients, thus eliminating the need for fertilizers. Australian researchers have successfully transferred into alfalfa the gene for an enzyme that aids in the synthesis of amino acids and thereby increases the protein content of the plants. These engineered plants will be a new source of protein-rich feed for Australian sheep.

Can genes from animals be made to work in plants? Steven Howell and his associates at the University of California at San Diego provided the answer to that question in 1986. They isolated the gene for luciferase, the enzyme that makes fireflies glow, and inserted it into tobacco cells. When whole plants were grown from the recombinant cells and the gene was activated, the plants glowed in the dark!



Figure 12-10 The hepatitis B vaccine being tested here for purity was produced by genetically engineered bacteria.

Figure 12-11 Transgenic bacteria are used to make important chemicals such as human insulin (left). This transgenic tobacco plant contains firefly genes (right). When the firefly genes are activated, the plant glows!

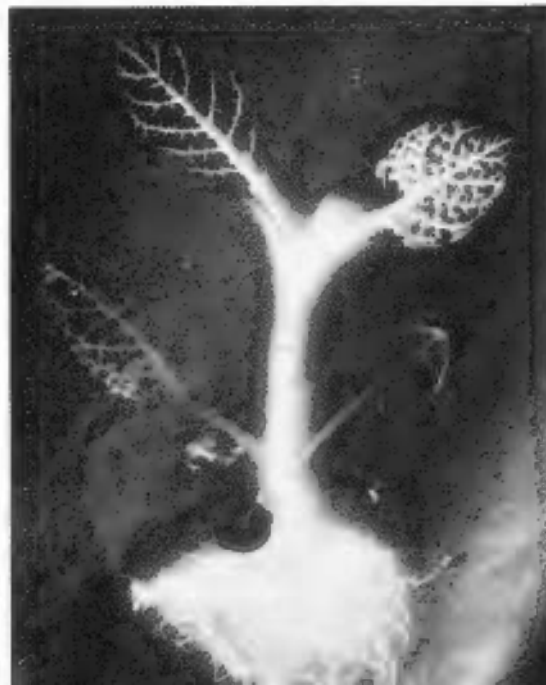
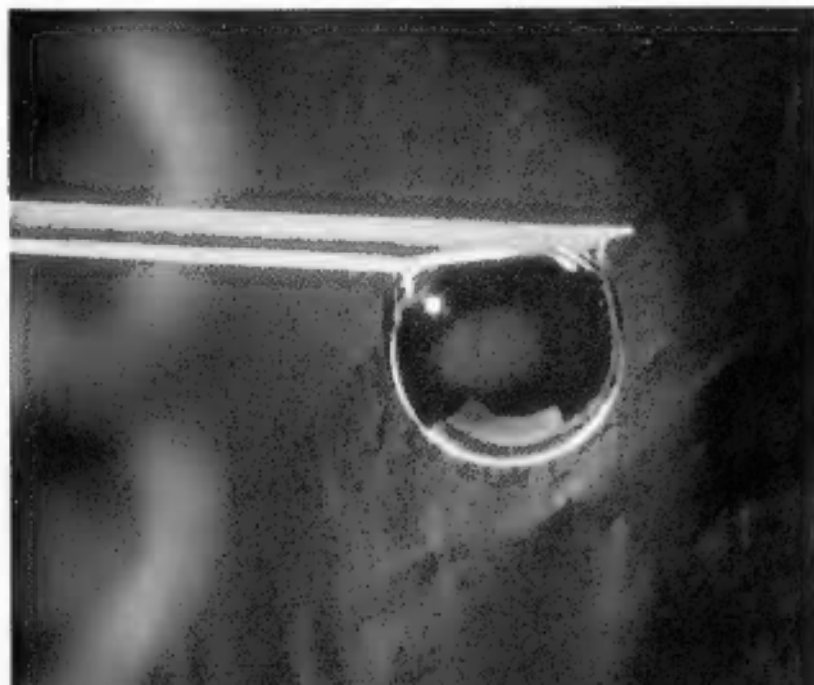




Figure 12-12 This giant mouse, shown next to a normal mouse, is one of the first types of transgenic mammals. The giant mouse developed from a mouse egg that was injected with recombinant DNA containing the gene for rat growth hormone.

Section Objectives

- Describe some possible applications of analyzing and sequencing human DNA.
- Discuss ethical issues involving new genetic techniques.

GENETIC ENGINEERING IN ANIMALS Genetic engineering has successfully produced a variety of transgenic insects, roundworms, and vertebrates. In one experiment, a group of researchers introduced the growth hormone gene from rainbow trout into carp and produced a bigger, faster-growing fish. The genes of the AIDS virus have been introduced into mice to help develop a strain of mice that can be used for research on the AIDS disease. A number of research groups are now experimenting with transgenic farm animals in hopes of producing meat and milk more quickly.

12-2 SECTION REVIEW

1. What are restriction enzymes? How are they used in genetic engineering?
2. Define recombinant DNA, plasmid, and clone. How do these terms apply to genetic engineering?
3. What is a transgenic plant? How does it differ from a hybrid?
4. What are some of the advantages of genetically engineered proteins such as human growth hormone?

12-3 The New Human Genetics

The rapid development of molecular biology has produced a number of other developments. For the first time it has become possible to think about curing genetic diseases. We have also begun to wonder about the practicality of decoding the entire human **genome**, which is all of the genes possessed by humans. And we have started to apply molecular biology to personal identification and the diagnosis of disease.

Analyzing Human DNA

As we saw in Chapter 11, researchers have already developed tests for genetic disorders, which compare human DNA to DNA sequences known to produce the disorders—Huntington disease and sickle cell anemia, for example. In the near future, DNA obtained from prenatal sampling may be tested for the presence of a great many other disorders, enabling physicians to treat some disorders before birth and to be prepared to treat others shortly after birth.

Researchers have also begun to look for genes that might predispose individuals to other medical problems, such as

heart disease, diabetes, and cancer. If tests that identify individuals at risk can be developed, early medical attention would be able to prolong many lives.

DNA Fingerprinting

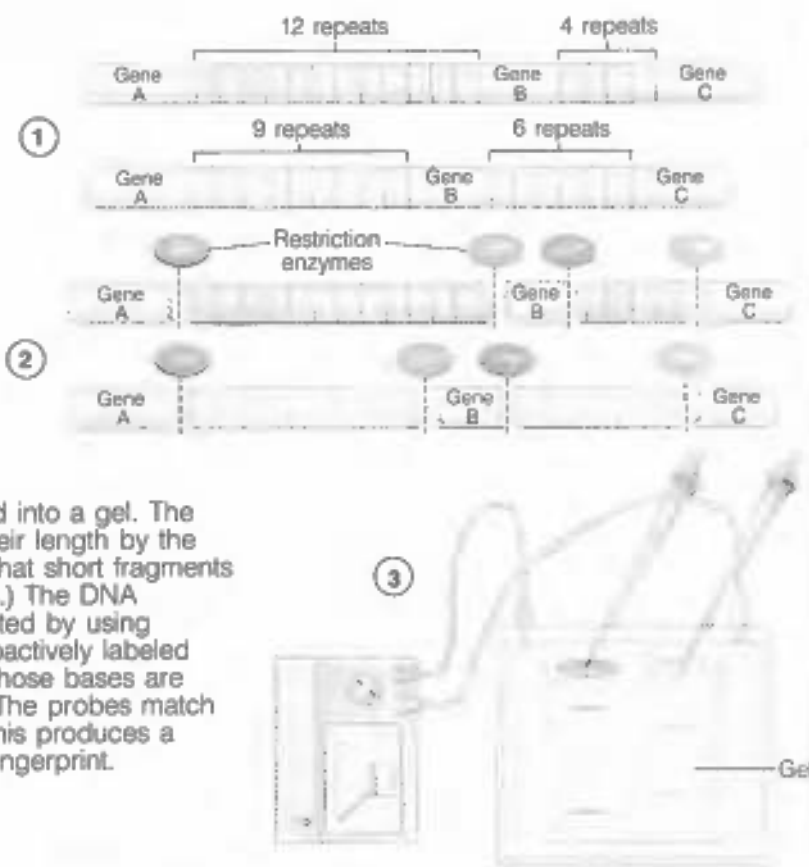
The great complexity of the human genome ensures that no individual is exactly like any other. In the last three years, medical researchers have used this biological fact to add a powerful new tool to criminal investigations. The tool is known as **DNA fingerprinting**. DNA fingerprinting takes advantage of the fact that large portions of the human genome are made up of repeated sequences of varying lengths that do not code for proteins. It has turned out that individuals may have completely different numbers of these repeated units between actual working genes. You may have 15 repeats between two genes; the person sitting next to you in class might have 6 repeats between the same two genes; and someone else may have 33.

Here's how DNA fingerprinting works: A small sample of human DNA is cut with a restriction enzyme. The resulting fragments are separated by size through the process of electrophoresis. Fragments that contain the repeats are then labeled

Figure 12-13 DNA fingerprinting can be used to match up a suspect with blood, sperm, or other bits of DNA-containing material left at the scene of a crime.

DNA Fingerprinting

1. There is a large amount of "junk DNA"—DNA that does not code for protein—in the human genome. Junk DNA is made up of repeated sequences that are called repeats. Although individuals may have identical genes, there may be different numbers of repeats between these genes. The more repeats, the longer the junk DNA between genes.
2. Restriction enzymes are used to cut DNA into fragments.
3. The DNA fragments are carefully injected into a gel. The fragments are separated according to their length by the process of electrophoresis. (Remember that short fragments of DNA move faster than long fragments.) The DNA fragments that contain repeats are detected by using radioactive probes. The probes are radioactively labeled pieces of nucleic acids (DNA or RNA) whose bases are complementary to those of the repeats. The probes match up with the repeats and stick to them. This produces a pattern of radioactive bands—the DNA fingerprint.



with DNA "probe," which binds to the DNA sequence of the repeats. This produces a series of bands that by their position show the lengths of the fragments containing the repeats. If enough combinations of restriction enzymes and DNA probes are used, a pattern of bands is produced that can be distinguished from the pattern of any other individual in the world.

DNA samples can be obtained from blood, sperm, and even hair strands with small pieces of tissue at the base. It is clear that DNA fingerprinting will be useful in solving crimes. Several rape suspects have already been convicted in the United States and Great Britain because DNA fingerprinting showed that their DNA patterns matched blood or sperm samples recovered from their victims. And in at least one case, a wrongly accused person has been set free.

Sequencing the Human Genome

Because molecular techniques can help us read the DNA sequence, several prominent scientists have suggested that a large project to sequence the entire human genome should be undertaken. This would be no small task. Working with today's technology, a very productive scientist might be able to sequence about 1000 bases in a week—50,000 bases in a year (allowing for two weeks' vacation)! At that rate, it would take a single scientist more than 100,000 years to sequence the complete genome. However, many scientists are optimistic that automated sequencing methods can be developed so the process could be speeded up dramatically.

A crash program to sequence the human genome would be a vast project. The amount of information gathered would be so enormous that only complex computer systems would be able to manipulate all the data. Nonetheless, there is little doubt that sooner or later, crash program or not, the complete DNA sequence of the human genome will be determined. When that day comes, we will be closer than ever to achieving the poet Alexander Pope's directive: "Know then thyself . . . the glory, jest, and riddle of the world."

Genetic Engineering of Humans

Because humans are animals, too, there is no *technical* barrier to the insertion of foreign genes into human cells. Many transgenic mammals have been produced by injecting DNA into fertilized ova (eggs) and then transplanting the ova back into a female reproductive tract. This strategy could work with humans as well.

A review of a few of the genetic diseases found in our own species indicates that there is plenty of room for genetic engineering of human cells. Cystic fibrosis, Tay-Sachs disease, and a host of other genetic disorders might be treated by replacing defective genes. The genes for a polypeptide in human hemo-

globin have already been inserted into bone marrow cells of mice, suggesting that it might be possible to treat human diseases like sickle cell anemia in the same way.

Ethical Issues

Despite these possibilities, there are problems, risks, and doubts that have persuaded many scientists that the time is not yet right to carry out these procedures on human beings. Of course it would be marvelous to be able to cure hemophilia or other genetic diseases. But could we be sure that experimentation on humans would involve only diseases? If human cells can be manipulated in this way, should we try to engineer taller people or change their eye color, hair texture, sex, blood type, ear shape? What will happen to the human species and to our conception of ourselves if we gain the opportunity to design our bodies? What will be the consequences if we develop the ability to "clone" ourselves by making identical genetic copies of our own cells? These are questions that science will rapidly force us to come to grips with.

If we acquire the ability to alter ourselves, we shall also acquire awesome responsibilities. How shall we decide which genes should be transplanted, altered, or redesigned? Who shall determine whether experiments with genetic engineering should be done? Scientists? A government agency? The local community?

As we said in Chapter 1, the purpose of science is to gain a better understanding of the nature of life. The more we understand life, the more we shall be able to manipulate it. As our power over nature increases, our society shall have to learn to use wisely the tools that science has given us. And we shall have to develop a thoughtful and ethical consensus of what should and should not be done with the human genome. Scientists alone should not be expected to assume all of the responsibility for these decisions. Society in its entirety should have to deal with these questions. To do anything less would be to lose control of our most precious gifts: our intellect and our humanity.

12-3 SECTION REVIEW

1. What are some potential benefits of genetic analysis?
2. What is DNA fingerprinting? How does it work?
3. What are some of the principal ethical issues involved in human genetic engineering?
4. If human bone marrow cells were removed, altered genetically, and reimplanted, would the change be passed on to a patient's children?

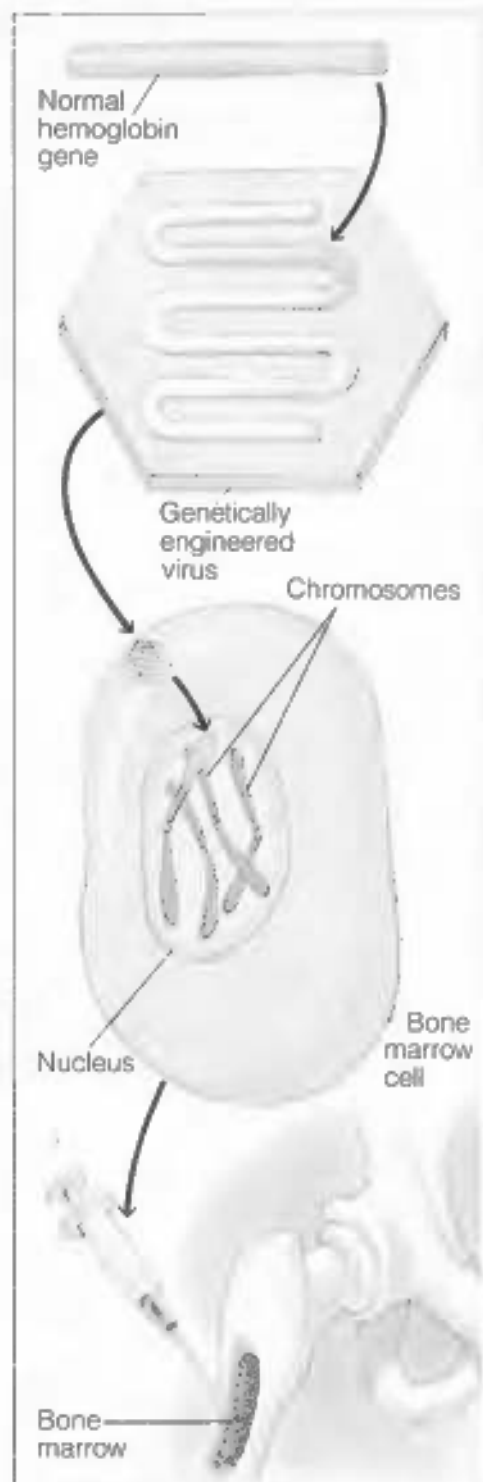


Figure 12-14 Gene therapy may someday make it possible to "correct" cells that contain defective genes and thus cure genetic diseases.

PROBLEM

How can DNA be used for the identification of criminals?

MATERIALS (per student)

scissors graph paper

PROCEDURE

1. The accompanying table describes the pattern of genes and repeats of a particular segment of DNA for five individuals. This information will be used to construct models of the DNA segment for each of the five individuals.

Individual	DNA Sequence
1	G1 G2 10R G3 4R G4 G5 7R G6 6R G7
2	G1 G2 1R G3 15R G4 G5 3R G6 2R G7
3	G1 G2 11R G3 8R G4 G5 5R G6 3R G7
4	G1 G2 6R G3 2R G4 G5 9R G6 7R G7
5	G1 G2 4R G3 5R G4 G5 12R G6 4R G7

Key: G = gene R = repeats

2. Cut a lengthwise strip of graph paper two boxes wide. Starting at the top, label the first box *G1* and the second box *G2*.
3. For each repeat, label a box *R*. For example, for individual 1, the ten boxes following *G2* would be labeled *R*.
4. Continue labeling the boxes through to *G7*, remembering to put the proper number of *R*'s (repeats) in the correct locations. Write the number of the individual on the back of the strip.
5. Fold a clean sheet of graph paper into sixths lengthwise. Unfold the paper and number the boxes up the left-hand edge, starting at the bottom, from 1 through 25. This sheet will be used to record the DNA fingerprints of individuals 1 through 5 and of an unknown criminal. Label the first of the six columns 1 for individual 1; the second, 2 for individual 2; and so on. Label the sixth column *CRIMINAL*.

6. Select one of the five individuals to be a criminal. *Note: Do not tell your classmates which individual you have selected.* Make a duplicate strip of DNA for that individual following the procedure outlined in steps 3 through 5.
7. Cut the strip representing the criminal's DNA between genes 4 and 5. This represents the cutting of DNA by restriction enzymes.
8. Arrange the two pieces of the DNA strip in order of size, with the largest first. This represents the separation of DNA pieces through electrophoresis.
9. Count the number of boxes in the longest piece of DNA. Color in a box in the column of your data table marked *CRIMINAL* directly across from this number. Repeat this procedure using the shorter fragment. You should have two marks in the column. These represent the marks that DNA tagged with a radioactive probe would leave on a photographic plate—a DNA fingerprint.
10. Exchange the DNA fingerprint of your criminal with one of your classmates.
11. Prepare DNA fingerprints for individuals 1 through 5.

OBSERVATIONS

1. Did any of the five individuals have the same DNA fingerprints?
2. Which individual was the criminal?

ANALYSIS AND CONCLUSIONS

1. If the possible number of repeats between two genes varies between 1 and 20, what is the probability of having exactly 3 repeats?
2. Why is it unlikely that two individuals would have the same DNA fingerprint?
3. If blood or hair samples are recovered at the scene of a crime, how could they be used to make a positive identification of a criminal?

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

12-1 Modifying the Living World

- By using carefully selected individuals as parents for the next generation, people can improve and change domesticated plants and animals.
- Inbreeding involves crosses between similar individuals.
- Hybridization involves crossing dissimilar individuals.
- Random mutations, which can be caused artificially, can produce useful variations in organisms.

12-2 Genetic Engineering: Technology and Heredity

- Genetic engineering changes DNA through direct manipulation.
- Restriction enzymes are used to cut DNA. The cut DNA can be combined with other

DNA molecules and inserted into organisms in various ways.

- There are techniques for reading the sequence of bases in DNA.
- Genetic engineering uses DNA to transform cells and organisms.

12-3 The New Human Genetics

- Human DNA can be analyzed to detect genetic diseases.
- DNA fingerprinting can be used to solve crimes and identify people.
- The technology exists to determine the sequence of the entire human genome.
- There are many ethical considerations that must be taken into account before new genetic techniques are applied to humans.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

12-1 Modifying the Living World

selective breeding
inbreeding
hybridization
mutagen

12-2 Genetic Engineering: Technology and Heredity

genetic engineering
restriction enzyme
plasmid
recombinant DNA
clone
transgenic

12-3 The New Human Genetics

genome
DNA fingerprinting

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

- Crossing individuals that have similar characteristics and are often closely related is called
 - hybridization.
 - inbreeding.
 - mutagenesis.
 - genetic engineering.
- A piece of DNA that is produced by combining DNA fragments from different sources is called
 - hybrid DNA.
 - cloned DNA.
 - plasmid DNA.
 - recombinant DNA.
- A large number of cells grown from a single cell is called a
 - clone.
 - hybrid.
 - chimera.
 - plasmid.
- A cross between dissimilar individuals is
 - cloning.
 - mutagenesis.
 - hybridization.
 - genetic engineering.
- Organisms that contain foreign genes are
 - mutagenized.
 - transgenic.
 - hybridized.
 - inbred.
- What is the name of the process of engineering changes directly into an organism's DNA?
 - mutagenesis
 - hybridizing
 - selective breeding
 - genetic engineering
- Which technique takes advantage of repeated DNA sequences that do not code for protein?
 - DNA fingerprinting
 - DNA sequencing
 - genetic engineering
 - cloning
- The process that uses electricity to separate DNA fragments according to their length is
 - electrophoresis.
 - DNA sequencing.
 - genetic engineering.
 - mutagenesis.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

- Offspring resulting from a cross between similar individuals often show hybrid vigor.
- A plasmid is a cell or organism whose DNA comes from different species.
- Crossing similar individuals is called selective breeding.
- Increasing the mutation rate is called genetic engineering.
- Transgenic organisms contain foreign genes.
- A chimera is a large number of cells grown from a single cell.
- A circular piece of bacterial DNA is called a clone.
- DNA fingerprinting produces a pattern of bands that is unique for each person.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

- hybridization, genetic engineering, selective breeding, inbreeding
- restriction enzymes, recombinant DNA, DNA cloning, mutagenesis
- clone, chimera, transgenic, recombinant DNA

CONCEPT MASTERY

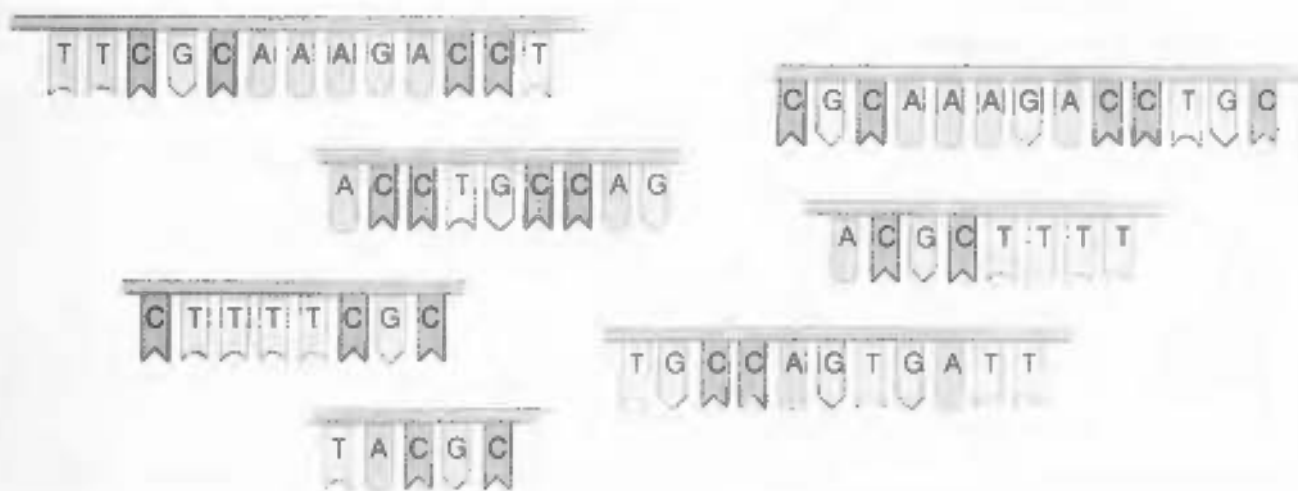
Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Explain why inbreeding and hybridization are sometimes considered to be forms of selective breeding.
2. Describe the processes involved in creating bacteria that produce human proteins.
3. How is mutagenesis useful to humans?
4. The nuclei from certain cells in an adult frog can be placed into frog eggs from which the nuclei have been removed. This produces genetically identical frog embryos. Explain why these embryos are considered to be a clone.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** Suppose a plant breeder has thornless rose bushes that have pink flowers, thorny rose bushes that have sweet-smelling yellow flowers, and thorny rose bushes that have purple flowers. How might the plant breeder develop a purebred variety of thornless sweet-smelling purple roses?
2. **Problem solving** The following fragments are obtained when a gene that consists of 10 codons is cut by restriction enzymes. What is the sequence of bases in the gene? (*Hint: Look for overlapping sequences on the fragments.*)
 3. **Making comparisons** Compare the advantages and disadvantages of breeding techniques and genetic engineering.
 4. **Applying technology** Describe the processes involved in isolating, cloning, and sequencing a gene.
 5. **Expressing an opinion** Should genetic engineering ever be done on humans? If so, under what circumstances? Explain your answer.
 6. **Using the writing process** If you could create the "ideal organism" by combining the traits of two organisms, what two organisms would you select and why?



Holographic Technician

Holographic technicians work with laser beams to create three-dimensional images called holograms. The technicians operate the equipment, care for the mirrors and lenses, and develop the resulting film.

Holograms are used today in a variety of fields. They are particularly helpful in science and medicine, where computer-generated images allow researchers and doctors to view the structures of parts of living organisms.

A holographic technician must complete a high school education and have some additional training at a technical or junior college.

For information on this career write to the Museum of Holography, 11 Mercer St., New York, NY 10013.

Plant Breeder

Plant breeders use a knowledge of genetics and biology to develop desirable traits in many kinds of plants. Traits that would be considered desirable include the ability to resist disease, to thrive in different soils and climates, and to produce large numbers of offspring. Plant breeders work in experimental nurseries, where they cross-breed various plants to observe and record the characteristics of the offspring.

A position as a plant breeder requires at least a Bachelor's degree in agronomy or horticulture.

For more information write to the American Society of Agronomy, 677 South Segoe Rd., Madison, WI 53711.

Molecular Geneticist

Molecular geneticists study patterns of heredity in various forms of life. They are concerned with how biological traits originate and are passed down from one generation to another. Some molecular geneticists specialize in studying diseases that are linked to genes and chromosomes.

To become a molecular geneticist, a person must earn a Bachelor's degree in chemistry or biology and a Ph.D. in genetics.

For more information write to the American Genetic Association, 818 18th St., NW, Washington, DC 20006.

HOW TO
FIND THE
RIGHT COLLEGE

When choosing a college, first consider what type of career or academic program interests you. Also decide what geographical location and student-body size would make you most comfortable. Other things to consider are financial constraints, availability of housing, and ease with which you can travel back and forth to school. Once you have a list of potential colleges, compare the courses they offer, their job placement records, and their extracurricular activities.

In addition to talking with counselors, you might want to read some college guides to learn about specific institutions. Two popular examples are Peterson's Guide to Four-Year Colleges and Barron's Profiles of American Colleges.

FROM
THE
AUTHORS



"You can choose your friends but not your relatives."

The first time that phrase made sense to me was when my baby cousin ruined a perfectly good trip to a restaurant by deciding that his meal would look better on the floor. Over the years my cousin turned out just fine, of course, and he even developed table manners. But for a few minutes I would rather have been related to a family of worms.

We don't choose our relatives, and we can't choose our genes. Each one of us has a biological inheritance that includes our blood type, our eye color, our appearance, and even our height. It's easy to feel trapped by that inheritance, limited by the biological traits that seem so important and so far beyond our abilities to change them. But don't make the mistake of being overwhelmed by your own genetics, especially in your studies. None of us reaches more than a fraction of the intellectual potential that we inherit. The limits on what we achieve in life stem less from our genes than from ourselves.

The biological capacities that we all inherit, regardless of our individual differences, are more than enough to give each of us the tools to achieve great things in whatever we set out to do. When you think about the men and women who have pioneered scientific research, dreamed up inventions, written great literature or music, what do you see? Great genes or great efforts? The answer, without a doubt, is the latter. What we inherit is the beginning of what we can be. It is not the end of it.

Ken Miller