



Biology

FIFTH EDITION

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Elwood Groves
Adelé Hensley
Rachel Santopietro



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BIOLOGY
Fifth Edition

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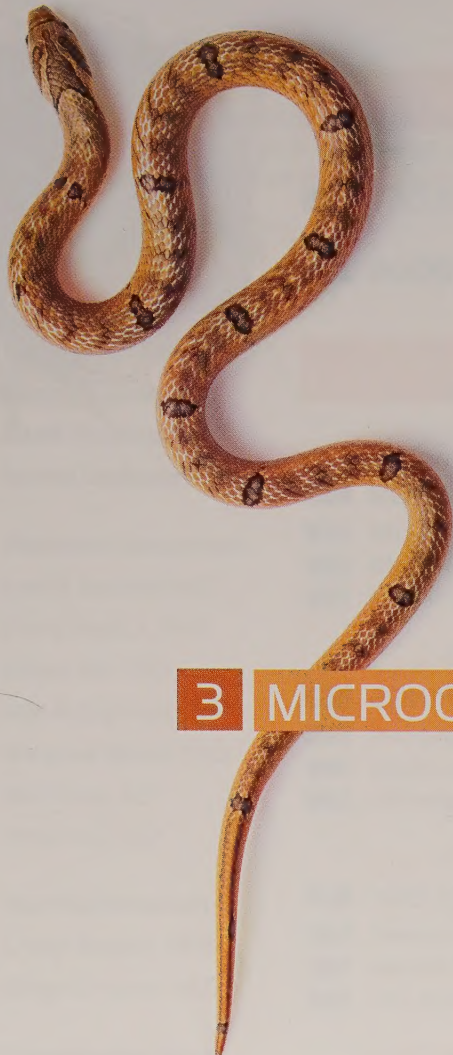
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MEGABIOLGY

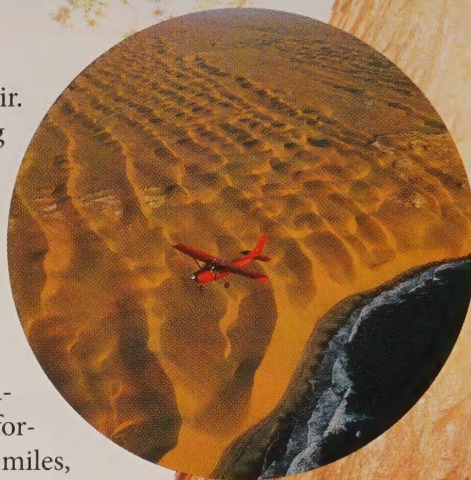
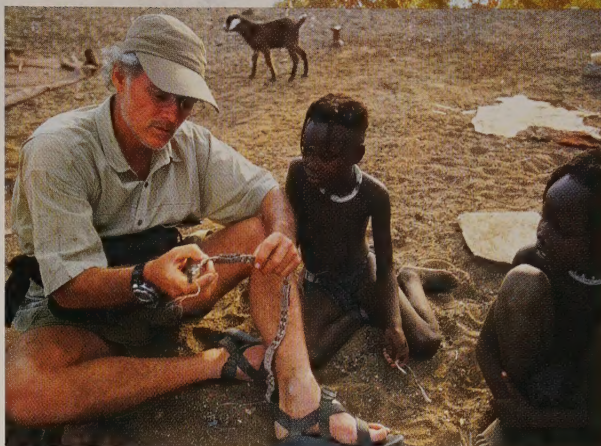
Michael Fay does big biology. As an Explorer-in-Residence for the National Geographic Society, he works as an ecologist and conservationist. In 1999, he hiked over 3000 miles across the drainage basin of the Congo River in Africa, cataloging every species of plant and wildlife that he encountered and observing the human impact on the rainforest. Documenting biodiversity and ecological health over a large tract of land is called a *megatranssect*. “To quantify a stroll through the woods” is how Fay describes his efforts. After 455 days of hiking with a group of Pygmies, Fay was inspired to push through governmental red tape to establish the first 13 national parks in Gabon to protect the area he had hiked through and had come to love.

In 2004, Fay surveyed Africa in a different way—from the air. He conducted a *MegaFlyover*, logging 60,000 miles flying at low altitude. He took a high-resolution picture every 20 seconds, collecting over 100,000 aerial images. Many of Fay’s photos have been used in Google Earth. Fay compiled the results of his MegaTransect of the Congo Basin and his MegaFlyover of the African continent to give information to conservationists and government officials.

In 2007 and 2008 Fay was at it again, this time doing a megatranssect of the Redwood forests of California and Oregon, forests containing the tallest trees in the world. He hiked 1800 miles, painstakingly taking notes on the health of this ecosystem and networking with other professionals to collect more data.

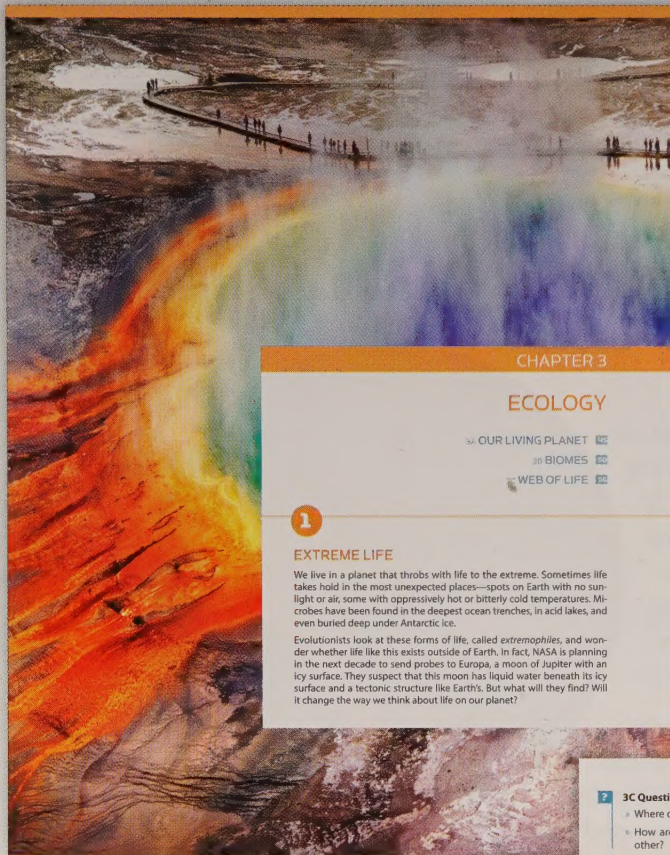
But why did Michael Fay do all this? He is motivated to help all of us to wisely use resources so that we can protect wildlife and beautiful, wild places for future generations. Some natural resources can be sustainably used, but some strategic natural resources must be protected for the health of society and for the benefit of future generations.

Is this a good thing? It is if you believe the Bible. Genesis 1 tells us that God placed Earth in our hands to care for and wisely use. The earth and all living things in it are God’s creation, but He has entrusted them to us. Michael Fay doesn’t claim to be a Christian, but he is trying to do something that the Bible calls worthy. He is spending his life trying to help people wisely use the earth. Let’s learn how biology can help us to keep the big picture in mind as we take care of the planet God has lovingly placed us on.



FEATURES OF THIS BOOK

This book is just for you! We've designed it to help you learn. Flip through the following pages to see the features that we've incorporated into this textbook to help you succeed in biology. In the back of the book you'll see appendixes, a glossary, and an index.



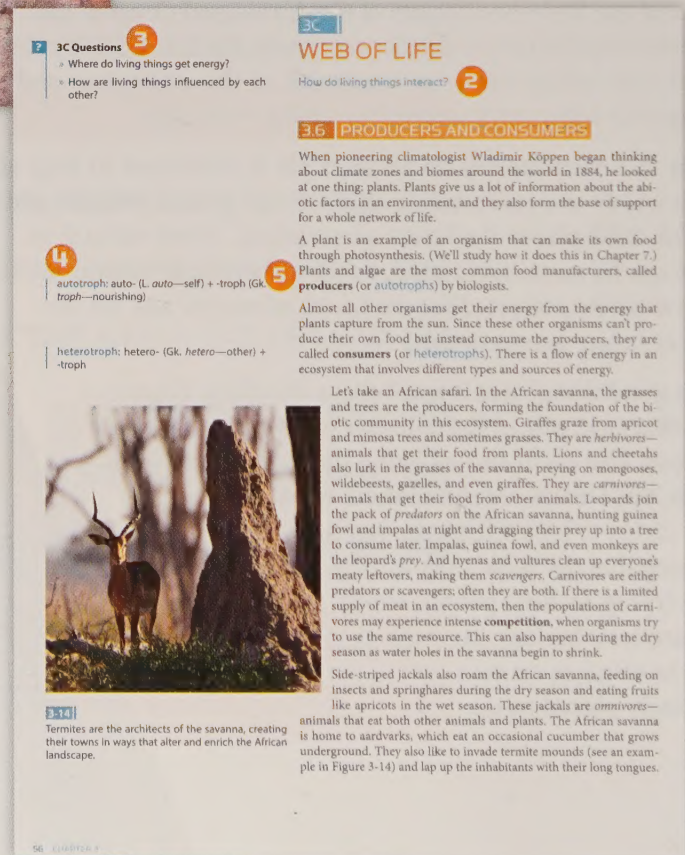
1 Opener—a story that highlights issues and developments in biology that need to be examined from a biblical worldview

2 Essential question—the “big question” that you will learn about in a section

3 Key questions—smaller questions that you can ask along the way through a section to help you answer the essential question

4 Blue terms—terms that have etymologies or extra information in the margin to go along with them

5 Bold-faced terms—glossary terms that you need to know



3.14 Termites are the architects of the savanna, creating their towns in ways that alter and enrich the African landscape.

Side-striped jackals also roam the African savanna, feeding on insects and springhares during the dry season and eating fruits like apricots in the wet season. These jackals are **omnivores**—animals that eat both other animals and plants. The African savanna is home to aardvarks, which eat an occasional cucumber that grows underground. They also like to invade termite mounds (see an example in Figure 3-14) and lap up the inhabitants with their long tongues.

6 Boxes—fun, extra information about biology

7 Review questions—These give you practice in applying what you've learned in a section or a chapter. Problem-solving and extra-thought questions are marked with a blue box: a **1**, for example, means that you need to think a little harder! Questions with an orange box (e.g., **2**) will require some research to answer.

18. What are some of the drawbacks of genetically modified organisms, especially crops?
19. How do DNA, genomes, and genetic engineering point to a master creator?

TRUE OR FALSE

20. The white fur of the Spirit bear (see Figure 9-2) is an example of a mutation that would be a part of this population's genetic load.
21. A survey of students in your school reveals that about 36% of the students have detached ear lobes. It is correct to conclude that detached earlobes is a recessive trait.
22. Large populations are most susceptible to genetic drift.
23. All mutations create problems in organisms for generations.
24. Selective breeding is an example of genetic engineering.
25. Transgenic organisms are a type of GMO.
26. We can use DNA fingerprinting to tell the difference between identical twins.

CRITICAL THINKING

Use the case study below to answer Questions 27–28.

8 CASE STUDY: GENE THERAPY FOR BUBBLE BOBLES

Scientists are experimenting with gene therapy on bubble babies, children born with a disease called severe combined immunodeficiency (SCID). Their immune systems are so weak that the only way they can survive is to live in a germ-free plastic bubble, limiting both their life expectancy and their quality of life. SCID is caused by two different mutations that produce different types of the disease. Early efforts in gene therapy to treat this disease resulted in four young children developing leukemia, with one of them dying, though the approach has cured 18 children born with the disease.



27. Scientists thought that the reason children in early studies developed leukemia was because of the viral vectors and oncogenes they contained. These oncogenes stimulated cells to reproduce therapeutic DNA. How did this cause leukemia?
28. Can you think of a way to solve this problem?

Research in Biotechnology

Interested in learning more about the cutting-edge tools of biology? Consider doing some research on stem cells, cloning, GMOs, gene therapy, and DNA profiling in forensics, medicine, and archaeology.

9

1. "human chimpanzee DNA comparison"

NA can be manipulated.

A gene can be transferred from one plant

modified organism.

use the tools of genetic engineering?

ally modified orange trees that use two

res immunity to citrus greening. The goal

in the United States without the heavy

should scientists, farmers, and orange juice

producers consider if they decide to grow genetically modified oranges?

10

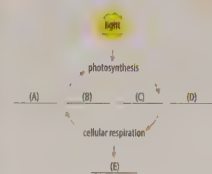


One of the major problems with genetically engineered seed is that the crops they produce are designed for modern farms. This translates into crops that rely on automated watering, regular fertilizing, and applications of pesticides and herbicides. Also, the desirable traits of genetically modified plants are not passed on to the next generation of seeds, so farmers need to purchase seeds year after year. This makes it difficult for farmers in underdeveloped countries who rely on rainfall and harvest their own seed for the next year's planting. Recently, Monsanto has been making an attempt to produce strains of crops specifically for underdeveloped countries, since they are the people who could benefit the most from biotechnology. The crops of small local farmers feed a larger percentage of the world's population than industrial farms, so it makes sense to develop seeds to help the neediest people in the world.

Introduction

You are an American farmer working for the Kenya-based African Agricultural Technology Foundation. You are working with Monsanto to produce water-efficient crops (specifically corn) to help small, drought-stricken Kenyan farms fight hunger.

7 7B SECTION REVIEW

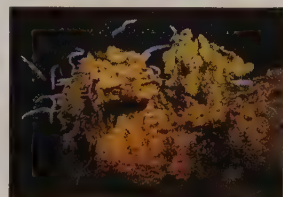


1. Why does the phrase "burning carbs" or "burning fat" used in connection with exercise, make sense in light of what you've learned about cellular respiration?
2. Fill in the process map to the left, relating photosynthesis, cellular respiration, water, carbon dioxide, oxygen, glucose, and ATP.
3. Why must glycolysis happen at the beginning of cellular respiration?
4. What is the difference between aerobic cellular respiration and fermentation? Include in your contrast the reactants, parts, and products.
5. Why does fermentation take place at all in cellular respiration if it produces only a small amount of energy?
6. Think about a person who is exercising more than normal. Why does fermentation even happen in the muscles since it doesn't produce very much energy? Is this a beneficial or harmful thing?
7. Compare the two types of fermentation.
8. Do a keyword search on the Internet for "human metabolic map." Find the citric acid cycle, which should look like a circle. Where is it on the map? What does this map show you about the processes in the cell?
9. What goes through your mind as you look at this metabolic map?

Off the coast of American Samoa in the Pacific lies an underwater volcano called Vailulu'u that rises almost 14,000 feet from the ocean floor. You'd think that nothing could live in the inky black, scorching waters there, right? Wrong! In 2005, marine biologists and geologists were stunned to find a population of foot-long greenish eels thriving in the dark, hot, acidic waters near the Nafanua cone of Vailulu'u, called "The Crater of Death."

An ecological community thrives there, and at the base of the food chain are bacteria that use a process called chemosynthesis, similar to photosynthesis, to pull nutrients from the water to make their own food. In chemosynthesis, bacteria absorb toxic hydrogen sulfide, oxygen, and carbon dioxide from water emitted from the volcano. The bacteria use these nutrients to get energy and make food. They grow in mats and are eaten by other organisms such as shrimp, clams, and giant tube worms (*Riftia pachyptila*) that can reach 7 feet long. The community near Vailulu'u is unusual because it is home to a large population of deep-sea eels, the first that has ever been discovered near an underwater volcano. Scientists are still unsure what

the eels are eating, but they suspect that chemosynthetic bacteria are related to the eels' unusual presence in this seemingly inhospitable place.



8 Case studies—opportunities to investigate specific areas in biology to apply what you have learned in the chapter

9 Margin boxes—give you a little more biology information or something to think about from a biblical perspective

10 Worldview Sleuthing boxes—inquiry-based investigations that help you think through controversial areas of biology through the lens of Scripture

Task

Your task is to develop a general plan to use biotechnology to produce and distribute drought-resistant corn that will allow farmers to reuse their seed and use a minimal amount of chemicals on their fields. You will communicate your plan in a 10-slide presentation.

1. Do some research on selective breeding, perhaps using information in the box on page 161.
2. Research the process and the tools used to genetically modify plants.
3. Plan your presentation and collect any photos or videos you need, giving proper credit. Make sure that you think of how to distribute the new seed.
4. Create your presentation and show it to another person.
5. Deliver your presentation to your class or family.

Logos

Several foundations, such as the Bill and Melinda Gates Foundation, have funded the collaboration between Monsanto and the African Agricultural Technology Foundation to produce a strain of corn called drought-TEGO. Scientists have used biotechnology to develop this corn to provide the most food for the people who desperately need it. This is a good example of how we can wisely use biology to help God's image bearers, with a mind for the future.

Earth and sky, woods and fields, lakes and rivers, the mountain and the sea, are excellent schoolmasters, and teach some of us more than we can ever learn from books."

JOHN LUBBOCK
NINETEENTH-CENTURY
ARCHAEOLOGIST AND AMATEUR
BIOLOGIST





1 LIVING IN GOD'S WORLD

CHAPTER 1
THE LIVING CREATION 

CHAPTER 2
THE CHEMISTRY OF LIVING THINGS 

CHAPTER 3
ECOLOGY 

CHAPTER 4
INTERACTING WITH THE BIOSPHERE 



CHAPTER 1

THE LIVING CREATION

THE STUDY OF LIFE 

VIEWS OF LIFE 

BALANCE OF LIFE 

A LITTLE LIFE

Marina's doctor had told her that the tissue growing inside her had the potential to be a human, but it wasn't yet. He said that it was her choice to let this fetus grow or to get rid of it. It certainly would be a lot easier to not be pregnant.

But now Marina was at a pregnancy center, plagued with doubts. As she looked at the sonogram, she wept. She saw ten tiny fingers and ten tiny toes, and she just knew that an abortion wasn't right. This little life depended on her. Questions flooded her mind. Was she wrong about what she had always thought about life?

THE STUDY OF LIFE

1.1 BIG QUESTIONS IN BIOLOGY

Marina isn't alone. Many women seeking abortions are plagued with doubts. They turn to crisis pregnancy centers, many getting sonograms. Almost 80% of women who see a sonogram of their baby continue their pregnancies because they recognize a life when they see one.

People have questions about life. Issues like abortion, genetic engineering, drugs, and evolution fill the headlines, showing that people struggle to answer these questions. God's Word has answers. Looking at science in the light of God's Word helps us understand these issues more clearly. Your journey through this textbook is structured around six big questions that will help you view life on Earth and the science of biology through biblical lenses.

1. Where did life come from?
2. How is life designed to function?
3. How does God provide energy for life?
4. How does worldview affect the way people view life?
5. How does science work in the real world?
6. What is the balance between preserving the earth's resources and using them to help people?

Everything you learn in this book will help you answer one of these six big questions. And knowing how to answer questions like these will prepare you for many of the issues that you'll face throughout your life. Let's get started!

1.2 IN THE BEGINNING

Big Question 1: Where did life come from?

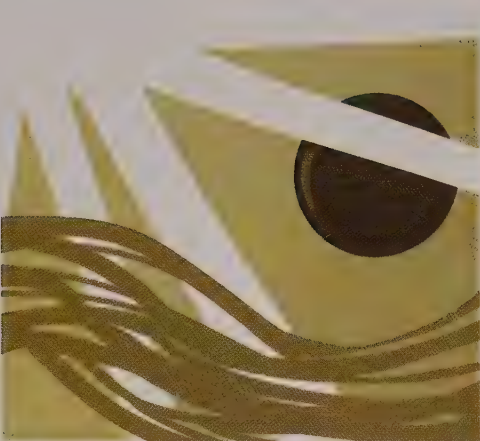
THE CREATION OF THE EARTH

We live in a world full of life. But where did it all come from? According to Genesis 1, God created the earth and everything in it in six 24-hour days. He created it *ex nihilo*, which literally means "out of nothing," about 7000 years ago based on inferences from biblical records. (See Chapter 10.) His carefully crafted, brand-new world was good, and once He put people in His world on the sixth day, He declared it to be very good.

God created people to fellowship with Him. He also had a job for them to do. The first command God gave to the first man and woman was to fill the earth and have dominion over it (Gen. 1:28). This is often

1A Questions

- » Where did life first come from?
- » How do living things stay alive, grow, and reproduce?
- » What makes something alive?



Bi The Flood

Only a few generations after Adam and Eve lived, people became so evil that God grieved over their wickedness and, in His righteous judgment, destroyed His creation with a worldwide flood. Noah, who found favor in God's eyes, was spared, along with his family, seven of every sacrificial animal, and two of every other kind of animal.

After the floodwaters subsided, Noah thanked God for preserving him and his family by offering a sacrifice. God then promised Noah and his descendants that life on the earth would never be entirely wiped out by water again. God established the rainbow as a sign that He would keep His promise (Gen. 9:13–15). God also restated the Creation Mandate to remind Noah and his family that even though the world was forever changed after the Flood, people's responsibilities to God remained unchanged (Gen. 8:20–9:3).



called the **Creation Mandate**. Why would God give us this job? Many creatures are stronger and have sharper senses than humans. Other creatures have amazing skills that humans don't have at all, like the ability to fly or breathe underwater. God asks us to manage the earth because we are a special creation, created in the **image of God** (Gen. 1:26–27), which is the combination of qualities that God has placed in people as a reflection of Himself. The image of God in us includes our personalities and emotions, our abilities to plan and reason, our sense of eternity, and our desire to create, love, and be loved (Eccles. 3:11).

Being God's image bearers makes us unlike any other creature in creation. One of the most important qualities that come with our unique position in creation is that we are given the choice either to obey the commands that God has put before us or to disregard them.

THE FALL OF CREATION

Adam and Eve chose to disobey God. In doing so, they brought a curse on themselves, on the rest of creation, and on their descendants. Since Adam, everyone who has ever lived has been born with a sin nature—an innate desire to disobey God—and the whole earth groans under the affliction of sin (Rom. 8:22). The command to care for the earth still stands, though it is now more difficult under sin's curse. Disease, death, and sin now frustrate our attempts to manage a fallen earth. Biologists feel this frustration as they work to fight decay, disease, and ultimately death. We see the effects of sin at work in a society that accepts evil, such as abortion.

THE REDEMPTION OF CREATION

But God didn't abandon His creation. He provided a way to save people from their sin and restore the world to the good and perfect way that He created it. He promised that from Eve would come a seed that would crush the head of the serpent who had tempted Adam and Eve to sin (Gen. 3:15). And He kept His promise. This Seed, Jesus Christ, came down to the earth as the God-man to perfectly fulfill God's intent for man's dominion (Ps. 8; Heb. 2:6–9).



Jesus came to help people. His acts of mercy—healing people, providing them food, protecting them from harm—also showed His authority over creation and His power to redeem mankind and reverse the effects of the Fall. His ultimate act of mercy was to take the penalty of our sin on Himself by sacrificing His life. Those who repent of their sin and place their faith in the sacrifice of God’s Son will be redeemed from the penalty of their sin. One day, Christ will come to the earth again and remove the curse entirely. In the New Earth, God’s people will be restored to rule over creation as He intended from the beginning of time (Rev. 22:5). Until then, we are called to shine in a world filled with sadness and sin as lights in a dark place, living out our redemption with good works (Matt. 5:14–16). Acts of kindness, sacrifice, and love should characterize the lives of God’s people, who look for the restoration of all things.

WHAT CREATION, THE FALL, AND REDEMPTION MEAN TO BIOLOGY

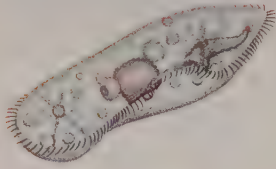
So why does this biology textbook begin with Creation, Fall, and Redemption? Because **biology**—the study of life—needs a foundation. Like Marina, you need something more than science to answer the most important questions about life.

In the Bible, God’s narrative of Creation clearly demonstrates that human life has value above all other life because people are made in His image. He wants us to treat other people as the special creation they are. In Matthew 22:39, God gave us one of His greatest commands: *to love others as ourselves*. Observing this command and the Creation Mandate gives us a biblical approach to any scientific study.

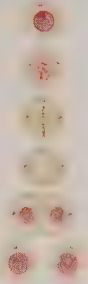
God then tells His image bearers that they are to care for His creation, including animals, children, trees, and everything else He made. And because we are made in His image, we should care for other people above all other parts of creation—including unborn lives. We are more important to God than anything else, and we are responsible for the well-being of His creation.

The Sanctity of Life

The word *sanctity* means “the state of being set apart or valued.” God values all the life that He created. How should that influence your actions toward other living things? God values people above all other aspects of His creation. Knowing this, how should you view an issue like abortion?



Cells. All living things are made of at least one cell. As you'll see in Chapter 5, cells are complex and rely on multiple interactions with other cells and the environment. Every cell, tissue, and system in the body contains *structure*, a specific arrangement of parts.



Reproduction. Cells come from preexisting cells; life comes from preexisting life. When your body replaces its cells, the information in the new cells is an exact copy of the information in the old ones. When a baby is conceived, two parent cells come together to form a new person with a new combination of genetic information.



Metabolism. The metabolism of an organism is the sum of all its chemical processes. In other words, it includes all the ways that an organism uses energy. Processes like photosynthesis, respiration, growth, and movement all require energy. These processes are part of an organism's *function*, the way that the structures in an organism work together.



Organization. Organisms use energy and information in the cells to maintain a high level of order in their bodies. When you eat a burger, it isn't randomly distributed throughout your body; it is methodically broken down into chemicals and then sent to the appropriate cells and systems in your body to be processed. In this way, the maximum amount of energy can be removed from the burger. Without this kind of efficient organization, your complex body would quickly fall apart.

Growth. Outgrowing your pair of running shoes is proof that you are a living creature. All growth involves the assembling of parts to make up an organism. Growth is not only an increase in size; it also includes replacing worn-out or damaged cells.



Response. No organism can exist in a vacuum. All organisms daily interact with and respond to things like temperature, moisture, sunlight, other organisms, and their own bodies. Living things have the ability to *adapt*, or to change in response to the environment. For example, when a capybara (*Hydrochoerus hydrochaeris*) gets hot, it adapts to the heat by either swimming in a marsh or wallowing in the mud.

1.3 THE ATTRIBUTES OF LIFE

Big Question 2: How is life designed to function?

What exactly is life? For centuries, people have grappled with what makes something alive. From the Greek physician Hippocrates to nineteenth-century biologists, people have tried to describe what they believed was the “vital force” that all living creatures possess. Since then, biologists have determined attributes that set living things apart from the nonliving world.

Most scientists agree that an organism must have *all* of these attributes to be considered alive. Otherwise, nonliving things like a snowflake might be considered alive because it moves and grows in the atmosphere, has a highly organized crystalline structure, and responds to temperature conditions in the environment.

At some point, no matter how organized an organism's body systems are, worn-out cells die faster than new cells reproduce, and the organism dies. Cell mutations and sickness are consequences of sin that lead to sin's ultimate consequence—physical death. But physical death isn't the end of life for people. God will one day resurrect the bodies of the redeemed, and they will live forever with Christ reigning over the New Earth (Rev. 22:5). Those who reject Christ's sacrifice will also be resurrected—to face eternal judgment in the lake of fire (Rev. 20:11–15).

Life is complex and difficult to define! But all living things have a similar design, making life much easier to study despite its complexity. This common design points to a loving, all-wise Designer.

1.4 ENERGY AND INFORMATION

Big Question 3: How does God provide energy for life?

As you read through the attributes of life, you may have noticed two themes. Organisms need energy to build and maintain their structures and functions, and they need information so that their cells know what to build, how to function, and how to create new organisms. Throughout this textbook, you'll see that every aspect of life comes back to energy and information, and God lovingly provides these for His world.

ENERGY

At some point today, you'll feel as if you've run out of energy. You may begin to feel sluggish, and your stomach may growl and demand food. So, naturally, you eat something. Food is the source of energy for people and many other organisms. Some organisms, such as plants and certain kinds of bacteria, can create their own food using energy from the sun.

Eating food is just one small part of how God supplies energy to living things. There are many ways that energy cycles through organisms and their environments. For example, the light energy of the sun, combined with chemicals taken from the air and soil, is converted to chemical energy in plants. Animals and humans take the chemical energy from plants and convert it into other forms, such as energy for motion, for warmth, and for the production of waste products. Bacteria and fungi break down waste products, extracting energy from them and returning nutrients back to the soil for plants.



1.1

Giant schools of fish serve as the main energy source for many dolphins, sharks, and birds.

INFORMATION

Once an organism gets its daily dose of energy, how does it know what to do with that energy? All cells contain information that directs the activity of an organism. That information is usually in the form of DNA or RNA molecules. In your body, these molecules direct various cells that digest food, feel pain, produce blood, and so on. The information in cells is passed along when either one cell splits in two or two cells join together as one. Your body uses this information to give you fingernails, hair, ears, and every other piece of you. Without information to control cells and energy to power them, life would quickly come to a screeching halt.

As you will learn in coming chapters, the information required to organize all the functions of an organism is immense and incredibly complex. It would take almost 500,000 DVDs to store the information found in 1 gram of your DNA! God has built into us a code of life with the information needed to carry on life processes. This is a marvelous gift—a gift that the greatest minds in science are still trying to unwrap.

1A REVIEW QUESTIONS

- 1. Why do you think people have abortions? Read Genesis 1:28. How does God's Word shed light on the value of children?
- 2. Summarize in your own words the creation of the earth, the fall of people and its consequences for the whole earth, and the redemption of the earth and people.
- 3. How has the Fall affected specifically living things?
- 4. What two commands from God can we obey by a biblical approach to science?
- 5. Fill in the table to classify the following terms or phrases as a structure or a function and relate them to one of the six attributes of life. For example, an egg cell is a structure and is part of reproduction. (Note: Not all parts of the table will be used.)

adaptability, digestion, arrangement of molecules, single-celled
bacterium, increasing number of cells

	Cells	Metabolism	Growth	Reproduction	Response	Organization
Structure				egg cell		
Function						

- 6. A virus can reproduce because it contains genetic material, but it has no metabolism and does not contain cells. Should a virus be considered alive? Explain your answer.
- 7. How do energy and information in cells relate to each other?
- 8. How are energy and information used to keep an organism's body organized?

VIEWS OF LIFE

Big Question 4: How does worldview affect the way people view life?

1.5 | WORLDVIEW MATTERS

The largest museums in the world have them. Prestigious universities have them too. Even private collectors and your local nature center have them. They are fossils. These fossils may have little plaques under them, telling you that it's a *Triceratops* fossil and that it's embedded in a sedimentary rock. Those are perfectly acceptable descriptions. But where did the fossil come from? How old is it? That's where people's beliefs about life come in. The answers to these questions depend on one's **worldview**, the perspective that a person uses to view and interpret the world.

You learned about a *biblical worldview* in Section 1A—a view of the world that's based on what God has told us in His Word, using Creation of the world, Fall, and Redemption to frame one's perspective. A *naturalistic worldview* sees the world as a series of natural processes that have no designer, no master plan. Someone with this worldview may believe that this living world is a product of random chance and that we alone determine our own destiny. Ideas like evolution and humanism (the idea that people are important and good apart from God) spring from a naturalistic worldview.

Specific beliefs that make up a worldview are known as *presuppositions*. They are statements or ideas that are not proven but that are used as the basis for reasoning. What presuppositions do you think might appear in the description of a dinosaur fossil? Someone with a naturalistic worldview may answer that the dinosaur came from a long line of evolutionary ancestors and that its fossil is millions of years old. An answer from a biblical worldview may be that the dinosaur came from other dinosaurs created by God and that the fossil is only a few thousand years old. Who knew that studying something as simple as a fossil could show so much about what you believe!

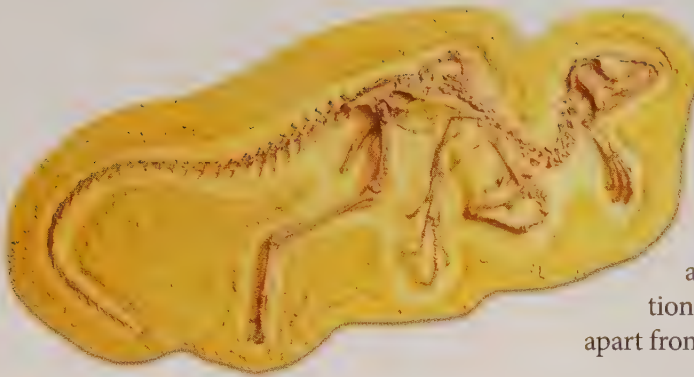
1.6 | THE NATURE OF SCIENCE

Big Question 5: How does science work in the real world?

In 2007, biologists who had been searching for new species in the mountains of Cambodia for almost a decade made a bizarre discovery: a frog with green blood and bones the color of turquoise. These biologists had discovered over 1000 species during their time in Cambodia, but the characteristics of this frog were unique. These and other biologists are now asking questions like, "Why does it have green blood and blue bones? Are there more creatures out there like

1B Questions

- » What do people base their views of science on?
- » How reliable is science?
- » What kinds of questions can science answer?
- » How does science work in the real world?



1-2

What can you observe about this fossil? What can you *not* observe?

1-3

The Baturite porcupine (*Coendou baturitensis*) was discovered in Brazil in 2013. Like the Samkos bush frog in Cambodia (*Chiromantis samkosensis*, see text), this tree-dwelling porcupine makes scientists wonder, "What else is still out there?"



this one?" In today's world of endless information, there are still surprises in God's creation.

The more that scientists learn about nature, the more questions they have. Sometimes they make breakthroughs that revolutionize the way we think about the universe, such as Galileo's observations of the moons of Jupiter and Pasteur's germ theory (see the margin box). What if biologists discovered something that completely changed the way we view the fundamental ideas of cell theory? Biology would need to be rethought and reinterpreted within this new framework.

Science is a great tool for understanding God's world and using it wisely, but it's inadequate as a foundation for a belief system because it doesn't deal with the biggest questions in life. Only an unchanging God can give us infallible truths in His Word, providing us with a sure foundation that will endure the passing of time.

A Germ of an Idea

Ideas in science are continually changing. For example, people have had different ideas about what causes sickness since the fifth century BC. Knowledge about disease grew over the centuries until scientists in the 1860s recognized the relationship between disease and germs. Scientists such as Louis Pasteur and Robert Koch, the Fathers of Microbiology, and Joseph Lister, the Father of Modern Surgery, were often criticized by their peers for their ideas. Why? People, including scientists, don't like their views of life to be challenged or changed.

1-4

In medieval times, physicians wore plague masks with good-smelling herbs in the "beak" of the mask. They believed that bad smells caused disease. Today, some people wear surgical masks to block germs from entering the eyes, nose, and mouth as a way to prevent disease.



CASE STUDY: A CHOICE OF LIFE AND DEATH

Femara is a drug used to treat cancer in older women. Studies have shown that women who take Femara could live longer than women who use other cancer drugs. However, in women of childbearing age, it can kill an unborn baby or produce birth defects if a woman takes this drug while pregnant. How should doctors balance these two facts?

Science can measure the world in repeatable and predictable ways by generating data (collectively called **observations**) that can be analyzed to explain *phenomena* (things that are observable) in the world. For example, studies have shown that women who take Femara after surgery have a 20% less risk of a return of their cancer. There have been no controlled scientific studies on the safety of Femara during pregnancy because of the cases that have arisen when women have lost children or have given birth to children with defects after having been on Femara. Actually, Femara has been used to increase the possibility of conception, but it has been known to occasionally produce birth defects. Science brought us this cancer drug, but it cannot tell us how to ethically use it.

So what would affect a doctor's decision to prescribe Femara? Ultimately, it boils down to his or her **interpretations** of science. Interpretations are important to using science in practical ways, but they are deeply affected by one's worldview and assumptions about truth and life.

Currently, the US Food and Drug Administration approves Femara only for women past childbearing years. But there are cases in which physicians have to make hard decisions about pregnant women with cancer. If a physician doesn't believe that unborn lives are made in the image of God, then he may feel it is most important to help his patient without regard to the impact on the baby. In fact, many people are in favor of abortion if the mother's life is in danger.

How can we solve such a dilemma? The Bible gives us answers to the biggest questions in life, questions that science alone cannot answer. God's Word gives us the perspective to critically analyze science from a biblical worldview to help us use science the way it should be used.



17 SCIENCE AS MODELING

1-5

The movements of this alligator are being modeled using motion-capture equipment. Scientists have used the model to create prosthetic tails for injured alligators.



Mr. Stubbs, a seven-foot American alligator (*Alligator mississippiensis*) that lives in a swimming pool at the Phoenix Herpetological Society, needed a tail. So herpetologists—scientists who study reptiles—used motion-capture equipment to model the motion of alligators in the wild. The motion information was then used to generate a mathematical model, which was used to create a similar tail made of rubber that helps Mr. Stubbs function like a normal alligator. He's still learning to use it, and he will never be able to be released back into the wild, but he likes his tail—he hasn't bitten it yet!

This \$6,000 prosthetic could help more than just Mr. Stubbs. The science used to develop this prosthetic could be useful for other animals and even for people who have lost limbs. Though Mr. Stubbs's new tail isn't just like a real one, it works well enough for him. This is an example of the work of science to develop models that help us understand the world around us in ways that help us use it better.

A **model** is a simplified representation of reality that describes or explains something in the world in a workable and useful way. A large part of science is modeling because we learn about the world by examining parts and pieces of it and looking at how those pieces work together. Just as with Mr. Stubbs's tail, our models are not the same thing as reality, but they are *workable*—they are practical and can be changed when we discover new information. Because models are different from reality and can change as we discover new information, science can't give us final answers.

1-6

Sometimes people need a reminder of just how workable and predictable the law of gravity is!



THEORIES AND LAWS

Models can represent concrete things, such as the plastic model of the human digestive system that many high schools have in their labs. Models can also represent abstract ideas, such as the attributes of life mentioned in Subsection 1.3 or the flow of energy through a cell in Subsection 1.4. Models don't lead to absolute truth, but they can help us visualize, organize, and understand areas of science so that we can use them to make useful predictions.

Two kinds of scientific models that you may already know about are theories and laws. A **theory** is a model that explains a set of observations. For example, the cell theory explains that cells are the smallest living things and that they are made up of many smaller parts that show amazing structure and function. For centuries, scientists observed cells and their actions until they were able to organize the observations into an explanation of how cells work.

A **law** is a model that describes how phenomena relate to each other in a predictable way. The law of gravity describes the relationship between objects on the earth and the earth's gravitational pull. These relationships can often be described mathematically, such as in the equation for the law of gravity.

$$F = G \frac{m_1 m_2}{r^2}$$

And so far, the law of gravity predicts quite well what will happen if you stand under a coconut tree for too long!

THE SCIENTIFIC METHOD

There are so many ways to observe the world and model it that there needs to be a process to sort through that information. One way that you can do that is by the scientific method. The **scientific method** is often described as a logical procedure that helps answer a scientific question. This method isn't about following a series of steps. Rather, it's about a way of thinking that helps people make sense of what they observe. It's part of the larger process of science. Let's take a look back in history to understand how scientists have used the scientific method to develop one of the most significant models in biology—the structure of DNA.

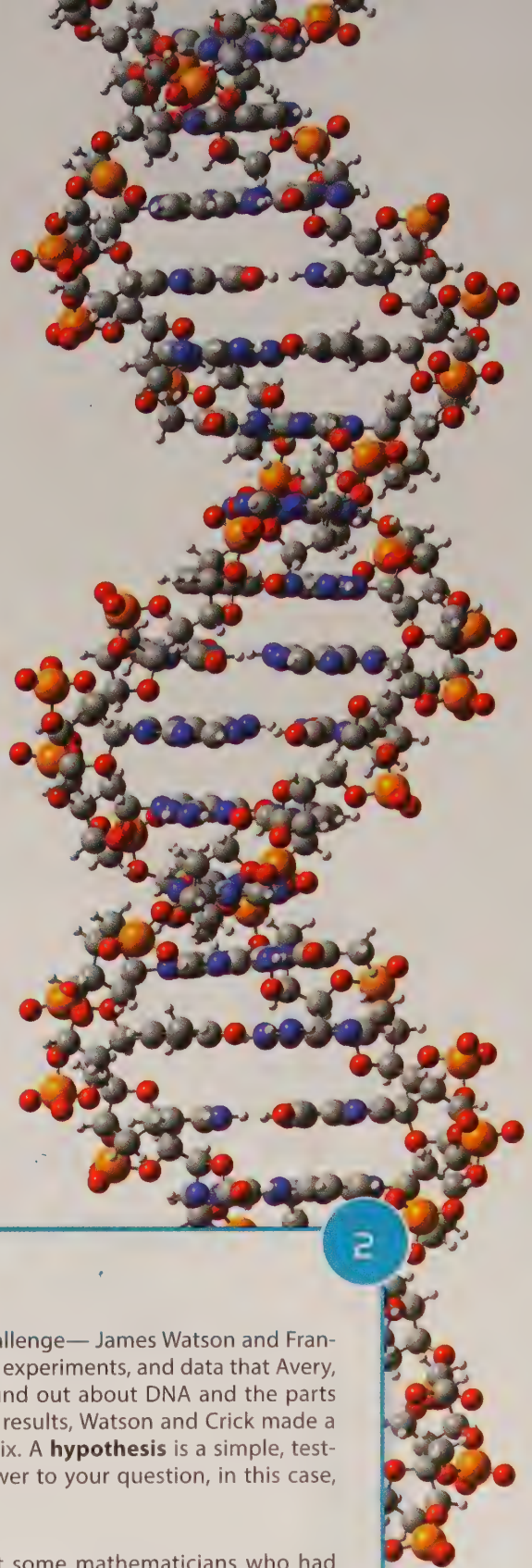
1 Ask a Question.

Biologists have been probing the cell for decades to see how it stored the information of life, beginning with a friar named Gregor Mendel experimenting with pea plants. In 1944 biologists Oswald Avery, Colin MacLeod, and Maclyn McCarty determined that there was a large molecule called *deoxyribonucleic acid (DNA)* that held this information, and they knew that it was a chain of smaller parts called *nucleotides*. (You'll learn more about DNA in the next chapter.) But they didn't know how these parts fit together to store information in the cell. Biologists were wondering, "What is the shape of the DNA molecule?"

2 Do Research.

Some young biologists rose to the challenge—James Watson and Francis Crick. They dived into the research, experiments, and data that Avery, MacLeod, and McCarty collected to find out about DNA and the parts that made it up. On the basis of their results, Watson and Crick made a hypothesis: DNA was a spiral, or a helix. A **hypothesis** is a simple, testable statement that predicts the answer to your question, in this case, the question about DNA's shape.

Watson and Crick also learned about some mathematicians who had determined in 1952 that a helix-shaped molecule photographed with x-rays produces an X shape. They also learned about a chemist's hypothesis that DNA was a triple helix. Armed with information and their hypothesis, Watson and Crick decided to assemble a DNA model out of cardboard and wire.



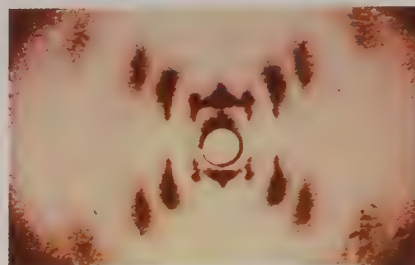
3

The Quest for Data

Experimenting isn't the only way to gather data for your hypothesis. You can also conduct a **survey**, a sampling of data gathered from an existing group of data. Things like polls and questionnaires are types of surveys. If you want to find out the average depth of all the ponds in Ohio, you could directly measure every single pond, or you could measure a large enough sample of ponds to find your average. Scientists also sometimes naturally observe phenomena that they can't reproduce in the lab, like an exploding star. These are called *natural experiments*.

Experiment.

An *experiment* is simply a way to test a hypothesis. Watson and Crick tried unsuccessfully to assemble their DNA helix. They showed their proposals to groups of scientists, including English chemist Rosalind Franklin. When Watson saw Franklin's x-ray photo of pure DNA crystals, what he saw confirmed their hypothesis that DNA was a helix. Franklin's x-ray photo was the perfect test for Watson and Crick's hypothesis.



4

Analyze the Data.

Watson and Crick gathered data from Franklin's x-ray photo to determine how all the parts of DNA fit together. They physically modeled the parts of DNA and worked with them until they developed the double-helix structure that explained how information can be copied in a cell.

5

Publish the Results.

Scientists today publish their findings in science journals, articles, and books. These published experiments often raise new questions in other fields that scientists will try to answer. In 1953, Watson and Crick published their findings in the scientific journal *Nature* for the scientific world to see. Watson and Crick's model of DNA's double-helix structure propelled biology into the field of molecular genetics. For their efforts, Watson and Crick received a Nobel Prize in 1962.



So what does the scientific method give us? It gives us a model that is workable and that has the ability to make useful predictions. However, a model is not the same thing as absolute truth. Models continue to be tested and refined as we gather data and learn more about the world in ways that help us understand and use it better. Viewing and using science this way helps us glorify God by fulfilling His commands.

18 REVIEW QUESTIONS

1. What is a worldview?
2. Living fossils are creatures that are alive today and that bear a striking resemblance to extinct creatures found in the fossil record. How do you think a creationist explains living fossils? How do you think an evolutionist explains them?
3. Read through the following scenarios and decide whether they are observations or interpretations of science.
 - a. A couple decides to keep their baby even after they discover that the baby will be born with severe disabilities.
 - b. Some birds fly south for the winter, while others don't.
 - c. New world monkeys have flat noses and old world monkeys have narrow noses. A biologist discovers a new world monkey with a narrow nose.
 - d. A researcher who develops a new drug determines that children under the age of 12 should not use the drug.
4. Can scientific models provide absolute answers? Explain your answer.
5. Evolutionists say that nature contradicts what the Bible says about the origin of life. Thinking back to the discussions on observation, interpretation, and modeling, how would a Christian respond to this evolutionary idea?
6. What is the difference between a theory and a law?
7. What does the case study on page 11 about the cancer drug Femara show us about what science can do? What does it show us about what science *cannot* do?
8. How can the science behind the use of Femara be used to fulfill God's commands?
9. You've noticed over the past several days that a flock of robins likes to sit in your front yard but never goes over to the neighbor's yard. Using the scientific method, how would you figure out why the robins prefer your yard over the neighbor's?

1-7

Horseshoe crabs (top) are considered the living fossils of extinct trilobites (bottom).



1C Questions

- » Why is conservation important?
- » How should we use biology?
- » Why is biology important?

BALANCE OF LIFE

Big Question 6: What is the balance between preserving the earth's resources and using them to help people?

1.8 PRESERVING AND USING OUR WORLD

Over seven billion people call this planet home, and hundreds more are born every minute. The United Nations predicts that the world population may surpass 8 billion by 2025 and 10 billion by 2083.

There are many people who view a growing world population as a problem. They say that nature is good and should be kept in its pristine condition. Technology consumes the earth and pollutes precious resources. “Mother Earth” must be protected at all costs because we came from the earth through evolution. This kind of thinking is aligned with a philosophy called **environmentalism**—the idea that the environment is fragile and should be protected and used as little as possible.

But Genesis 1:28—the Creation Mandate—tells us that God placed people on the earth to populate it and manage its resources. God also tells us in Matthew 22:37–39 that His greatest commands are to love Him and others, and managing resources is a way that we can do that. Being good stewards of the earth means that we need to preserve some things, keeping their future use in mind.

Conservation is the preservation and wise use of natural resources. Notice that the word “use” is in that definition. Using resources is part of conservation, though they must be used wisely with a mind for the future.

We can obey the Creation Mandate and the command to love God and others through biblical conservation. These biblical ideas help us keep a balanced view of how we conserve the earth's resources. We



1-8

US national parks are preserved for people to enjoy, for wildlife to have a home, and for water sources and historical sites to be protected.



should respond to situations that don't seem balanced by asking, "Is this how God wants us to manage the earth?" and "Does this show love for God and His image bearers?" Throughout this textbook you'll see how conservation can ultimately be used to glorify God and fulfill His commands.

1.9 | WIELDING THE TOOLS WISELY



1-9 |

Fertilizer helps farmers increase the growth of their crops, providing for a growing world population.

If we are to conserve God's world, how should we use science to meet the challenges of a growing world population? One of the most powerful tools in biology is **biotechnology**, the use of technology to enhance living organisms and their processes. Using biotechnology, scientists have developed more-nutritious grains, prettier flowers, more treatments for disease, and alternative fuel sources that keep our environment cleaner. But scientists also use biotechnology to abort unborn lives, to create "perfect" babies, and to excuse sin such as homosexuality as part of a person's genetic programming.

Because of the potential dangers in biotechnology, it and other tools of science are closely monitored by **bioethics**, the study of ethical situations in biology and medicine. Bioethics brings a moral tone and discerning eye to controversial topics in biology, but it doesn't look to God's Word for its foundation. Bioethics is often based on a naturalistic, evolutionary worldview that places all life on equal footing. We need a biblical worldview—seeing issues in biology through the lens of Scripture to discern how we should best use the tools of science.

1-10 |

The probes and saws and the machine that makes copies of DNA are all useful tools. People choose to use them for either the benefit or harm of others.





1-11

This exoskeleton suit, which can help paralyzed people walk again, is just one example of what happens when different fields of study work together to create something that helps others in amazing ways.

110 THE BIOLOGY CONNECTION

Learning interacts with life. As you've seen in the history of the development of the model of DNA, many disciplines must come together to make progress in our God-given stewardship responsibility.

Seeing the connections between biology and other fields is a way to fulfill the Creation Mandate and love others. A great example of this is prosthetics. The field of prosthetics requires the combined efforts of physicians, engineers, machinists, and physical therapists to produce something that helps thousands of people enjoy their lives again.

But the command to love others isn't limited to getting people back on their feet. It also extends to helping people thrive. That's why part of our stewardship should be to continually evaluate the ways that we help people to see whether we can do a better job. For example, neuroscientists and computer programmers have joined forces with those in prosthetics to create a prosthesis, such as a cochlear implant, that's responsive and allows a person to regain a lost sense of hearing.

Biology helps us manage the earth and help other people, thinking about a future world in which the unborn lives of today will be the citizens of tomorrow. We must work in biology in ways that connect the disciplines to fulfill God's commands and that ultimately point people to Christ.



1-12

Doing the work of biology from a biblical worldview for God's glory can make the world an easier, safer, and better place for the generation to come.

1C REVIEW QUESTIONS

1. What are the two ways that people should handle resources?
2. (True or False) Conservation is the idea that resources should be used as little as possible.
3. Some environmental groups say that people are overfishing the oceans. Can you think of a solution to preserve wild fish populations that still allows people to enjoy the bounty of the ocean?
4. Why is a worldview important for issues in biotechnology?
5. List two products that are the result of a combination of fields of study. Include the fields of study that were combined.

REVIEW QUESTIONS

CONCEPT REVIEW

1. Why did God give people the task of managing the earth?
2. Which two commands can give us a biblical approach to studying biology?
3. The ability to adapt is part of which attribute of life?
4. What are the two ways that an organism can grow?
5. Make a drawing to show the flow of energy from the sun to a person through natural processes in living things.
6. Draw the flow of information from DNA molecules to the digestion of food.
7. Wombats don't have tails. Because of this, the offspring of wombats don't have tails either. Is this an example of the flow of energy or of information? Explain your answer.
8. What is the difference between a biblical worldview and a naturalistic worldview?
9. During a visit to the American Museum of Natural History in New York, you see an exhibit of skeleton fragments. The signs on the exhibit say that these are the remains of a Neanderthal, a relative of modern humans that lived 200,000 years ago. What two presuppositions are revealed in the signs on the exhibit? Which worldview do these presuppositions represent?
10. Describing the eating habits of a new species of frog is a(n) (observation/interpretation) of science. Describing how the frog's eating habits were created by God is a(n) (observation/interpretation) of science. (*Hint: See the Key Terms to the right.*)
11. What does it mean for a model to be *workable*?
12. What kind of answers can models give us? What kind of answers can they *not* give us?
13. The model of DNA is based on observations and works very well to explain how information is transferred from one cell to another. Why might the DNA model need to be changed one day?
14. How does worldview affect the way people form models?
15. How can a Christian fulfill the Creation Mandate and the command to love God and others through conservation?
16. You've been asked to help someone figure out whether an experiment is ethical or not. What should you base this bioethical decision on?

Key Terms

Creation Mandate	4
image of God	4
biology	5
worldview	10
observation	11
interpretation	11
model	12
theory	12
law	12
scientific method	13
hypothesis	13
survey	14
environmentalism	16
conservation	16
biotechnology	17
bioethics	17

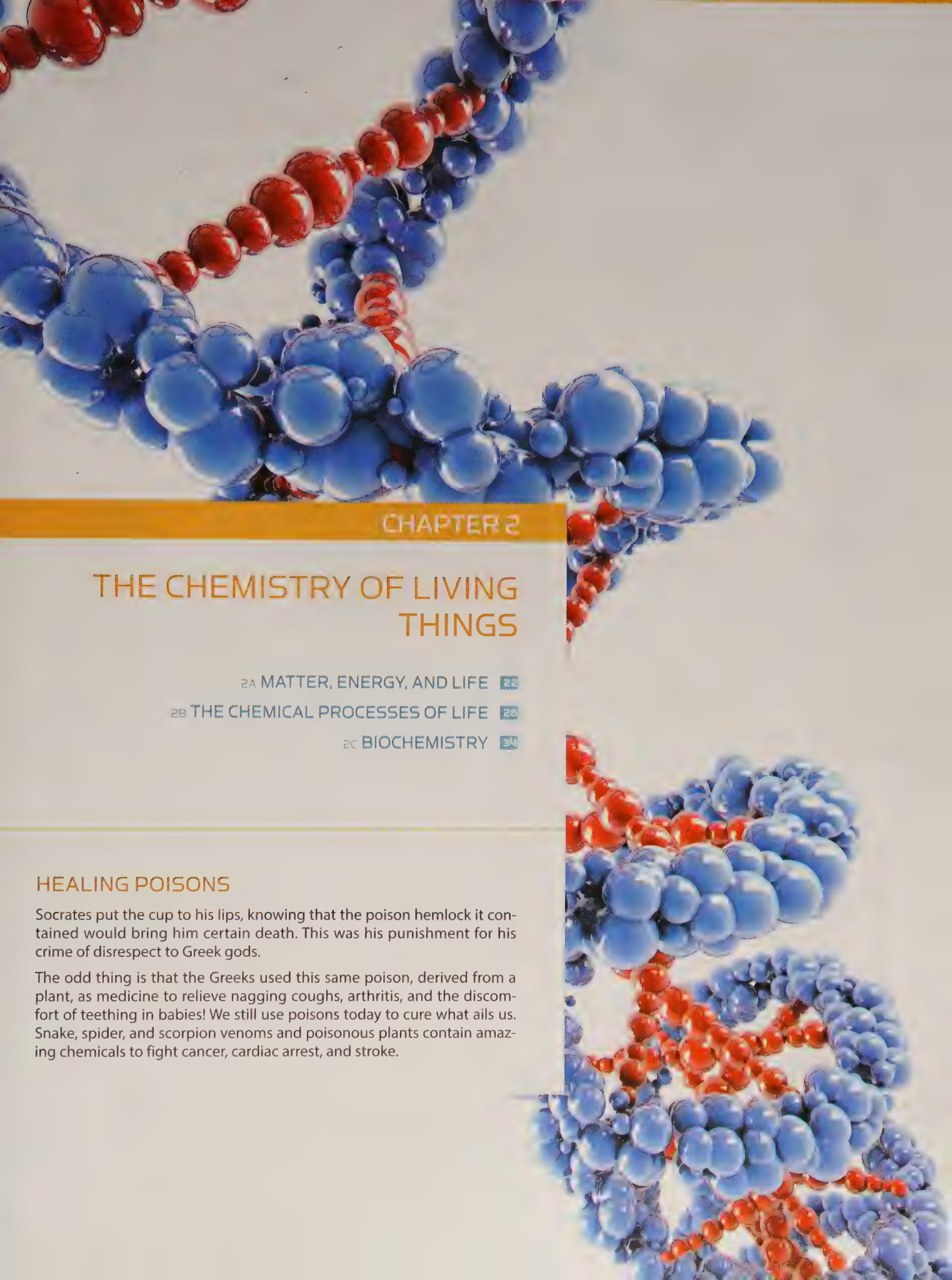
TRUE OR FALSE

17. God's Word can help people with the way they do science.
18. Response in an organism is a type of structure.
19. Organisms need either energy or information, but they don't need both.
20. Because science is always changing, we should *not* look for truth in science.
21. Once science has answered a question, there's never a reason to ask that question again.
22. Theories and laws are both types of models.
23. The goal of the scientific method is to find a workable answer.
24. The wise use of trees for lumber is an example of environmentalism.
25. Biotechnology is generally regarded as harmful.
26. Part of carrying out the Creation Mandate is to use the tools of science wisely.
27. Combining different fields of study leads to more useful products.

THINKING CRITICALLY

28. Choose the sentences in the following example that speak of an activity that can be handled by science and those that cannot.

(1) Astrobiologists are studying other planets and moons to try to find water on them. (2) They believe that if they find water, then they may find evidence of life arising on another planet. (3) These scientists often test their interstellar technology by using it in the most extreme environments on Earth. (4) As a result, they have discovered many fascinating things about hydrothermal vents deep in the ocean and bacteria living under the ice in Antarctica. (5) Astrobiologists think that if they ever find evidence of life on another planet, it will lead them to discover the origin of life on Earth.
29. Design a sample survey to find out how many dandelions are in your city's park.
30. Which part of the scientific method might happen when an idea from biology is combined with an idea from engineering?



CHAPTER 2

THE CHEMISTRY OF LIVING THINGS

2A MATTER, ENERGY, AND LIFE 25

2B THE CHEMICAL PROCESSES OF LIFE 28

2C BIOCHEMISTRY 34

HEALING POISONS

Socrates put the cup to his lips, knowing that the poison hemlock it contained would bring him certain death. This was his punishment for his crime of disrespect to Greek gods.

The odd thing is that the Greeks used this same poison, derived from a plant, as medicine to relieve nagging coughs, arthritis, and the discomfort of teething in babies! We still use poisons today to cure what ails us. Snake, spider, and scorpion venoms and poisonous plants contain amazing chemicals to fight cancer, cardiac arrest, and stroke.

2A Questions

- » What is matter, and what is it made of?
- » What is energy, and how do living things get it?
- » What's the difference between a physical and a chemical change?
- » Which kinds of chemical compounds are involved in living things?

2-1

The cone snail (right) has a dagger-like tooth that it launches to inflict a sting similar to that of a bee. Scientists are exploring the possibility of using chemicals in its venom as a potential pain reliever that doesn't produce an addiction like morphine does.



2A

MATTER, ENERGY, AND LIFE

What are living things made of?

2.1 MATTER

So what's the difference between a poison and a medicine? They are both chemicals that affect the way living things grow and operate. One of the most fruitful applications of studying life is to use chemicals from living things, like the poison from the hemlock (margin, lower left), to develop medications that can save and improve people's lives. People's lives matter because we are made in God's image.



Living things are deeply affected by matter and the changes it undergoes. The study of matter and the changes it experiences is called *chemistry*. **Matter** is the physical stuff that makes up the universe. You are made of matter, breathing matter, using matter, and eating matter all the time! But you aren't the only one. All living things—bees, banana trees, chimpanzees—interact with chemicals this way. There is a vital relationship between life, chemistry, and matter.

Atoms are the basic building blocks of matter. They are the smallest individual particles of which matter is made. However, atoms also have parts. They have a nucleus that is massive but extremely tiny compared to the rest of the atom. It is in the nucleus that positively charged *protons* and neutral *neutrons* are found. Whizzing around the nucleus is a cloud of negatively charged *electrons* that seem to occupy different levels similar to the planets around the sun. The electrons in the outermost level are called *valence* electrons.

An atom with the same numbers of electrons and protons is electrically neutral. If these numbers don't match up, then the atom has an electrical charge, making it an *ion*. Extra electrons produce a negative ion, or *anion*. A *cation* has a net positive charge, which occurs when there are fewer electrons than protons.

2-3

A neutral oxygen atom has 8 protons, 8 neutrons, and 8 electrons. There are 6 valence electrons in the outermost level.





23

mechanical energy. When whales make sounds, they generate *acoustic energy*. When glowworms make light, they produce *light energy*. When platypuses generate heat, they produce *thermal energy*.

Thermal energy comes from moving particles. The measure of the speed at which these particles move is the **temperature** of a substance or organism, its relative hotness or coldness. So when you have a fever, the average speed of your particles is higher!

But what about the manatee (*Trichechus inunguis*) grazing in underwater pastures? Living things need to *get* energy from somewhere before they can *produce* it. Animals can't make their own energy; they get energy from their food. This energy is stored in the chemicals that make up food—we call it *chemical energy*. Plants, which also do not make their own energy, get their energy by transforming the sun's energy. So you can see that energy can be changed from one form to another. It's important to note that living things depend on these transformations.

Energy also tends to spread out. Plants concentrate energy in their stalks and leaves, and then other organisms eat the leaves. Plants also release energy as they emit water vapor and carbon dioxide, both of which disperse into the atmosphere. Living things depend on energy's tendency to disperse. This is called **entropy**.

Entropy—a Good Guy

Maybe you're used to thinking about entropy as disorder, the kind of evil force that makes your room messy! That's not what entropy is at all. Rather, it's the tendency of energy to disperse, or spread out. Imagine a world where energy did not spread out but could spontaneously concentrate. Would this be dangerous or helpful?



2.3 CHANGES IN MATTER

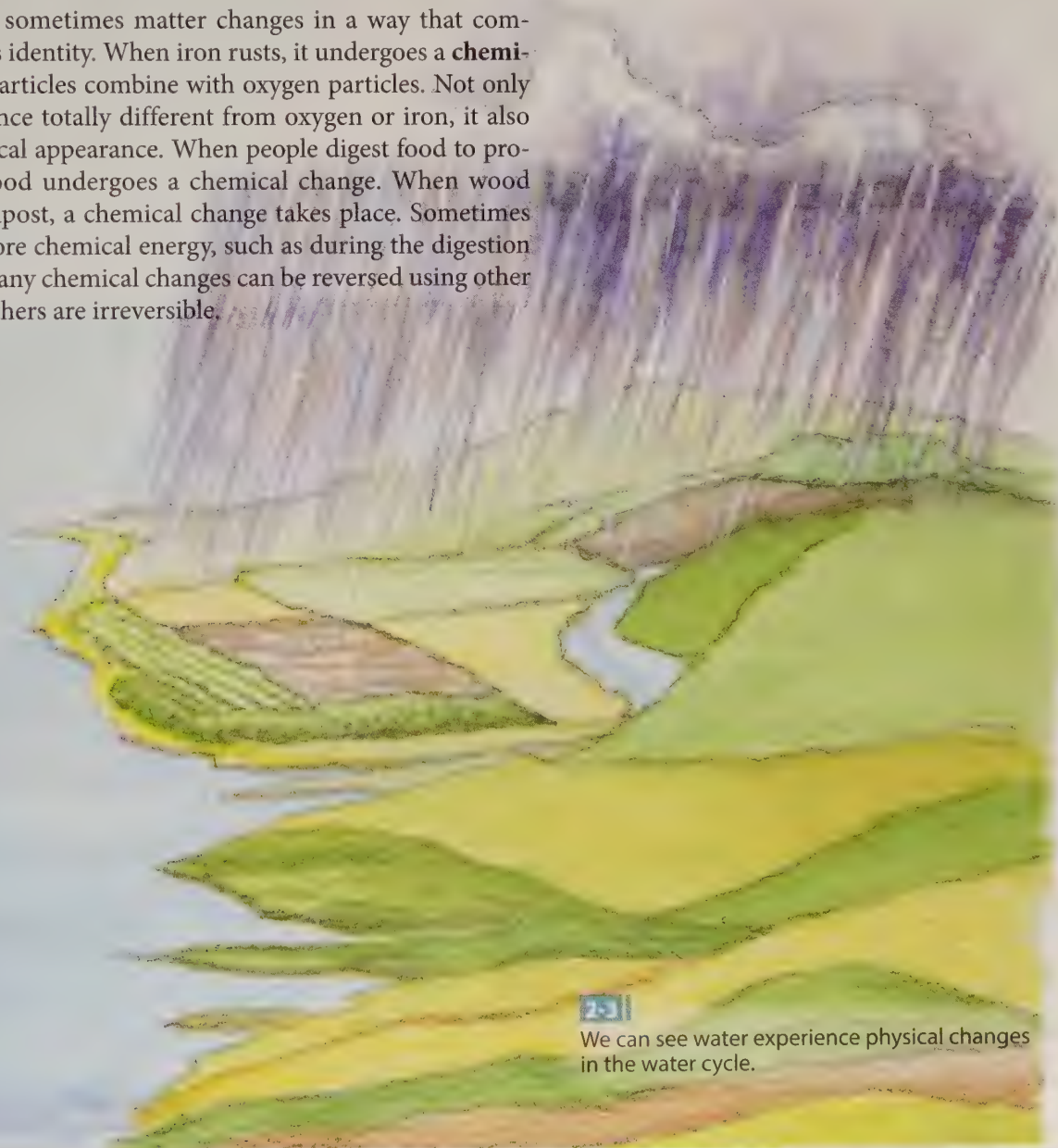
Just as energy can change from one form into another, matter can also change from one form to another. One of the basic laws of science is that the amount of matter and energy in the universe never changes. This is called the law of conservation of mass and energy. The conservation of energy is called the *first law of thermodynamics*. Living things do not create new energy or matter; they can only change the form of matter that is already out there. That is why we observe cycles of matter in the environment, such as the water cycle, the nitrogen cycle, and the carbon cycle. You'll learn more about these cycles in later chapters.

Changes that don't change a matter's identity are called **physical changes**. This could include icicles melting in the spring and water evaporating from the ocean to form clouds, or even air bubbles dissolving into a churning mountain stream. Although many physical changes can be reversed using other physical changes, some are irreversible. An example would be when wheat is ground into flour.

On the other hand, sometimes matter changes in a way that completely transforms its identity. When iron rusts, it undergoes a **chemical change** as iron particles combine with oxygen particles. Not only is rust a new substance totally different from oxygen or iron, it also has a different physical appearance. When people digest food to produce glucose, the food undergoes a chemical change. When wood rots to produce compost, a chemical change takes place. Sometimes chemical changes store chemical energy, such as during the digestion of food. Although many chemical changes can be reversed using other chemical changes, others are irreversible.

A Different Kind of Kaboom

When you think of chemical changes, you think, "KABOOM!" Well, here's a different kind: nuclear change. Nuclear changes are usually associated with substances that are radioactive. For example, carbon, one of the main elements associated with life, has six protons. However, there are different forms or *isotopes* of carbon that depend on how many neutrons it has. Carbon-12 is stable, but carbon-14 is radioactive. Because of this, the type of carbon in things that used to be alive can tell us something about how old they are—if we make some assumptions. This is called *radiocarbon dating*. For example, scientists used radiocarbon dating to determine the age of the Dead Sea Scrolls.



2-3

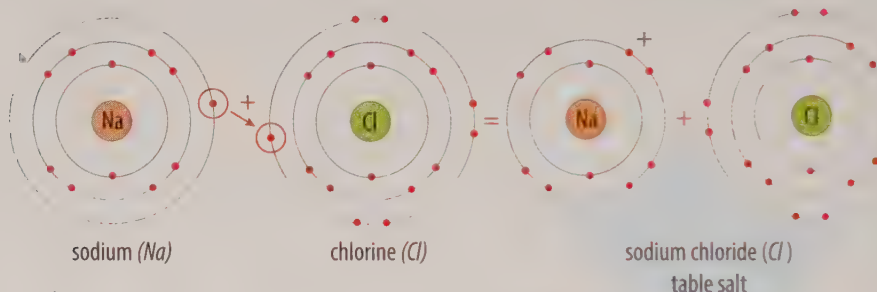
We can see water experience physical changes in the water cycle.

2.4 COMPOUNDS AND MOLECULES

When substances made of only one kind of element undergo a chemical change, their atoms react with the valence electrons from other atoms in a way that stores energy. Stored chemical energy that holds two atoms together is called a **bond**. For example, when iron (Fe) rusts, a chemical change occurs as the iron forms bonds with oxygen in the air (O_2) to form rust (Fe_2O_3). Iron and oxygen are also involved in the chemical process that allows your blood to carry oxygen to all the different parts of your body. Rust is an example of a **compound**, a pure substance made of two or more elements chemically combined.

IONIC COMPOUNDS

When atoms in the process of bonding give away their valence electrons, they transform into ions. One becomes a cation and the other becomes the anion. These oppositely charged ions attract to form *ionic compounds*. The smallest part of an ionic compound is called a *formula unit*. Formula units build on each other to form crystals.

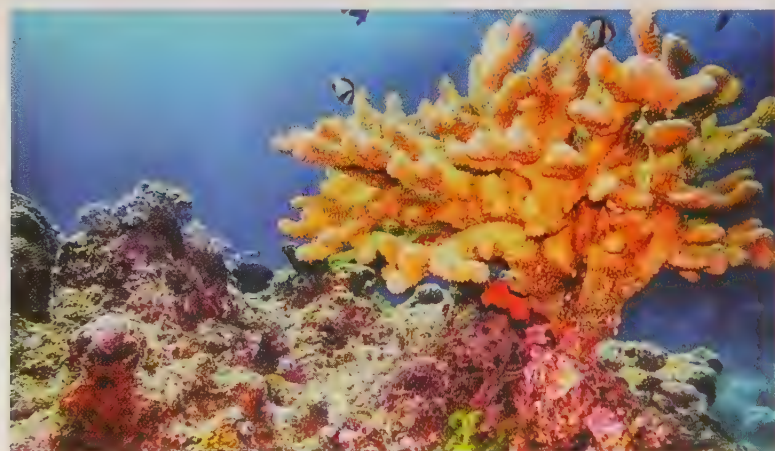


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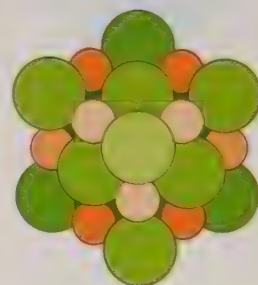
Sodium donates a valence electron to chlorine to form a sodium chloride (NaCl) formula unit that combines with other formula units to form a crystal.

2-5

Corals produce a skeleton made of an ionic compound, calcium carbonate.



Ionic compounds are important to living things. You use toothpaste containing sodium fluoride (NaF) because your teeth are made of ionic compounds. You drink milk fortified with calcium phosphate ($Ca_3(PO_4)_2$) because your bones are made of ionic compounds. Many domesticated animals such as horses need salt blocks to lick because salt provides minerals necessary for their biological functions.

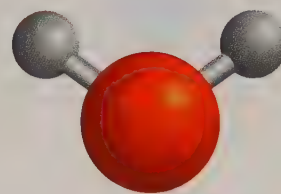
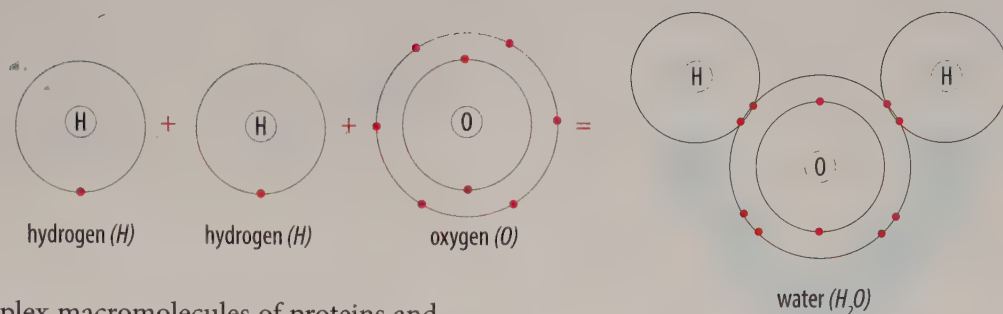


COVALENT COMPOUNDS

Sometimes atoms in the process of bonding share their valence electrons instead of donating them. An example is water, a chemical essential to life. Two hydrogen atoms each share an electron with a single oxygen atom. Then the oxygen atom shares one electron with each hydrogen atom to form a *covalent compound*. The smallest part of a covalent compound is called a **molecule**.

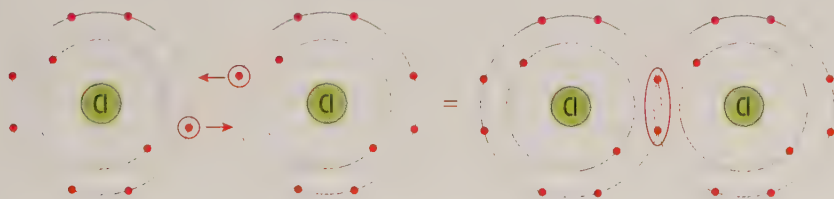
Atoms in a covalent molecule never form ions; the numbers of electrons and protons in these atoms

are equal. For covalent compounds, the pair of shared electrons is the bond that holds the atoms together. Molecules vary in complexity from simple molecules made of two of the same atoms, such as oxygen (O_2), to the immensely complex macromolecules of proteins and DNA that contain hundreds of thousands of atoms. Some of the compounds most essential to life and its processes are mammoth—and some are minuscule.



2A REVIEW QUESTIONS

1. What is the difference between a poison and a medicine? How can we use science to know the difference?
2. Write your own definition of energy.
3. Give an example of an energy transformation involving a living thing, stating the initial type of energy and the final type of energy.
4. Create a table or T-chart (see Appendix B) that compares physical and chemical changes, including a definition, observable changes, and examples.
5. List at least two differences between ionic and covalent compounds.
6. The illustration below shows the formation of a bond.

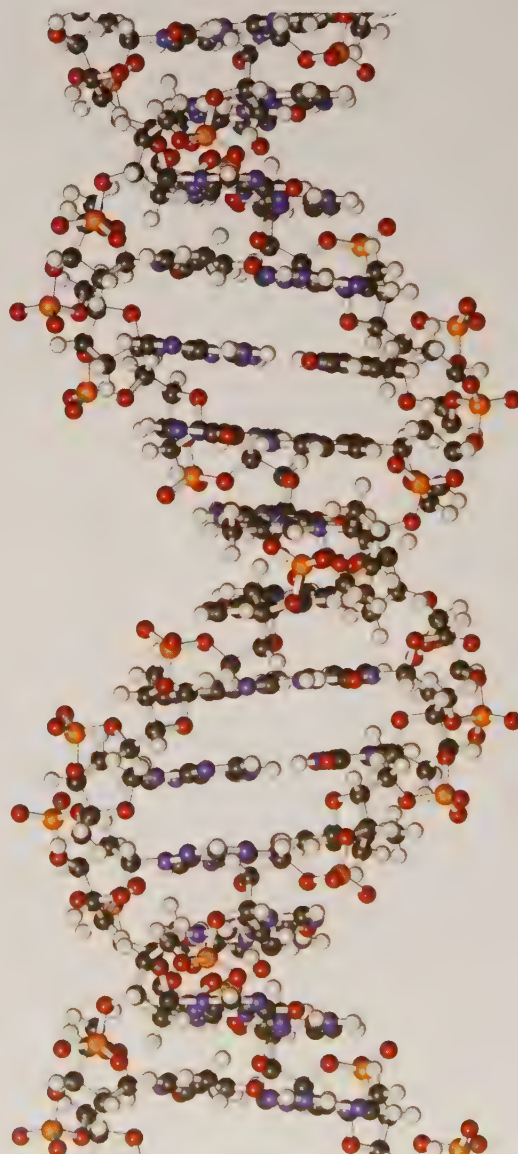


What kind of compound is forming? How can you tell?

7. Draw a hierarchy chart (see Appendix B) that shows the relationships between matter, atoms, elements, pure substances, ionic and covalent compounds, formula units, and molecules. Include examples in your chart.

2-6

Water forms when hydrogen atoms share electrons with an oxygen atom. Compare a water molecule with the DNA molecule below!



PHARMACOLOGY

You may never have thought about the medicines in your cabinet as being poisons, but they really are. So how do they make you feel better? It's all because of pharmacology. Pharmacology is the scientific study of the way drugs work. It is an area of science that overlaps biology and chemistry with the purpose of giving people the most relief with the fewest negative side effects. Drugs are tested in a process that can last for seven years before they make it from the lab to the pharmacy down the street. This is practical science that helps you where you live.

2B Questions

- » How does the nature of matter affect life?
- » What kinds of chemical reactions release/absorb energy?
- » What makes a chemical reaction speed up, slow down, or not even happen?

THE CHEMICAL PROCESSES OF LIFE

How do chemical processes keep life going?

2.5 PHYSICAL CHANGES

Break out your raincoat! It's a rainy day. A sky heavy with gray clouds trails a fine rain onto a mountainside covered with balsam trees and mountain maples as you hike along the trail. The rain picks up. Water runs down the trail, sending insects scurrying, picking up soil particles, running over rock faces of limestone, washing into streams that churn as they swell with rainfall.

A rainy day demonstrates several physical changes. The change from liquid water in the ocean, to water vapor in the air, to cloud formation is one example. We've seen how physical changes alter matter in ways that don't change its identity. Let's look at some specific physical changes that are essential to keep living things alive in this everyday example.

SOLUTIONS

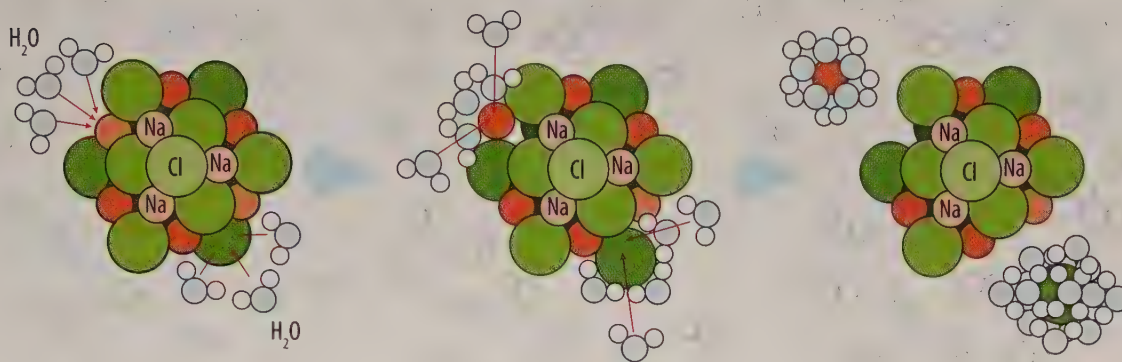
When the water runs down the trail and picks up debris, it forms a *mixture*. We can see the bits of soil, pebbles, and twigs that get washed into the rainwater. When water runs over limestone deposits, some of the limestone will break up in the water so much that we can't see it. Limestone is an ionic compound called calcium carbonate (CaCO_3), and it actually breaks up into calcium and carbonate ions mixed in with the water. This forms a solution.

A *solution* is a uniform mixture. The process by which one substance (limestone) is broken up into smaller pieces, usually ions, by another substance (water) is called **dissolving** (see Figure 2-8). There is more water than limestone, so water is called the *solvent*, and the limestone, the substance that is dissolved, is called the *solute*. The amount of solute packed into a solvent is called the *concentration* of a solution.

2-7

Name some physical changes happening in this picture.

A solute isn't always a solid. For example, when the rainfall washes into churning mountain streams, some air dissolves in the water. This is very important for fish, salamanders, and other aquatic animals that rely on dissolved oxygen to breathe. In this case, the oxygen is the solute.



Most rainfall is not pure water. It sometimes reacts with pollution, such as sulfuric acid or nitric acid in the air, to form acid rain. An **acid** is a substance that dissolves in water to form hydrogen ions (H^+). A **base** is a substance that dissolves in water to form hydroxide ions (OH^-) or other ions like chloride (Cl^-) or fluoride ions (F^-) that can accept hydrogen ions. When a strong acid and base react with each other, the hydrogen and hydroxide ions combine to form ... water! Acids and bases affect soil and water in the environment as well as digestion and even blood in living things.

Living things live in and use solutions. The atmosphere is a solution of gases, and the oceans are liquid solutions. Later on in this chapter we'll see more of water's amazing ability to dissolve and affect life.

2-8

The water molecules tear apart the salt crystal until it is completely dissolved in the solution.

DIFFUSION

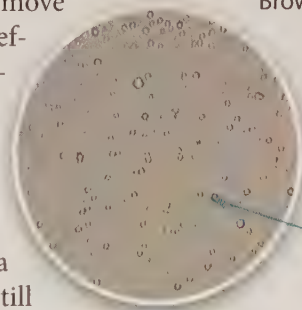
Scoop up a cup of pond water and put it under a microscope. What do you see? Lots of little particles (and maybe some critters!) being jostled around. Why are they moving around like that?

Particles are in constant random motion. We've already seen that temperature is related to the average speed that particles in a substance move. This motion is caused by collisions between particles. Maybe you've seen dust particles in a shaft of sunlight that move around but never seem to settle out of the air. This effect, seen only in particles, is called *Brownian motion*. Brownian motion affects the motion of especially small particles.

Matter, like energy, tends to spread out. If a skunk sprays a wildcat in a windless forest, the stinky smell still spreads to fill the area. If an octopus squirts a moray eel with its ink in a quiet tide pool, the ink still spreads to fill the water. Both examples demonstrate the

2-9

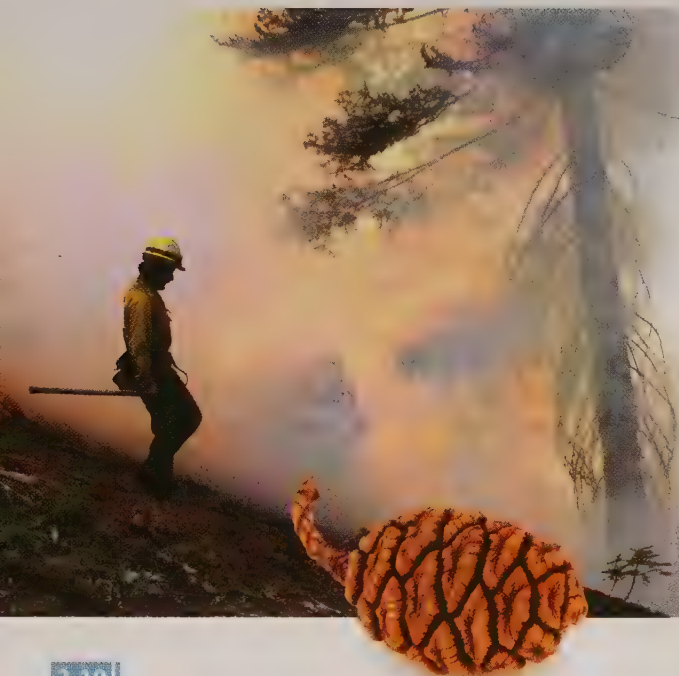
Looking under a microscope is all it takes to see Brownian motion in, well, motion!



PARTICLES IN MOTION

dispersion of substances through Brownian motion alone, not because of wind or water currents, in a process known as **diffusion**. The ability of matter to spread out is another physical change that living things rely on. You'll see just how important diffusion is when we study the processes that make living things grow later on in Unit 2.

2.6 CHEMICAL CHANGES



Fire! Smoke! Heat! There's a forest fire in the Mariposa grove of Yosemite. Smoke fills the air, and waves of heat undulate from the fire. Days later, the mighty Sequoia trees (*Sequoiadendron giganteum*) in this grove with their fire-resistant bark still rise firm and unmoved, though slightly charred, from the scorched forest floor. But this is a good thing. The Sequoia cones open only in fire to release the seeds of a future grove of mighty Sequoias.

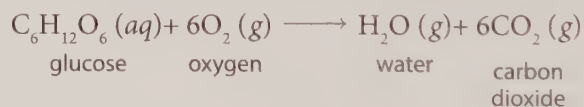
Burning is a good example of a chemical change because there are visible signs of chemical changes that hint at the unseen molecular changes taking place. So a forest fire is an example of a chemical change. You know from Section 2A that a chemical change transforms the identity of matter. Molecules in the leaves and wood of underbrush change or *react* with oxygen in the air to leave charred remains. Some of the most obvious signs of a chemical change include the formation of a gas, a change in color, or the release of heat and light. These all happen in a forest fire, and that's a good thing for the few Sequoia saplings that may sprout up days, weeks, or even months later.

2-10

A forest fire shows some of the visible signs that a chemical change is taking place.

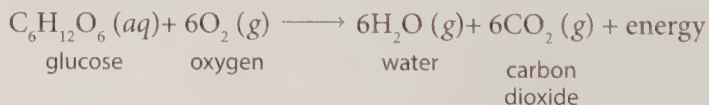
CHEMICAL EQUATIONS

Knowing that a chemical change or *reaction* occurred is just the starting point. What did we begin with? These are the **reactants**. What did we end up with? These are the **products**. Chemists pack all the answers to these questions into an expression called a *chemical equation*. The chemical equation below shows what happens in a forest fire.



The first reactant, $\text{C}_6\text{H}_{12}\text{O}_6$, is glucose, which is the food of plants and is found dissolved in water in the stems of plants. In a forest fire, this would combust, or burn, in the presence of oxygen to form water vapor and carbon dioxide gas. So glucose and oxygen are the reactants, and water vapor and carbon dioxide are the products.

This process releases lots of thermal and light energy. So you could say that energy is a product also.

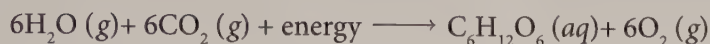


Mystery Numbers

The numbers in front of the oxygen and carbon dioxide in the equation are called *stoichiometric coefficients*. They balance out the chemical reaction so that there is the same number of each atom on both sides of the equation, since matter is conserved during chemical changes.

Chemical reactions that produce energy are called *exothermic reactions*—the energy of the products is lower than the energy of the reactants because some of the chemical energy stored in the glucose is not stored in the water vapor and carbon dioxide. Instead, it escapes as heat and light.

But the opposite reaction also happens in the Mariposa Grove. This reaction doesn't happen during the forest fire; it happens when plants make glucose during photosynthesis, and so the reverse reaction takes place.



In this case, plants need energy to form glucose, and they get this energy from the sun. This is how a plant stores energy and makes its own food. This is an example of an *endothermic reaction*, a chemical change in which the reactants have less energy than the products. See Figure 2-11. You can also see the energy necessary to get a reaction started. Both exothermic and endothermic reactions need energy to get jump-started. This energy is called the *activation energy*, E_a .

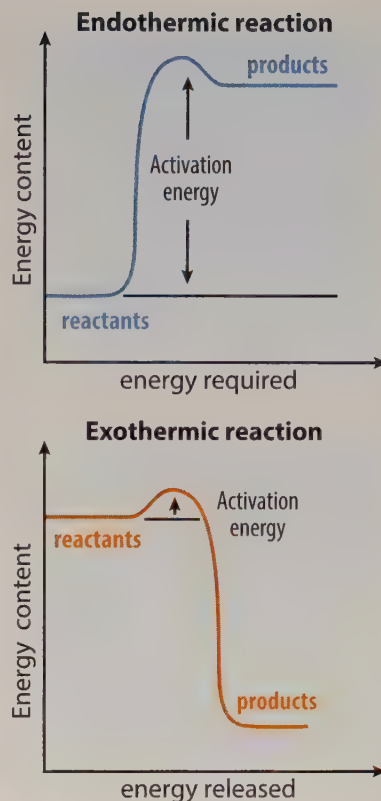
CATALYSTS AND ENZYMES

The symbol E_a is such a little symbol, but it makes a big difference for living things. Some of the chemical reactions necessary to keep something alive and growing have huge activation energies. There is no possible way for this reaction to happen without an immense energy investment. That's good for harmful reactions that we don't *want* to happen, like spontaneous combustion! But what about reactions that living things *need* to happen?

There is a way to overcome this energy mountain. A **catalyst** is a substance that provides an alternate route from reactants to products that doesn't require as much energy to jump-start. This means that the reaction has a lower activation energy. It speeds up without using up all the energy in the process. And, as an added bonus, it doesn't affect how much energy is stored or released during the reaction. Catalysts are like the key that unlocks a reaction so that it can take place.

Where do living things get catalysts? One special class of catalysts, called **enzymes**, naturally occurs in living things. They are large molecules, 10–100 times larger than any molecules scientists have been able to make in the lab. And they are super customized to make processes that are necessary to life happen like clockwork.

Enzymes are responsible for most vital chemical reactions. For example, an enzyme called *RuBisCO* helps plants create glucose during the process of photosynthesis. Scientists have found more than a thousand enzymes, and each one is specific to a chemical reaction occurring within a living organism. The presence of an enzyme typically makes a reaction happen millions of times faster! Without



2-11

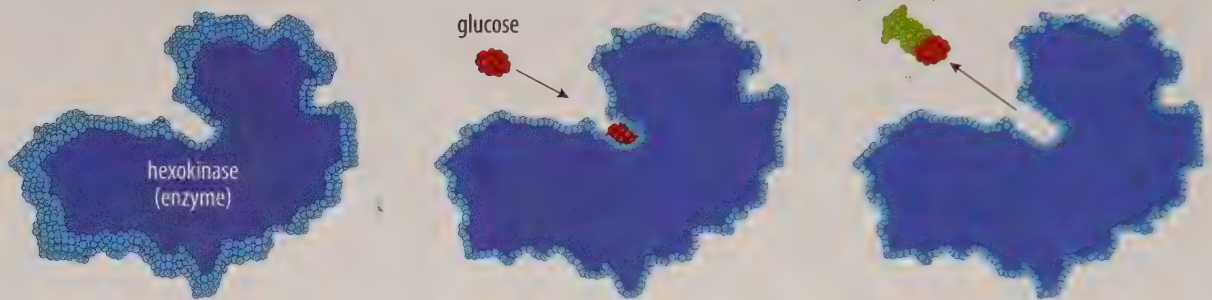
Both endothermic and exothermic reactions proceed from left to right, with the vertical axis showing how much energy is stored in both the products and reactants. Which reaction has a higher activation energy?

2-12

RuBisCO, short for ribulose-1,5-bisphosphate carboxylase/oxygenase, is an enzyme that helps plants convert carbon dioxide in the atmosphere into glucose. Scientists think that it is the most common enzyme on the planet. But that doesn't mean it's not special—life on Earth depends on this one enzyme!

2-13

Hexokinase (blue) is an enzyme that breaks down glucose (red). Mitochondrial hexokinase (green) inhibits this process to prevent glucose from being broken down by keeping it from “docking” on the enzyme.

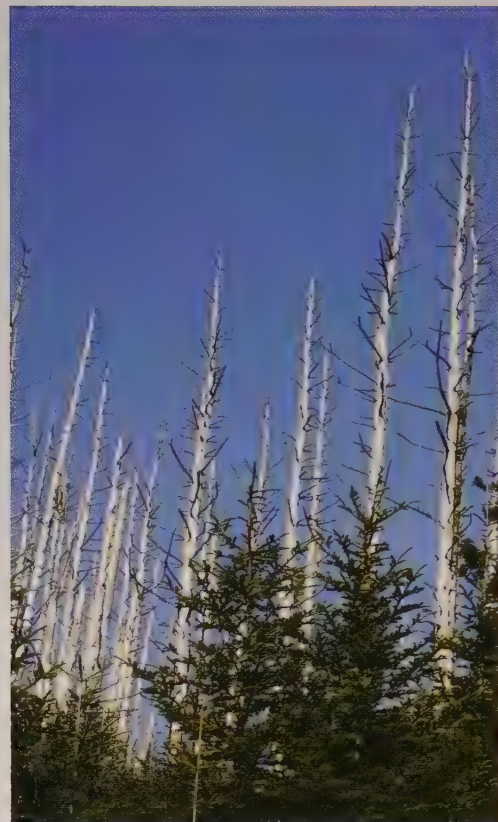


Some catalysts, such as those that make food spoil, do things that we would prefer didn't happen! An **inhibitor** is a substance used to reduce a catalyst's undesirable effects. Inhibitors work by bonding to the catalyst's active site or binding to the substrate in order to make it difficult or even impossible for the substrate to bind to the active site. Neurotoxins, like atropine in the poison found in nightshade plants, are valuable inhibitors. It is one of the most important medications that doctors use in emergency healthcare today because it prevents cardiac arrest. It works by blocking an enzyme that helps transmit signals to the heart that trigger cardiac arrest.

Chemically speaking, it's hard to distinguish a medicine from a poison. Both can be catalysts and inhibitors. But the difference in effect between the two can be obvious—whatever helps people is medicine, and whatever hurts them is poison. It takes both a good knowledge of chemistry and a biblical worldview to use medicines the right way. When we take chemicals from plants and animals that are naturally toxic and use them in ways that help people, we are pressing God's world to function the way that it should.

28 REVIEW QUESTIONS

1. Review the hierarchy chart that you created in 2A Section Review Question 7. Add solutions and mixtures to your chart.
2. Identify each of the following as a physical or chemical change.
 - a. dew forming on a fern
 - b. the growth of a dandelion
 - c. rock being ground into powder by a moving glacier
 - d. minerals dissolving into a local stream
 - e. acid rain killing a balsam over time
3. Imagine that diffusion didn't happen, that matter never dispersed on its own. How would this affect life? How does this illustrate God's care for life?
4. How does dissolving rely on diffusion?
5. Draw a curve on your paper similar to the ones in Figure 2-11 on page 31 for each of the reactions below. Identify the activation energy, reactants, and products. Label each graph as an exothermic or endothermic reaction.
 - a. $\text{H}_2\text{O} + \text{CO}_2 (g) + \text{energy} \longrightarrow \text{H}_2\text{CO}_3$ (reaction that removes carbon dioxide from your blood by forming carbonic acid)
 - b. $\text{C}_6\text{H}_{12}\text{O}_6 (aq) + 6\text{O}_2 (g) \longrightarrow 6\text{H}_2\text{O} (g) + 6\text{CO}_2 (g) + \text{energy}$ (reaction that turns stored glucose into heat)
6. Consider Figure 2-12. Life on Earth depends on the effectiveness of Ru-BisCO. It doesn't do its job very fast or very well, making mistakes about 27% of the time, so plants need a lot of it. How would you respond to evolutionists who say that if there were a Creator, He would have made such a key enzyme more efficient?
7. Compare substrates and inhibitors.
8. Create an analogy that relates enzymes, substrates, and inhibitors.
9. How can we use chemistry to help living things, especially people, who bear God's image?



2-14

These trees in the Great Smoky Mountains National Park were killed by acid rain that sometimes falls there.

BIOCHEMISTRY

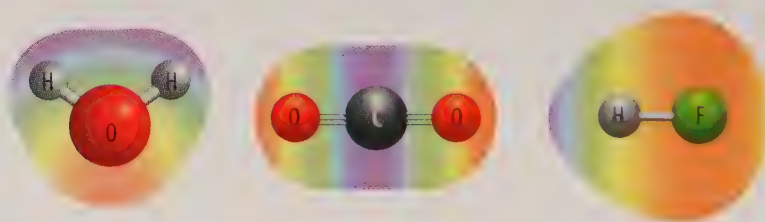
What chemical compounds are important to life?

2.7 WATER

What can you live the longest without? In 2012, a Swedish man found buried under snow in his car went without food for about two months. But that's only because he had an unlimited supply of just one thing that living things need—water.

Water is one of those things you take for granted unless you don't have it. Since your body is 65% water, in hot conditions you can become dehydrated after just an hour without it. At most, you can live only 3–5 days. Not only people, but all life that we know about needs water. Without it you're, well, sunk.

What makes water so important to life? Recall that water is a molecule that has two hydrogens bonded to a central oxygen. This molecule is shaped like a boomerang. The oxygen pulls electrons closer to it than each hydrogen does, so the electron cloud around the molecule is lopsided, although the whole molecule has an overall neutral charge. It forms areas of charge similar to the poles on a magnet. The electron cloud around the molecule is shifted toward the oxygen, forming an area of negative charge around the oxygen and areas of positive charge around the hydrogen atoms. Because these areas of charge are asymmetrical, water is a **polar** molecule.



The polarity of water makes it very good at dissolving things. Recall that rainwater dissolves oxygen, calcium carbonate, and even sulfuric acid and nitric acid in the atmosphere. Water is a superhero when it comes to dissolving things. The cells in your body that keep life going rely on water to move nutrients around. Without it, processes that sustain life begin to shut down because cells don't have the materials they need to keep working.

Water's polar structure and boomerang shape also allow it to interact with other water molecules. The hydrogens on one water molecule attract the oxygen on another water molecule. Hydrogens on a water molecule can also attract fluorine and nitrogen on other molecules. These intermolecular attractions are called *hydrogen bonding*. Hydrogen bonding is a big deal in biology. In Chapter 6 you'll learn how hydrogen bonding helps DNA stay in its coiled shape and proteins have

2C Questions

- » How is water important to life's design?
- » What is the difference between an organic and an inorganic compound?
- » How can I distinguish between carbohydrates, proteins, lipids, sugars, and nucleic acids?
- » What do carbohydrates, proteins, and nucleic acids have in common?

2-15

The diagrams to the right show the surface charges of covalent molecules. Black balls represent carbon, red, oxygen, grey, hydrogen, and green, fluorine. Red areas of the electron cloud have a negative pole, while blue ones have a positive pole. You can see water's structure in the first diagram. Which molecules are polar?

their signature kinks and curls. The shape of an enzyme is customized to help biochemical reactions, and this shape is dramatically affected by hydrogen bonding.

Because of hydrogen bonding, water molecules attract each other, creating surface tension that can support the weight of a water strider and a basilisk lizard sprinting across its surface. The attraction of water molecules for each other is called **cohesion**.

Water's polarity also allows it to attract other substances besides water in a process called **adhesion**, one of the forces that helps water move through conduits in stems and leaves. As long as another substance is polar, water molecules will attract and stick to that substance.



2-16

The basilisk lizard is one of many animals that use the surface tension of water to walk on its surface, an example of cohesion.

SHIELD OF ICE

It is wintertime in the woods of Maine. A blanket of snow covers the ice on a pond while more snow flutters down. Wait—there's a mound in the middle of the pond—it must be a beaver lodge.

Beavers (*Castor canadensis*) spend all winter without breathing the air *outside* their lodges since they have underwater front doors! They fill their time swimming under the ice and lounging in their air-filled lodges. In the still winter air, you noiselessly walk up to the mound over freshly fallen snow and hear the sounds of beavers gnawing on bark from their winter stash of branches that they have stored and retrieved from the mud at the bottom of the pond.

2-17

This beaver pond will freeze over in the winter to create a shield of ice for wintering beavers.

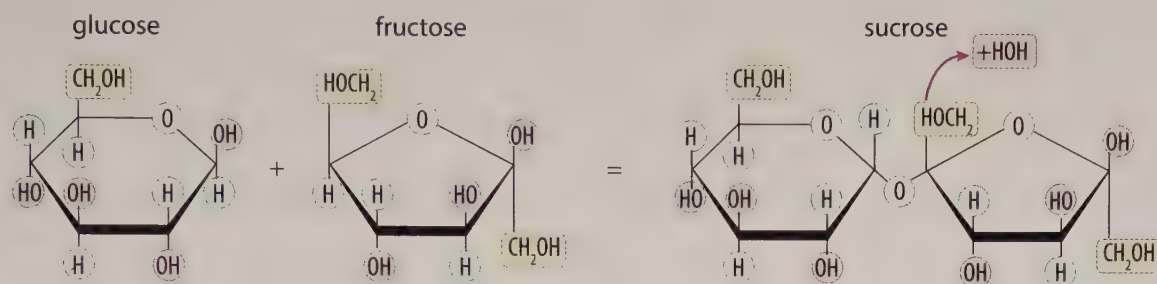
On the perimeter of the pond you have a rare sighting of a lynx! You realize with relief that this predator can't get to the beavers, who are protected by a shield of ice that protects their lodge and the pond.

Why does ice float like this? If water behaved like most liquids, the ice would be denser, making it sink to the bottom of the pond. The hydrogen bonds in water make ice less dense than water, causing it to float. Because of the structure of the bonds in water, it takes a long time for water to undergo temperature change. It will take many warm days to thaw the beaver's winter shield because so much energy is required for water to change its state. As a result, beavers enjoy a nice time under the ice!



CARBOHYDRATES

Carbohydrates are organic compounds made of carbons, hydrogens, and oxygens. These molecules are the most abundant biological compound, making up a huge part of our diet, and are the fuel of plants. The exoskeletons of all the insects, crabs, and scorpions on this planet contribute even more to the presence of carbohydrates in living things. Simple carbohydrates are called **sugars**. Glucose is one of the most important sugars for living things, containing six carbons as you saw in Subsection 2.6. People and animals also use other sugars. You're probably most familiar with sucrose, commonly known as table sugar.



Not all carbohydrates are as simple as glucose and sucrose, and maybe you think those look scary! Carbohydrates can form long chains or *polymers* of six-carbon sugars that coil into a spring shape. Corn starch used for cooking and cellulose in plants are two examples of long, complex carbohydrates.

2-20

Compare the structures of glucose, fructose, and sucrose. Many foods we eat contain all three of these sugars.

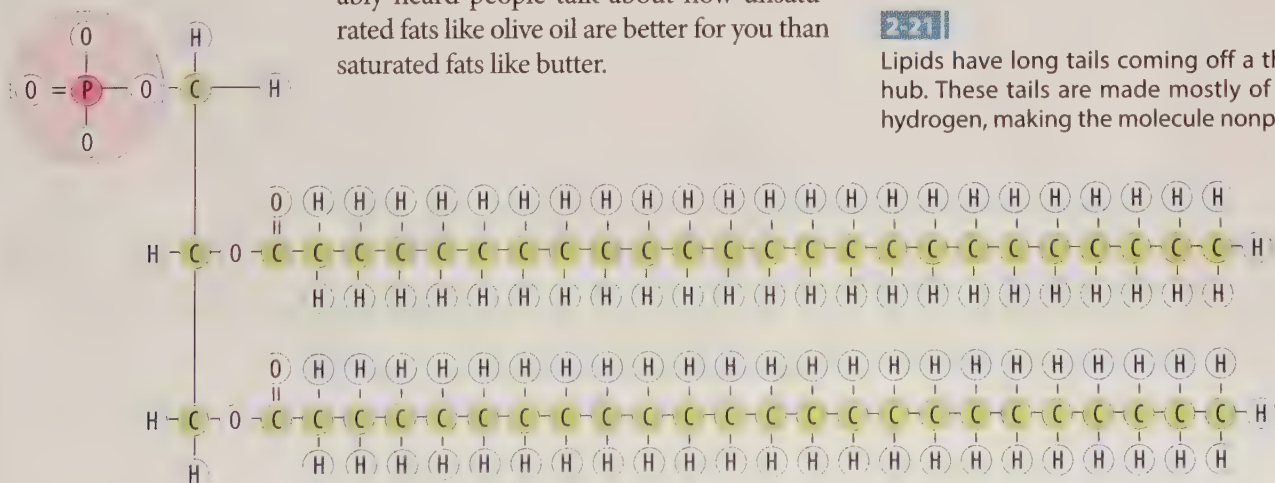
LIPIDS

Although water mixes with many different substances, it doesn't mix with lipids. This is so because **lipids** are nonpolar molecules. They have three long chains that come off a three-carbon base and are made mostly of carbon and hydrogen. It is this characteristic that makes them insoluble in water.

Lipids are incredibly important to biology because living things often use them to store energy. Lipids include substances like fats and oils. When lipids contain a double or triple bond between the carbons in their long chains, they don't have the maximum number of hydrogens, making them *unsaturated* fats. *Saturated* fats have only single bonds. You've probably heard people talk about how unsaturated fats like olive oil are better for you than saturated fats like butter.

2-21

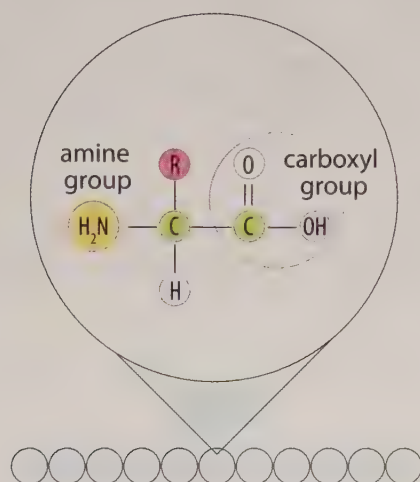
Lipids have long tails coming off a three-carbon hub. These tails are made mostly of carbon and hydrogen, making the molecule nonpolar.



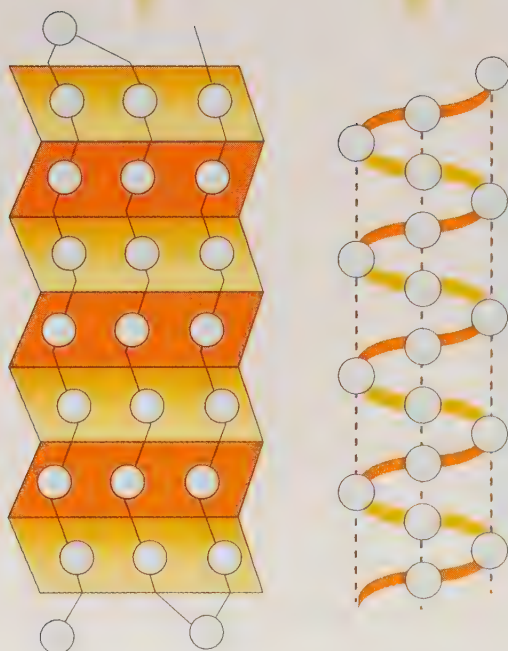
2-22

Three of the four branches off the central carbon in an amino acid are identical for every amino acid. It is the R group (which stands for a generic carbon chain) that makes each amino acid unique.

Amino acids form a helix or pleated sheet that is part of a longer chain. These chains fold together into a protein structure.



OR



PROTEINS

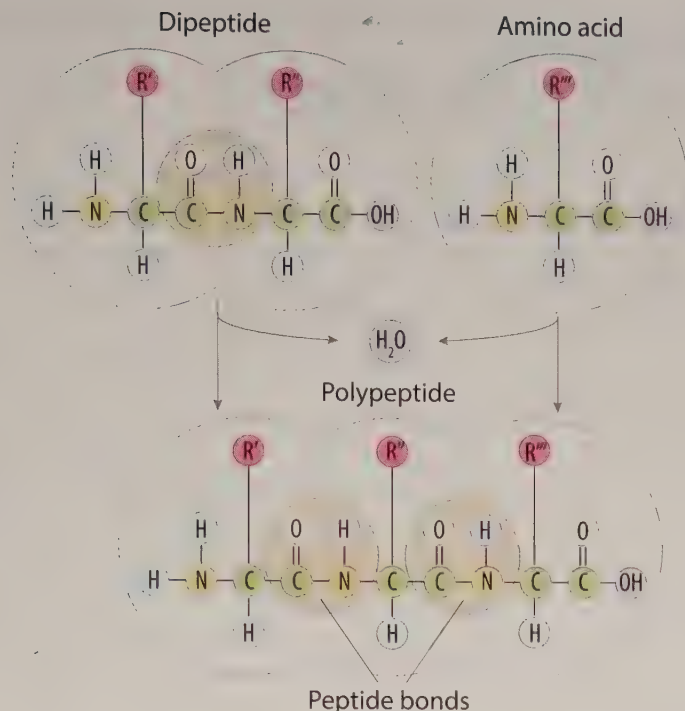
Proteins are some of the most important substances in living things. Our muscles, hair, blood and skin rely on protein chemistry. But proteins are actually polymers of smaller organic compounds. These organic compounds, called amino acids, are much simpler than lipids, and are even simpler than many carbohydrates. **Amino acids** are molecules that have a central carbon bonded to four groups—an amine group (NH_2), a carboxylic acid group (COOH), a hydrogen, and an R group. The hydrogen in the carboxylic acid group makes them acids. The R group on the central carbon represents a slot that can be filled by atoms or groups of atoms. This empty slot makes amino acids different from each other. You might have heard of some of them, like tryptophan in turkey meat—the chemical that is often unfairly blamed for making you sleepy after a large Thanksgiving dinner!

The amine group end of an amino acid reacts with the carboxylic acid group of another to release water. A protein is a polymer of amino acids linked together this way. Proteins can form spirals or helices held in place by hydrogen bonds, or they can form sheets that look like folded pieces of paper. These structures can combine to form larger and larger structures until we get a customized protein that can function in its own unique way, like the hemoglobin protein that carries oxygen in our blood.

NUCLEOTIDES

Another molecule that is a key molecular building block of life is a nucleotide. **Nucleotides** are made of three parts: a base that has nitrogen in it, a sugar, and a phosphate group (PO_4). Figure 2-24 on the next page shows the relationship between these different parts. Maybe you noticed the word “base” in the description. The base part of a nucleotide can accept hydrogen just like a hydroxide ion can.



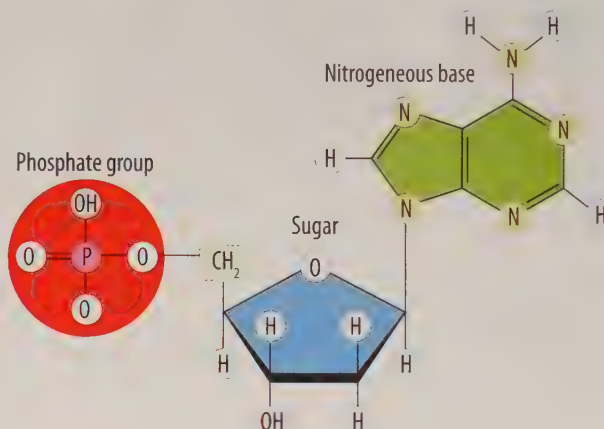


2-23

Polypeptides form when amino acids combine to release water through the formation of a peptide bond.

2-24

Nucleotides have three parts: a base including nitrogen, a sugar, and a phosphate group.



Nucleotides hook together as polymers to form nucleic acids. In Chapter 6 we'll discuss how they form a double strand that is held in a coil by hydrogen bonds, the signature structure for DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). DNA and RNA contain instructions for living things to make proteins. Because proteins are so essential to biological processes, nucleic acids are like the "blueprints" that make each ant, each butterfly, and each person unique. You will learn more about how this happens when we zoom in on the cell in Unit 2.

REVIEW QUESTIONS

1. Do you think that similarities found in life, like the fact that all life forms we know about need water, prove that evolution happened? Why or why not?
2. Why is water so important to life? Include examples in your answer.
3. What is the difference between an organic compound and other kinds of compounds?
4. Define an organic compound in your own words.
5. Give one example of a carbohydrate, protein, and lipid not mentioned in your textbook.
6. After contrasting glucose and sucrose in figure 2-20, what do you notice?
7. What do carbohydrates, proteins, and nucleic acids have in common?
8. What makes carbohydrates, proteins, and nucleic acids different?
9. What goes through your mind when you consider how God's design of nucleic acids makes you unique in a world full of living things?

REVIEW QUESTIONS

Key Terms

matter
 atom
 element
 energy
 temperature
 entropy
 physical change
 chemical change
 bond
 compound
 molecule
 dissolving
 acid
 base
 diffusion
 reactant
 product
 catalyst
 enzyme
 inhibitor
 polar
 cohesion
 adhesion
 organic compound
 carbohydrate
 sugar
 lipid
 amino acid
 nucleotide

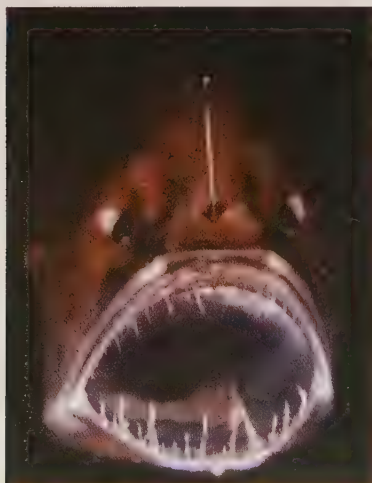
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CONCEPT REVIEW

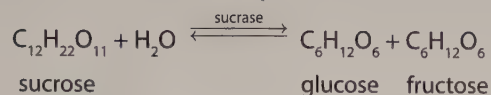
1. What is chemistry?
2. What makes up each of the following substances?
 - a. elements
 - b. covalent compounds
 - c. ionic compounds
3. Write a brief paragraph that describes the relationship between matter, energy, and life.
4. What do we call the tendency of energy to spread out?
5. List the five types of energy mentioned in the text.
6. Identify the primary kind of energy released in each of the examples below.
 - a. a migrating butterfly
 - b. a chirping cricket
 - c. an anglerfish (*Castor canadensis*) glowing in the ocean depths (see Figure 2-25 below)
 - d. an emperor penguin (*Aptenodytes forsteri*) spitting up crop milk to feed its baby
 - e. a mother kangaroo warming the joey in her pouch
7. Give an example of a physical or chemical change not given in your textbook.
8. What is one of the basic laws about the amount of matter and energy in the universe? State this law in your own words.
9. Create a T-chart that compares ionic and covalent compounds. Include the kinds of elements that make up these compounds, the smallest parts of these compounds, and what makes up the bonds in these compounds.
10. Your stomach contains hydrochloric acid (HCl). As an acid, what properties does it have?
11. What is the difference between a solution and other mixtures?
12. What do we call the tendency of matter to spread out? What makes this happen?
13. Ocean water has sodium chloride (NaCl), potassium chloride (KCl), calcium chloride (CaCl_2), and magnesium sulfate (MgSO_4) salts in it. Identify the solvent(s) and solute(s) in ocean water.

2-25

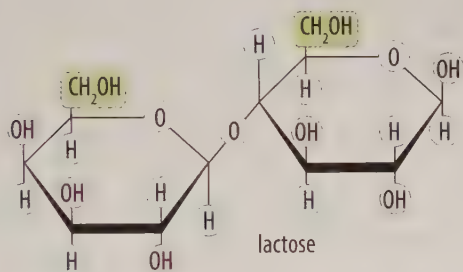
Some angler fish live in the benthic zone, near the ocean floor. Imagine meeting this guy down deep!



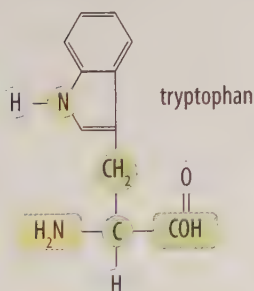
Use the following chemical equation to answer Questions 14–17.



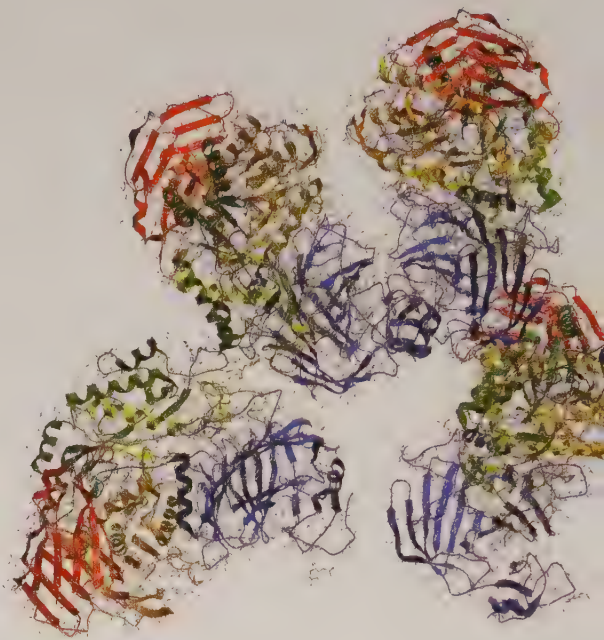
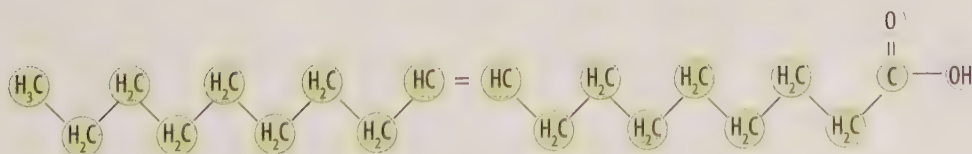
14. Name the reactants and products in the equation.
15. Notice the chemical over the arrow—sucrase. This chemical helps sucrose break down into glucose and fructose, a process that takes a long time otherwise. What kind of chemical compound is sucrase? What does it do to the activation energy?
16. The chemical L-arabinose blocks the work of sucrase. It is used in flavorings and artificial sweeteners to prevent the digestion of sugar in an effort to help people lose weight. What kind of chemical compound is L-arabinose?
17. Scientists had to work to create L-arabinose and discover uses for it. How does this scientific work fulfill God's commands?
18. What property of water makes it so good at dissolving substances? What else does this property help water do?
19. Why are organic compounds so named?
20. Describe the number and types of bonds that carbon forms.
21. Identify each of the following chemical structures as a sugar, lipid, amino acid, protein, or nucleotide
 - a. lactose in milk



- b. tryptophan in turkey meat



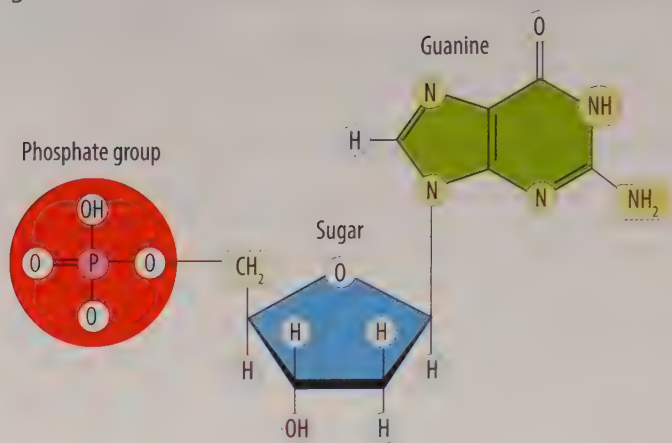
- c. olive oil



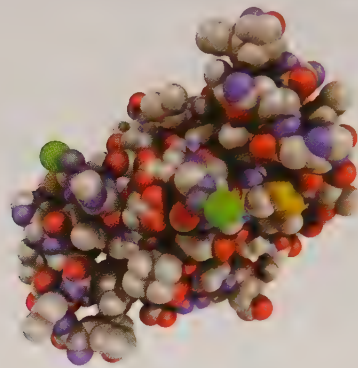
2-26

Sucrase, a chemical that helps sucrose break into glucose and fructose

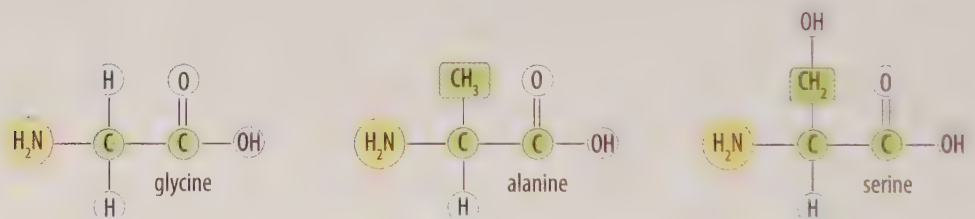
d. guanine in DNA



e. insulin in the human body (see figure 2-22)



22. Link the following three amino acids into a chain, or peptide, using peptide bonds. (*Hint:* See Figure 2-23 on page 39.)



TRUE OR FALSE

23. Only living things are made of matter.
24. It is possible for living things to add new energy to the universe, such as when plants make energy.
25. Chemical changes can often be reversed by more chemical changes.
26. Salts are covalent compounds.
27. Sand floating around in seawater is an example of a solution.
28. Chemical reactions in living things usually happen without any help.
29. Water has properties important to life that many other liquids lack.
30. Organic compounds are made of only carbon atoms.

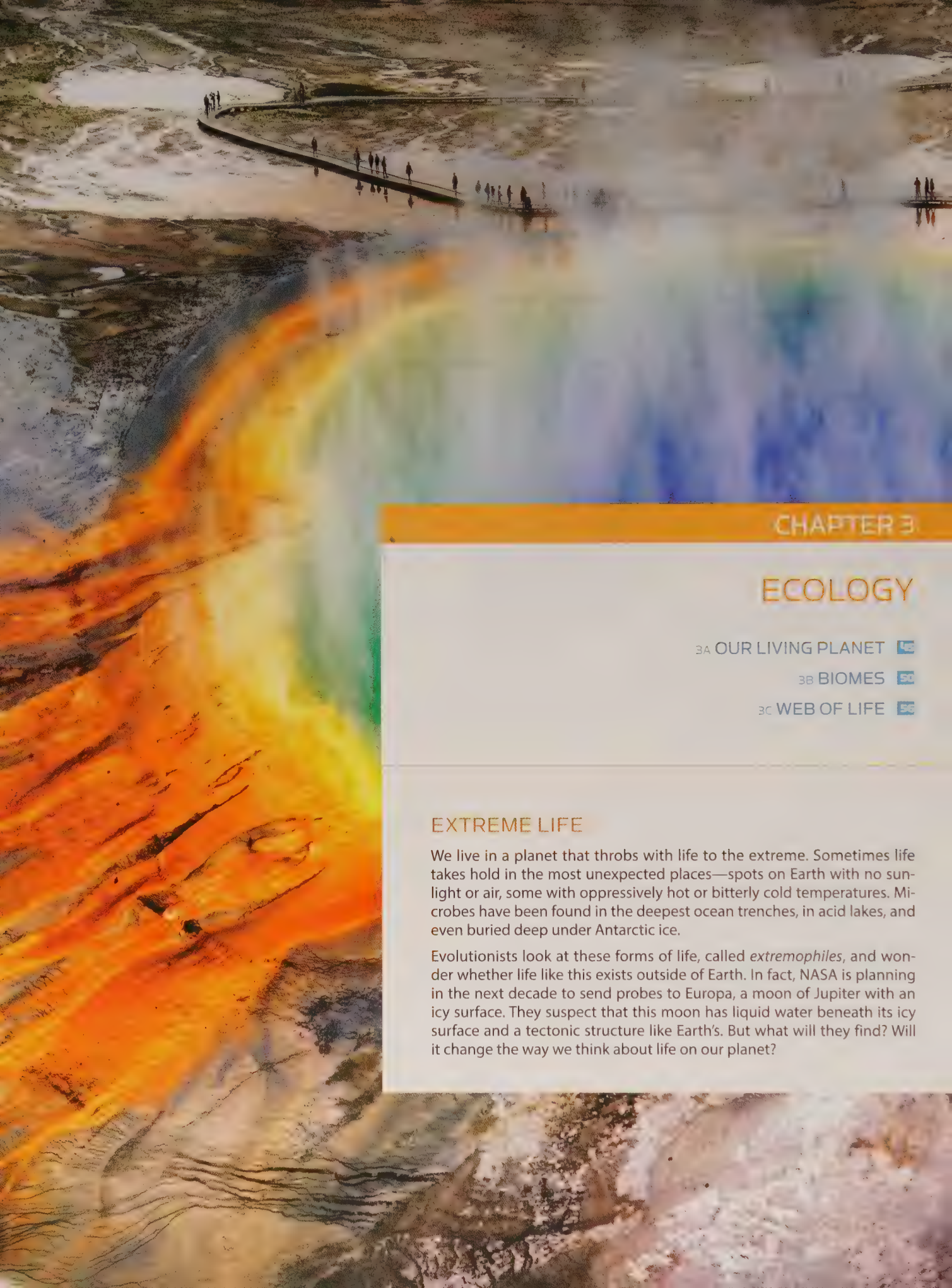
CRITICAL THINKING

31. How are matter and energy related?
32. You are witnessing a salt crystal dissolving on the molecular level. Write a paragraph describing what you see as the crystal dissolves in water.
33. Study the examples of exothermic and endothermic reactions on page 31. What do you notice? What can you conclude about chemical reactions from these examples?
34. Why do you think living things need water?

Use the table below, which shows some properties of different chemicals, to answer Questions 35–38.

Chemical	Density	Color	Melting point
water (H ₂ O)	1.0 g/mL	clear	0 °C
salt water	1.02 g/mL	clear	0 °C
ice	0.9 g/mL	clear	0 °C
salt (NaCl)	1.6 g/mL	white	801 °C
sodium (Na)	0.9 g/mL	silver	97.7 °C
chlorine (Cl ₂)	0.003 g/mL	light green	–10.5 °C

35. Dissolving salt in water is a physical change. How can you prove this from the data in the table?
36. Melting ice to form liquid water is a physical change. How can you prove this from the data in the table?
37. Forming sodium chloride from sodium and chlorine is a chemical change. How can you prove this from the data in the table?
38. If dissolving salt into water to form salt water is a physical change, why is there such a great difference between the data for salt and that of salt water?
39. Do some research on a poison that could be used as medicine, such as yellow scorpion venom (*Leiurus quinquestriatus*), which has the potential to fight cancer. What process must researchers follow to ensure that this drug isn't causing more harm than good?
40. Do some research on the Hippocratic Oath, a promise that doctors often make to commit to using their knowledge and skill in medicine for helpful purposes, not harmful ones. Read this oath and evaluate it from a Christian worldview.
41. Choose a career involving chemistry that interests you. Look online for information to write a one-paragraph summary about that career.



CHAPTER 3

ECOLOGY

3A OUR LIVING PLANET 

3B BIOMES 

3C WEB OF LIFE 

EXTREME LIFE

We live in a planet that throbs with life to the extreme. Sometimes life takes hold in the most unexpected places—spots on Earth with no sunlight or air, some with oppressively hot or bitterly cold temperatures. Microbes have been found in the deepest ocean trenches, in acid lakes, and even buried deep under Antarctic ice.

Evolutionists look at these forms of life, called *extremophiles*, and wonder whether life like this exists outside of Earth. In fact, NASA is planning in the next decade to send probes to Europa, a moon of Jupiter with an icy surface. They suspect that this moon has liquid water beneath its icy surface and a tectonic structure like Earth's. But what will they find? Will it change the way we think about life on our planet?

OUR LIVING PLANET

What makes Earth a good place for life?

3.1 THE BIOSPHERE

The search for life originating outside our living planet on places like the moon, Mars, and Europa is called *astrobiology*. It is a hot, new field that is the moving force in NASA's space program. The problem for astrobiologists is that they haven't found life that comes from anyplace other than Earth despite spending millions of dollars developing the finest technology. None at all! So why look for life in space when there is so much around us?

Scientists are looking to extend their beliefs about life on Earth to space. If life and everything in the universe is a product of chance and a big bang, why wouldn't we see life elsewhere in the universe? In their view of biology, evolution is life's designer. The late Carl Sagan (former professor and astronomer at Cornell University) once said, "The universe is a pretty big place. If it's just us, seems like an awful waste of space." Life should be easy to find wherever we look, but that's not what we observe.

God designed life, and He made Earth for life. We see this in the wording and unfolding of the Creation account. The heavens, the earth, the waters, and the stars, sun, and moon are all mentioned in direct connection to the living things that God created. The stars are mentioned almost as an afterthought because life on this planet is the centerpiece of God's creation, though all of creation declares His glory (Ps. 19:1; Rom. 11:36). Earth is the shelter, the haven, the home for God's precious, living creation in the hostile environment of space. When we look around our living planet, we can see evidence of a God who cares and who provides for the living things He loves. The realm of life on Earth, called the **biosphere**, extends from a few kilometers into the atmosphere to a few kilometers into the earth's crust. This thin shell around us is the only place that we know of where life can occur.

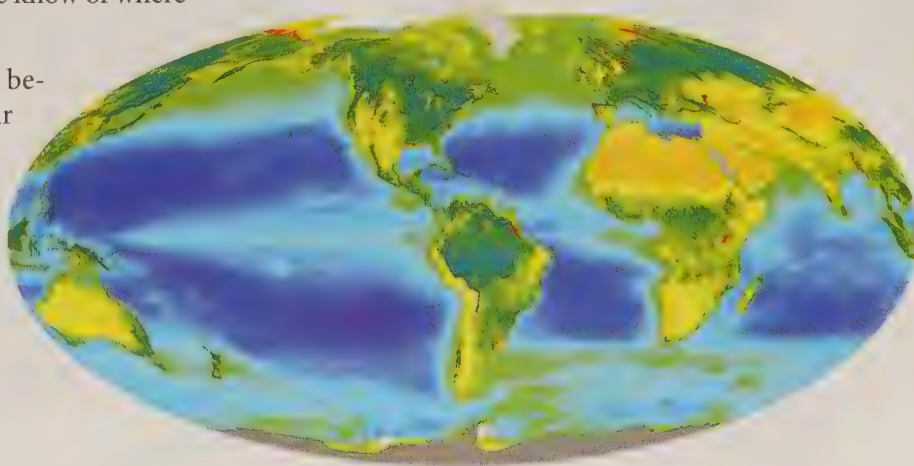
Ecology is the study of interrelationships between organisms and their relation to their physical surroundings. Organisms both affect their environment and are affected by it. Organisms also affect each other. Ecologists explore these relationships as they try to understand the interactions of life and environment. We can use this understanding in ways that help us wisely care for God's good Earth.

3A Questions

- » How do ecologists categorize the living and nonliving parts of Earth?
- » How are living things affected by their environment?

3.1

This map gives you a sense of the areas of the world where life is concentrated. Notice the regions (shown in green) that have an abundance of plants.





3-2

American bison in Yellowstone National Park have a major impact on other living things and on the environment itself. They are considered a keystone species in their environment, an organism that has a huge impact despite being small in number compared to other populations.

Ecology keeps the big picture in mind, rather than focusing on any one type of plant or animal. For example, in the 1800s, American bison (*Bison bison*) were hunted to the brink of extinction. Today, herds of bison enjoy protection in state and national parks. Since these herds have grown, ecologists have noticed that the mixed-grass prairies they inhabit enjoy many benefits. Bison graze only on grasses, increasing the possibility of other plants to mix with the grasses, thus providing a healthy balance of nutrients and species. Bison also return nutrients to the soil and shape their environment in ways that benefit prairie dog colonies. These prairie dogs provide food for ferrets, foxes, hawks, and eagles. Abandoned prairie dog homes provide an environment for snakes, lizards, and toads. So you see that one type of animal can make a big difference in the well-being of many different living things. An area supporting a wide variety of organisms indicates that this corner of the biosphere is ecologically healthy. Ecologists use the term **biodiversity** to refer to the number of species (*species richness*) in an area. Biodiversity also considers the *species evenness*, or the proportionality of the populations of species, relative to each other. This variety is related to biological information present in the cells of living things—genetic variety gives an area of the biosphere a kind of built-in flexibility to deal with changes in the environment such as pests and disease.

3.2 HOME FOR LIFE

3-3

Notice the relationship between biomes, ecosystems, communities, and individual organisms.

When you come home after a busy day out, what makes it feel like home to you? Your family is there. A refrigerator filled with food you like is there. Your bed is there, along with your pets, video games, comfy chair, and all the things that you need. Your home is probably in a neighborhood, which is in a city, which is in a state, which is in a country, which is on a continent. Your address has some of this information in it.



Other living things also have homes that house family members, food, and the things they need to thrive. Ecologists give their homes something similar to an address, dividing the biosphere up into large areas that have a fairly consistent environment and are home to a set of organisms suited to it. These areas are called **biomes**. Biomes can cover large portions of the earth's surface, perhaps up to a continent. For example, tundra is found on land close to the Arctic Circle. Most of the earth's tundra is in the Northern Hemisphere since there is very little land close to the Antarctic Circle (in the Southern Hemisphere) that will support the tundra biome. You'll learn more about the biomes of the world in the next section.

Within a biome, ecologists investigate **ecosystems**, a limited area smaller than a biome in which living and nonliving things interact. For example, the Atlantic puffin (*Fratercula arctica*) likes to hang out on rocky cliffs near the Atlantic Ocean. It likes islands, and Iceland is its favorite place—about 60% of all Atlantic puffins live there. The rocky cliffs are the ideal place, since they are inaccessible to predators, close to the puffin's food supply, and are easy places to take off and land. The rocky shores of Iceland are an example of a **habitat**, or a smaller part of an ecosystem that an organism prefers. Puffins prefer the coasts of islands to the inland. They dig burrows under the grasses of these cliffs to line with feathers, twigs, and grasses. The way that puffins live in their habitat is their ecological **niche**. Their niche includes their indirect effect on the habitat, including the erosion of cliffs due to their burrows. Their niche also involves the direct changes the puffins make to their habitat, such as the local populations of fish they eat and eels they feed their chicks. You might say that the puffin's habitat is *where* it lives, and the puffin's niche is *how* it lives.

So why do so many puffins make Iceland their home? A variety of factors make it an ideal location for them. Some aspects of their ecosystem—the water, the wind, the rocky cliffs, the cooler temperatures—are elements of the physical environment. These nonliving aspects of an ecosystem are called **abiotic** factors. Other factors—the fish they eat, other puffins, and the seals, foxes, and gulls which prey on them—are living parts of their ecosystem, or **biotic** factors. This would include parasites, like the fleas and ticks that sometimes plague puffins. The living things that inhabit the same ecosystem are called a **community**, similar to the neighborhood that you live in.

Puffins spend most of the time during the year bobbing around on the ocean. But they're not loners. They nest in colonies and often lay eggs all at the same time, and the number of breeding couples in a colony changes every year. They rely on each other to defend the colony from predators. The more the merrier! This is an example of a **population**, a group of organisms of the same species interacting in the same area. Ecologists monitor the populations of animals living in an ecosystem to learn more about the ecosystem and the relationship between biotic and abiotic factors in that environment.



Rocky cliffs on the Atlantic Ocean are the habitat for the Atlantic puffin. These birds make their burrows on rocky cliffs near the ocean so that they can easily take off to hunt for fish during the breeding season. Every year they return to the colony where they were born. Name the biotic and abiotic factors in this photo.



habitat: (L. habitare—to dwell)

niche: (Fr. niche—recess in a wall, or nest)

MOONBIRD

The red knot (*Calidris canutus*), a coastal bird that prefers to live in gigantic flocks, makes an epic migration twice a year across several continents. It travels about 9000 miles one-way, one of the longest migrations in the bird world. One bird, with the unassuming name of B95, is a 20-year-old male who has lived so long and made the trip so many times that he has covered a distance equivalent to flying to the moon and halfway back. Conservationists have named him Moonbird. B95 is more than just a bit of traveling trivia. Tracking his annual migrations has helped scientists learn more about the life expectancy of red knots.

Moonbird travels from his winter home in Argentina and Chile to his breeding grounds in the Canadian Arctic. A migration this long requires an immense amount of energy. When migrating, Moonbird shuts down part of his digestive system to conserve energy and eats food that is easier to digest. When he gets to Delaware Bay off the coast of New Jersey, Moonbird encounters hosts of horseshoe crab eggs laid during their breeding season. He times his migration to meet up with this easy food source, the perfect fuel for the final leg of his migration marathon.



3-5

Red knots traveling from South America to Canada time their trip to correspond with the season that horseshoe crabs lay their eggs.

CASE STUDY: THE GREAT BARRIER REEF

Off the coast of Australia lies the Great Barrier Reef, the largest coral reef in the world. Corals are alive, and they attract other living creatures such as sea turtles, clown fish, sea anemones, and crown-of-thorns starfishes. Striped surgeonfish (*Acanthurus lineatus*) tend to stay near the reef because they have slender, elongated bodies that can slip between cracks in the reef when pursued by predators such as barracuda. Striped surgeonfish are bottom feeders, scooping algae off the ocean floor. But they feed on photosynthetic organisms, so they live only in shallow areas of the ocean. They are territorial, vigorously defending their grazing grounds from other striped surgeonfish and other algae eaters such as damselfish. Male striped surgeonfish are usually surrounded by a harem of females. The striped surgeonfish is important to its ecosystem because it keeps algae and plankton from taking over the area and returns nutrients to the water to nourish other living things.



3-6

The striped surgeonfish is sometimes called a doctor fish because of the scalpel-sharp venomous spine located near its tail.

Within a population, an ecologist can look at the attributes of the population, such as how many live in a certain area, the ratio of males to females, and so on. This could involve studying individual puffins or puffin couples. (See Figure 3-3 to see how biomes, ecosystems, communities, and individuals relate.) The goal would be to learn about the things individual puffins need, the way they raise their chicks, the way they behave in relation to the colony, and the way individual puffins or groups of puffins interact within the colony. This is an example of how ecologists study individual organisms to learn more about populations, communities, and ecosystems to better care for the place we all call home.

3A REVIEW QUESTIONS

1. Why do you think NASA is thinking of sending a probe to Europa to search for life rather than to the moon or Mars, both neighbors of Earth?
2. Respond to Carl Sagan's quote below in light of Psalm 19:1.
"The universe is a pretty big place. If it's just us, seems like an awful waste of space."
3. What part(s) of Earth would the biosphere *exclude*?
4. The textbook gives the example of your address as an illustration of the relationship between the biosphere, biome, ecosystem, community, population, and individual. Use the analogy of a computer connected to the Internet to explain the relationship of these terms, where a letter key on the keyboard represents an individual organism and the Internet represents the biosphere.

Use the case study on the Great Barrier Reef on the facing page to answer Questions 5–12.

5. What is the striped surgeonfish's ecosystem?
6. List three abiotic factors in its ecosystem.
7. Name three members of its community.
8. What is the relationship between biotic factors in the striped surgeonfish's ecosystem and its community?
9. What is the striped surgeonfish's habitat?
10. What is its niche?
11. What makes the Great Barrier Reef a good place for the striped surgeonfish?
12. Do you think we could find this fish in other places? Why or why not?

BIOMES

3B Questions

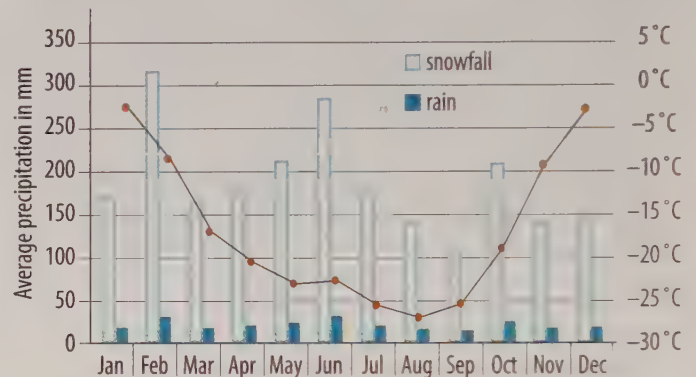
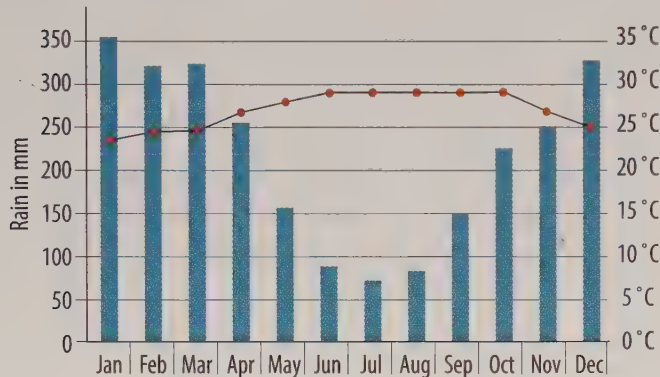
- » What kinds of biomes are there?
- » How do mountains and oceans compare to other biomes?

Why do certain organisms live in certain places?

CLIMATE

3-7

Two climates, two sets of temperature and precipitation data. Notice the axes labels on the bottom, left, and right of the graphs. The bars show precipitation data, and the lines on top of the graph show temperature data.



3-8

Where do you think weather is warm year-round? cold year-round?

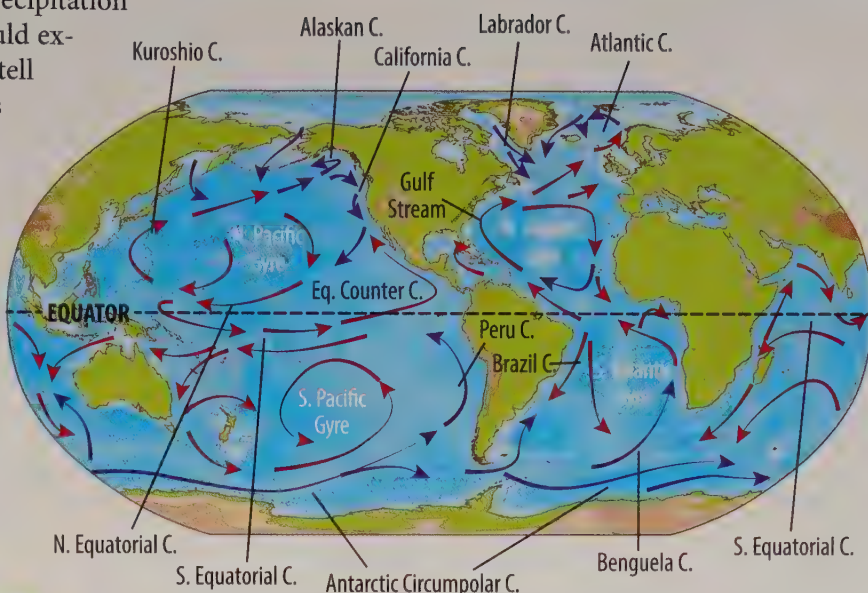


Weather tells you what the earth's atmosphere is like right now, but *climate* is the average weather of an area over an extended period of time. Figuring out both today's weather and an area's climate relies on temperature data and precipitation (rain, snow, sleet, hail, or freezing rain) data. A meteorologist (who studies weather) can tell you whether you need a raincoat for the day; a climatologist can tell you what kind of wardrobe you need!

Though an area's climate is defined by its temperature changes and precipitation over an extended period of time, there are other factors that affect climate.

- **Seasons.** The seasons are a direct result of the earth's tilt. Changing seasons bring changes in temperature and precipitation.
- **Latitude.** The latitude of an area affects how extreme the changes associated with seasons can be. For example, some areas have monsoons associated with changing seasons. In general, warm areas are closer to the Equator and cold areas are closer to one of the poles.
- **Elevation.** An area's elevation can have the same effect on climate as latitude, affecting the swings of temperature and precipitation.
- **Bodies of Water.** The presence of large bodies of water affects an area's climate because water changes temperature slowly, moderating how fast air temperatures can change. Warm ocean currents can make areas that we might expect to be cooler stay warmer during different seasons.

Climatologists think of the earth's surface as a system of zones that are based on the temperature and precipitation data of that region. In many cases, you could examine the plants that live in an area and tell something about the average temperatures and precipitation in that area over a long period of time. Figure 3-10 (below) shows the five different climate zones of the world: polar, temperate continental, temperate marine, tropical, and dry. Each climate zone has a different combination of high, medium, or low temperatures and precipitation. Many of these zones have mountains, forests, or bodies of water that create subzones. Also notice that areas of the world that are far apart can have similar climates.

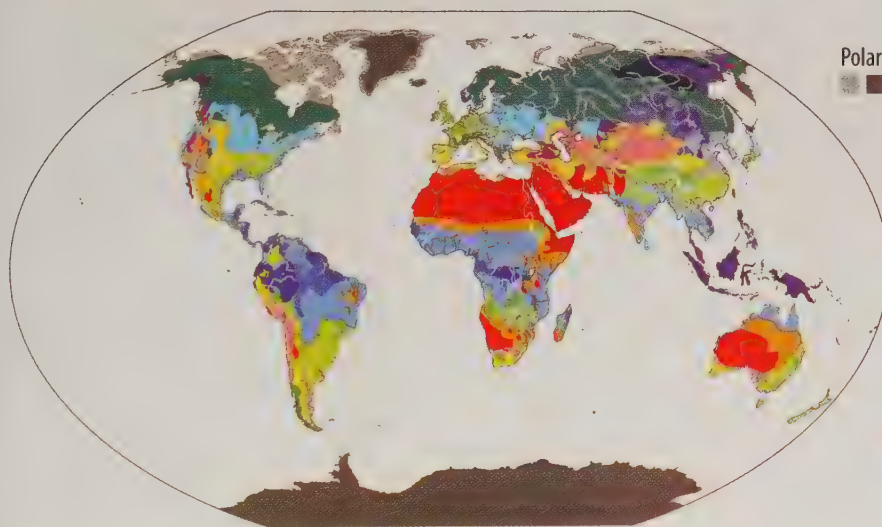


3.4 BIOMES OF THE WORLD

Climate zones don't change suddenly as you move from one zone into another. One zone gradually merges into another, with temperatures and precipitation gradually changing. In fact, some living things flourish in places where there is a transition from one kind of climate to another, like the puffins who live on the cliffs along the ocean.

3-9

Shown above are the ocean currents of the world. Blue arrows show cold surface currents; red arrows show warm surface currents. The tan regions are deserts created by these currents, as the currents determine weather. Precipitation is affected by terrain such as mountains, which also create deserts.



Polar Climate

Temperate Continental Climate

Temperate Marine Climate

Tropical Climate

Dry Climate

3-10

Climate zones of the world. Which zone do you live in?

So what effect do climate zones have on life? Climate zones are defined by abiotic factors, but biomes add biotic factors to the mix. Remember that biomes are large areas that have a fairly consistent environment and are home to a set of organisms suited to that environment. Let's take a tour of the major biomes of the world.

You, a Biome

Did you know that *you* are a biome? Your body forms an entire ecosystem for microorganisms called the *human microbiome*. In fact, in your body there are ten times more cells that are *not* human than those that are! But the microbes that live in and on you are not all harmful; most are actually very important to your health.



1 TUNDRA

Caribou (*Rangifer tarandus caribou*)

The tundra has frozen land (called *permafrost*) year-round, with little vegetation except for hardy plants such as mosses, lichens, and wildflowers that take root in the top few inches of soil that thaw in the summer. There are few trees. Precipitation varies from a few inches to several feet of snow. Short summers punctuating long winters allow insects buried in the soil to hatch, providing food for birds. Other animals such as caribou and grizzly bears feed during the summer and migrate elsewhere or hibernate to avoid the harsh winter.

2 DECIDUOUS FOREST

Northern saw whet owl (*Aegolius acadicus*)

Trees, such as oak, birch, ash, and maple, form deciduous forests in temperate zones that receive moderate rainfall and have moderate temperatures. These trees experience changes in all four seasons and support an abundance of wildlife, such as cicadas, songbirds, owls, and raccoons.

3 DESERT

Pink fairy armadillo (*Chlamyphorus truncatus*)

Water is precious in the desert, a biome that gets less than 25 cm of rain a year. Temperatures can change dramatically from scorching daytime temperature to chilly nights, though overall, deserts have high temperatures. Some deserts are cold, occasionally getting snow. Organisms in this biome, such as cactuses, succulents, reptiles, insects, and spiders, survive by conserving water. Most animals, such as rattlesnakes and kangaroo rats, are more active at night.

4 SAVANNA

Giraffe (*Giraffa camelopardalis*)

Savannas are the realm of lions, baobab trees, and wildebeests. These biomes have widely spaced trees that dot a rolling landscape of grasses. This biome has moderate to high temperatures year-round and has moderate but seasonal precipitation. The rainy season brings 100–150 cm of rain, relieving parched plants, animals, and the earth, and reducing the fires that can break out during the dry season.

5 CONIFEROUS FOREST

Pileated woodpecker (*Dryocopus pileatus*)

Evergreen and fragrant, the coniferous forests have two seasons each year, with cooler temperatures and moderate precipitation. These conifers change the soil and block out the light for other plants, making the conifers the kings of the forest. Hemlocks, firs, and redwoods are the sole supporters of the other life here, including elk, wolverines, moose, pileated woodpeckers, and rabbits.

- DESERT
- CHAPARRAL
- CONIFEROUS FOREST
- TUNDRA
- GRASSLANDS/SAVANNA
- TROPICAL RAINFOREST
- DECIDUOUS FOREST
- ICE
- WATER





6 GRASSLANDS

Przewalski's horse (*Equus ferus*)

Rippling fields of grasses give the grassland biome its name. This temperate biome doesn't get enough rainfall to support trees (25–75 cm per year), but moderate rainfall and temperatures do support grasses that are crucial to the many herbivores that live here, such as wild horses, pheasants, and gazelles.

7 CHAPARRAL

Thorny dragon (*Moloch horridus*)

The scrubby chaparral, like the grasslands, receives moderate amounts of precipitation. Cool, wet winters alternate with warm, dry summers. Droughts and fires are common. Chaparral plants typically have tough, waxy leaves to retain moisture and thorns to deter browsers like deer and antelope. Although chaparral covers the least amount of Earth's surface, it has a large number of plant species—an estimated 20% of all plants!

8 TROPICAL RAINFOREST

Raja Brooke's birdwing butterfly (*Trogonoptera brookiana*)

Dripping vegetation, warm, humid air, and an amazing year-round biodiversity categorize the tropical rainforest. Rainfall exceeds 250 cm per year, supporting an abundance of life, such as lemurs, sloths, pythons, geckos, and cacao trees. The forest is so tall that there are layers of growth, beginning with the top, or *emergent layer*, then the *canopy*; these two layers get the most light and rainfall. The *understory* beneath the canopy is home to poison dart frogs and birdwing butterflies. The lowest and shadiest level is the forest floor. (See Figure 3-11, next page.)

3.5 VERTICAL BIOMES

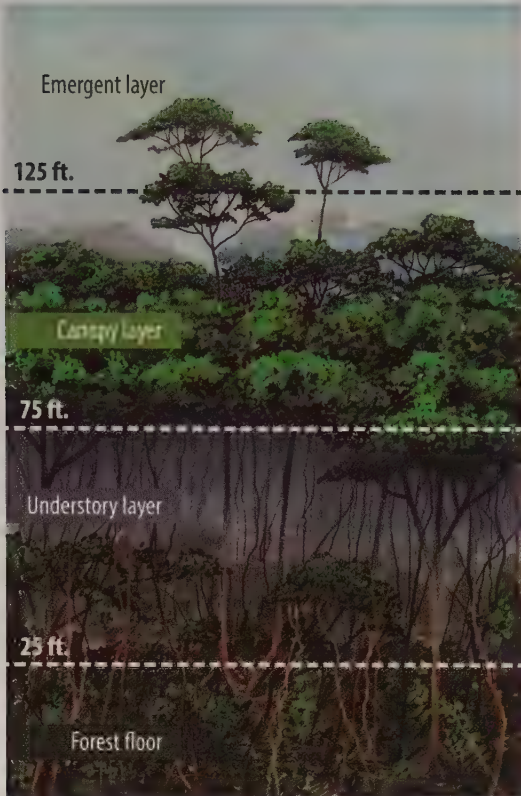
In the tropical rainforest biome description on page 53, you will notice that the types of plants and animals vary from the emergent zone, to the canopy, to the understory, to the forest floor. Vertical layers within a biome form because the temperature and amounts of light and rainfall can change with elevation. Ecologists call this ecological layering in a biome **vertical zonation**.

MOUNTAIN BIOME

Another biome that experiences vertical zonation is the highland or *mountain biome*. For example, Mount Kilimanjaro in Tanzania starts in the African savanna. As hikers travel to its volcanic summit, they pass through a tropical rainforest, grassland, moorland, an alpine desert, and an ice cap. Other mountains typically have a deciduous zone, a coniferous zone, and a tree line beyond which there is insufficient rainfall and temperatures too low for trees. Beyond this *timberline* is an area of ice and snow. Gaining 1000 feet in elevation usually produces about a 6 °C (10 °F) change in temperature, the equivalent of traveling 300 miles toward a pole.

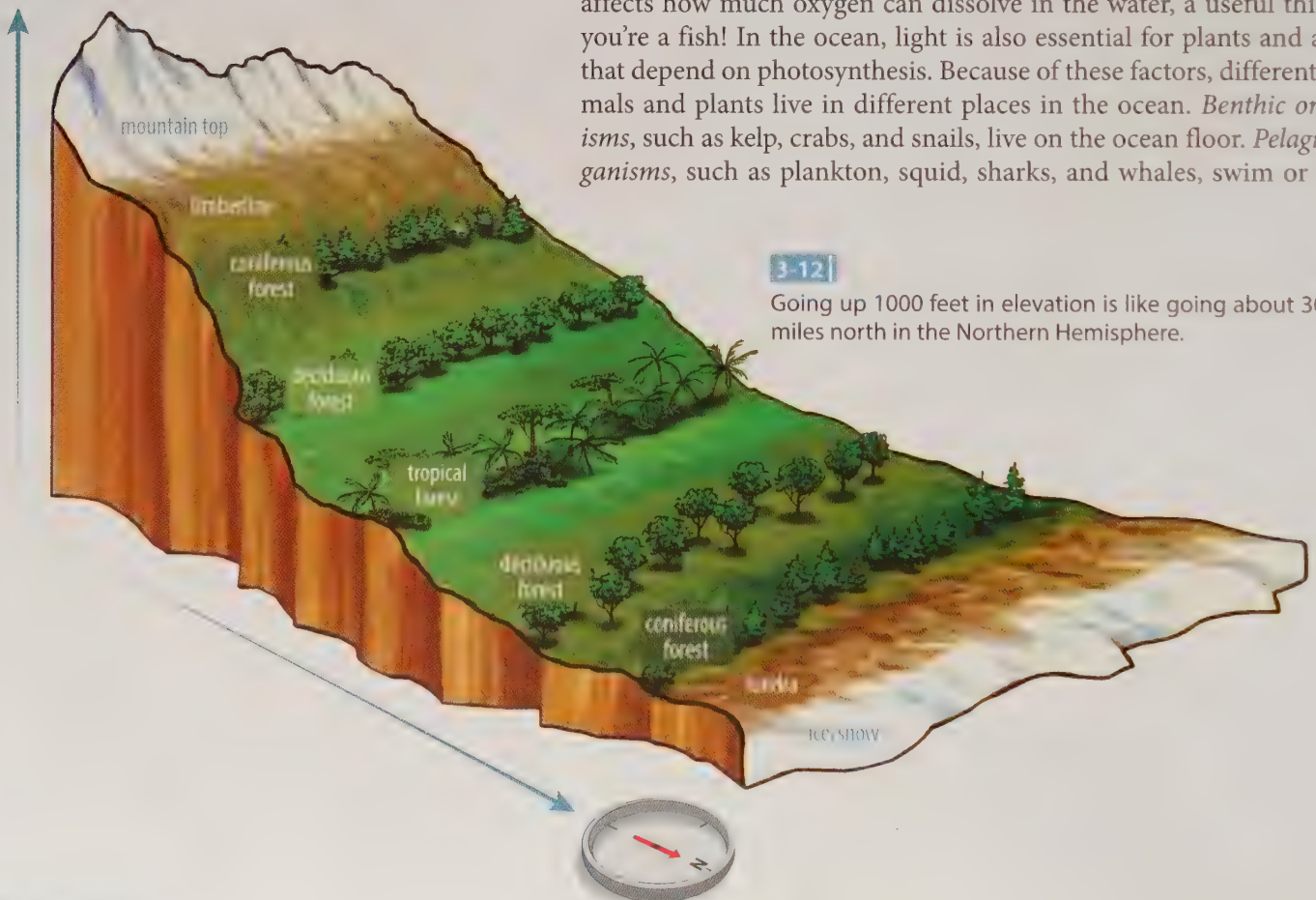
AQUATIC BIOMES

A third biome that experiences vertical zonation is the *aquatic biome*. Oceans cover about 71% of our planet, and life in the oceans depends on light. Water temperature is driven by sunlight; in turn, temperature affects how much oxygen can dissolve in the water, a useful thing if you're a fish! In the ocean, light is also essential for plants and algae that depend on photosynthesis. Because of these factors, different animals and plants live in different places in the ocean. *Benthic organisms*, such as kelp, crabs, and snails, live on the ocean floor. *Pelagic organisms*, such as plankton, squid, sharks, and whales, swim or drift



3-11

The amount of rainfall, temperatures, and types of species change with altitude in the tropical rainforest.



3-12

Going up 1000 feet in elevation is like going about 300 miles north in the Northern Hemisphere.

with the currents. As you can see in Figure 3-13, benthic and pelagic organisms that need light live in the photic zone, the thin upper layer of the world's oceans. Benthic and pelagic organisms that don't need light can live in the aphotic and abyssal zones where there is little or no light. Life looks very strange and alien down there!

When we step back and look at all the different biomes of the world, we can see an amazing tapestry of environments that are home to many different living things. In the quilt of life, the interactions of organisms and ecosystems show a variety and care that point to a caring and creative Designer.

3B REVIEW QUESTIONS

1. What is the difference between a climate zone and a biome?
2. List some abiotic factors that affect a biome.
3. Why do some biomes have very few trees?
4. Copy Table 3-1 on a separate sheet of paper and fill it in. Label temperature and precipitation as low, moderate, or high for each biome. Compare Figure 3-10 with pages 52–53 to relate the climate zones with the biomes.

Table 3-1

Biomes of the World

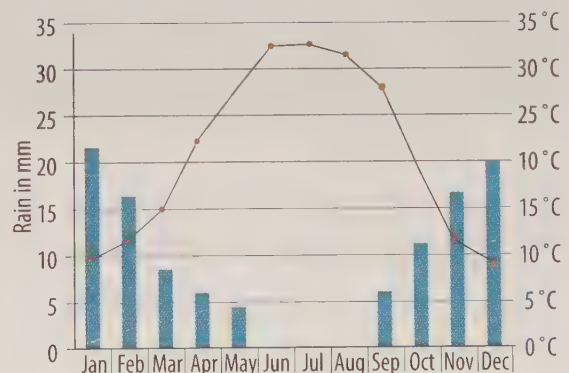
Biome	Temperature	Precipitation	Climate zone	Examples of animal life
tundra				
deciduous forest				
desert				
savanna				
coniferous forest				
grassland				
chaparral				
tropical rainforest				

5. List the biomes that Moonbird passes through during his migration from Argentina to the Canadian Arctic.
6. Which biome would the climate graph to the right match? Give three examples of things that could live in this biome.
7. Why do vertical zones form in an ecosystem?
8. How do naturalists explain order, design, and function in the biosphere? How should a Christian respond to this order?



3-13

Light drives the zones of life in the oceans.



3C Questions

- » Where do living things get energy?
- » How are living things influenced by each other?

WEB OF LIFE

How do living things interact?

3.6 PRODUCERS AND CONSUMERS

When pioneering climatologist Wladimir Köppen began thinking about climate zones and biomes around the world in 1884, he looked at one thing: plants. Plants give us a lot of information about the abiotic factors in an environment, and they also form the base of support for a whole network of life.

A plant is an example of an organism that can make its own food through photosynthesis. (We'll study how it does this in Chapter 7.) Plants and algae are the most common food manufacturers, called **producers** (or **autotrophs**) by biologists.

Almost all other organisms get their energy from the energy that plants capture from the sun. Since these other organisms can't produce their own food but instead consume the producers, they are called **consumers** (or **heterotrophs**). There is a flow of energy in an ecosystem that involves different types and sources of energy.

Let's take an African safari. In the African savanna, the grasses and trees are the producers, forming the foundation of the biotic community in this ecosystem. Giraffes graze from acacia and mimosa trees and sometimes grasses. They are **herbivores**—animals that get their food from plants. Lions and cheetahs also lurk in the grasses of the savanna, preying on mongooses, wildebeests, gazelles, and even giraffes. They are **carnivores**—animals that get their food from other animals. Leopards join the pack of **predators** on the African savanna, hunting guinea fowl and impalas at night and dragging their prey up into a tree to consume later. Impalas, guinea fowl, and even monkeys are the leopard's **prey**. And hyenas and vultures clean up everyone's meaty leftovers, making them **scavengers**. Carnivores are either predators or scavengers; often they are both. If there is a limited supply of meat in an ecosystem, then the populations of carnivores may experience intense **competition**, when organisms try to use the same resource. This can also happen during the dry season as water holes in the savanna begin to shrink.

Side-striped jackals also roam the African savanna, feeding on insects and springhares during the dry season and eating fruits like acacia pods in the wet season. These jackals are **omnivores**—animals that eat both other animals and plants. The African savanna is home to aardvarks, which eat an occasional cucumber that grows underground. They also like to invade termite mounds (see an example in Figure 3-14) and lap up the inhabitants with their long tongues.

autotroph: auto- (L. *auto*—self) + -troph (Gk. *troph*—nourishing)

heterotroph: hetero- (Gk. *hetero*—other) + -troph



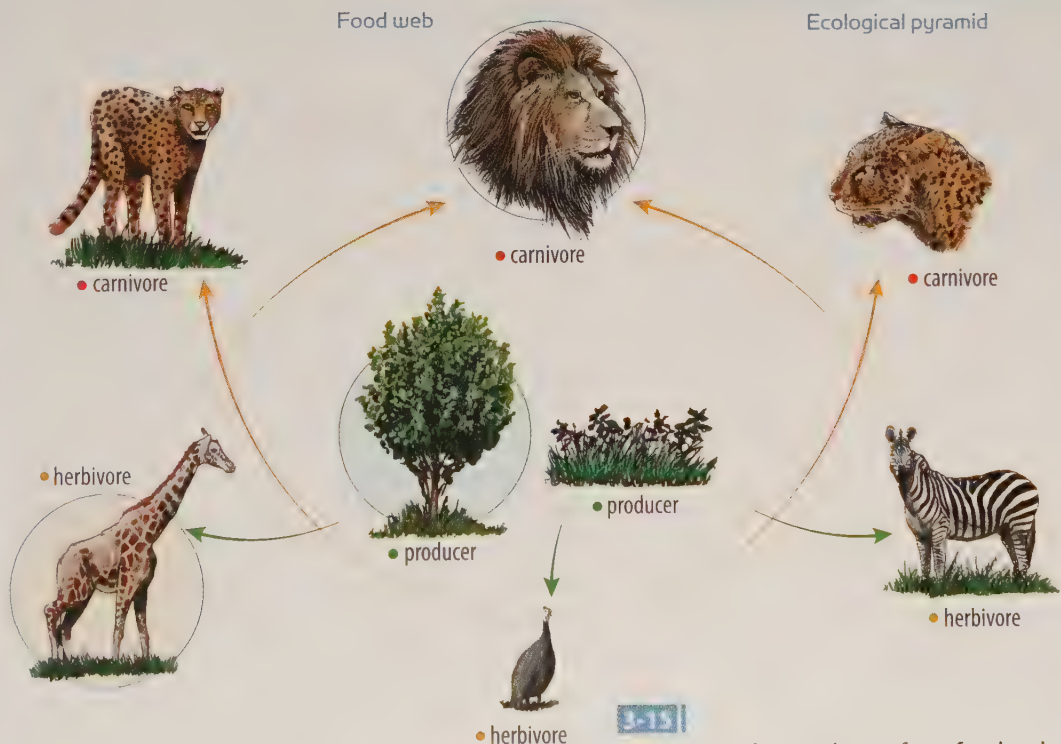
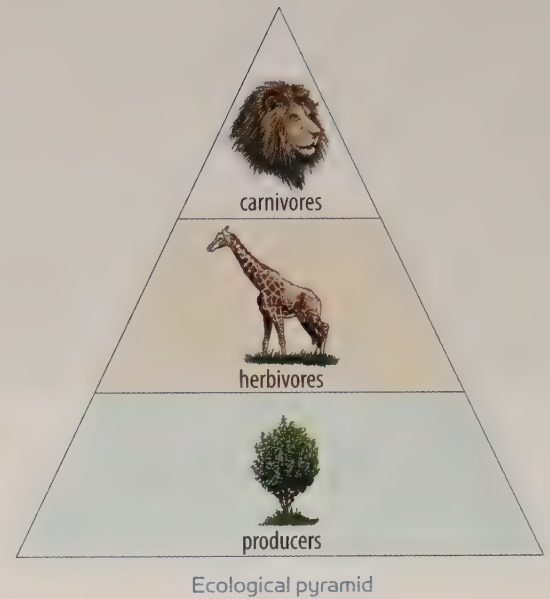
3-14

Termites are the architects of the savanna, creating their towns in ways that alter and enrich the African landscape.

Termites are tiny but they use the power of the colony to reshape and renew the savanna landscape. They create mounds that offer burrows for animals and act as termite high-rise apartments. They also feed on dead plants, wood, and even animal dung—the waste products of plants and animals, called **detritus**. Termites recycle the nutrients in these substances to enrich the soil as they make their mounds. Plants can grow here in the future, or termites can return nutrients to the biome when other animals like armadillos and mongooses eat them. Organisms that break down nutrients are called **decomposers**. Termites get a little help breaking down detritus from microbes that live in their guts.

Energy in a biome passes from one organism to another in a sequence known as a *food chain*. For example, apricot trees grow in the savanna, feeding giraffes who feed lions. Food chains need producers, consumers, and decomposers to work. But as we've also seen in the savanna, the food chains of different animals can overlap, creating a web of life, or a **food web**. Food chains are connected in a food web.

Another way to demonstrate the flow of energy in an ecosystem is to use an **ecological pyramid** that illustrates a food chain. Each layer, or *trophic level*, represents a different type of organism in the food chain, and each depends on the level below it for energy, though these pyramids don't cover all the energy gained or lost in an ecosystem. The bottom layer is usually the producers, followed by herbivores, omnivores, and carnivores. The bottom layer is broadest because there are more producers in that part of the food chain, representing a greater amount of living matter, or *biomass*. The healthier an ecosystem is, the more biomass it supports.



Food chains fit together to form food webs. The ecological pyramid in this diagram has trophic levels labeled for producers, herbivores, and carnivores.



3-16

What kind of symbiotic relationships can you see in this picture?

Tracking the energy through an ecosystem, producers make food from the sun's energy. With each step in the food chain, or each trophic level, there is a transfer of energy from one organism to another. Ecosystems that are full of life abound in producers, allowing the ecosystem to support several trophic levels on the ecological pyramid.

3.7 SYMBIOSIS

White rhinoceroses, giraffes, and hippopotamuses graze in the rustling fields of the savanna. Some gray birds flit between these grazing animals, appearing to hitch a ride like mini-tourists on a safari. These animals interact with each other within their habitat, a phenomenon that ecologists call **symbiosis**. Let's consider several types.

Oxpeckers pick off and eat ticks that burrow into the tough hides of giraffes, rhinoceroses, and hippopotamuses and possibly weaken them. They are actually doing the large animals a favor! The ticks exhibit **parasitism**—they are organisms that depend on a much larger animal, called a *host*, for food. Over time, parasites weaken their hosts. The oxpeckers are predators of the tick, helping out the host animals and themselves. A mutually beneficial relationship between several members of an ecological community is called **mutualism**. It's a win-win situation for everyone—except the tick!

The rhinos tramp and munch their way through the savanna, raising up a cloud of insects. Cattle egrets, a type of bird, trail the rhi-

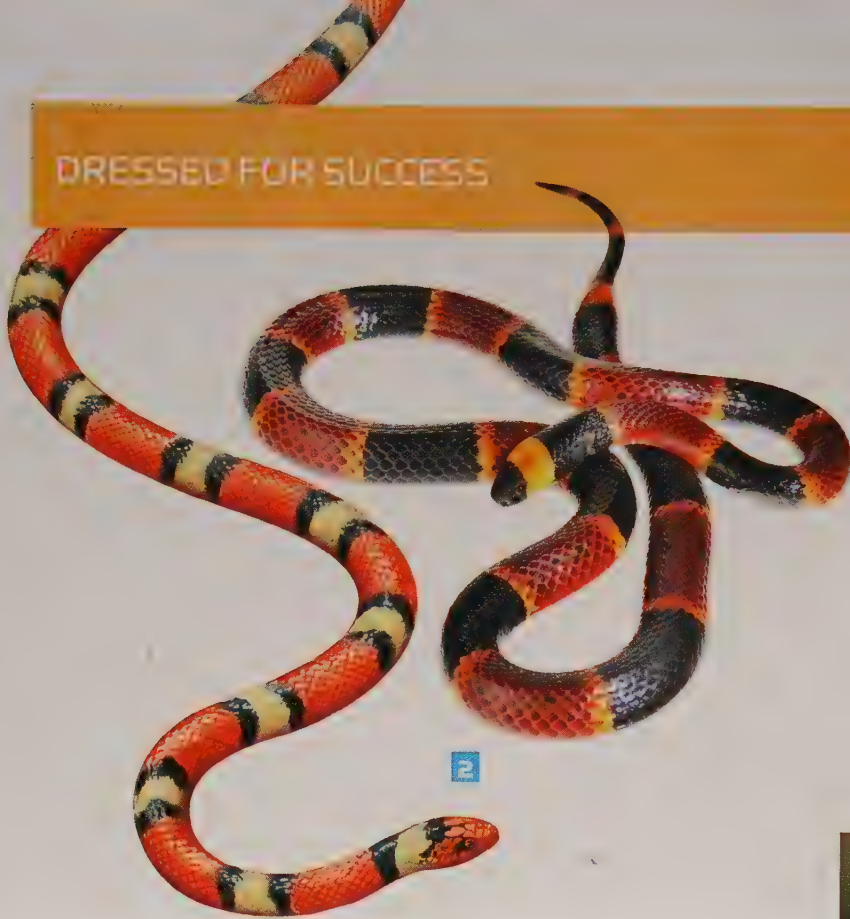


nos, scooping up the insects. The egrets illustrate a kind of symbiosis known as **commensalism**: they benefit from the rhinos, but the rhinos are neither helped nor harmed by the egrets.

Symbiosis is usually a good thing, but nature is not always kind. Interactions between organisms can be neutral or injurious to one or both of them. For example, the black mamba, one of the most venomous snakes in Africa, shares a neighborhood with the oxpecker, but it isn't directly affected by the oxpecker. This relationship is called **neutralism**. But grazing herbivores could startle a black mamba hiding in the grasses. It can then be spotted and picked off by a watching mongoose. The grazing herbivores are not affected by the black mamba, but the snake is definitely impacted by the herbivores! This relationship is called **amensalism**—one organism is injured while the other is unaffected. We've also seen how animals must kill for nourishment or compete with each other for limited resources, especially dwindling water holes during the dry season. Relationships between organisms can change quickly in the environment, such as when two lions produce offspring but eventually abandon a sick or injured lion cub during a famine, drought, or predator attack. The African savanna can be a harsh, cruel, unforgiving place.

Does this bother you? We see that God provides for His creatures, but we live in a cursed, fallen world where sin has marred God's creative order. All of nature—each biome, ecosystem, community, and organism—waits for the time when He will restore His fallen creation, and the lion will lay down with the lamb.

DRESSED FOR SUCCESS



An animal's physical appearance affects how it interacts with its environment and with other animals. An animal's coloration can make the difference between getting eaten and surviving! Look at the examples below.

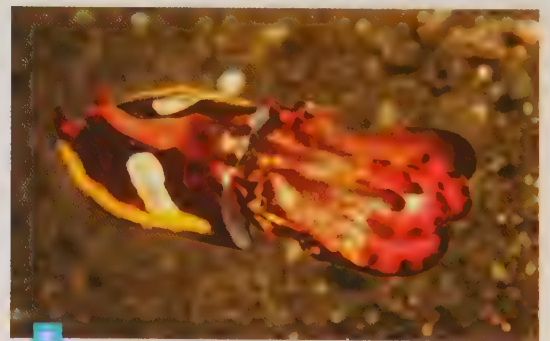
1 The birds of paradise from New Guinea put on an exotic display of coloration to attract a mate.

2 The scarlet king snake (left), thought to be harmless, actually mimics the venomous eastern coral snake (right). Biologists call this *mimicry*.

3 These two species of poison dart frogs are both toxic to predators and mimic each other for added protection.



Can you see the gecko on this tree? Animals use camouflage, a form of mimicry, to avoid predators.



The bright coloration of a flamboyant cuttlefish warns that it is poisonous for other animals to eat. Biologists call warning coloration *aposematism* (AP uh seh MAT ih sum).

3C REVIEW QUESTIONS

1. Give an example of a producer and a consumer.
2. Give an example of an herbivore, omnivore, and carnivore from the deciduous forest biome.
3. What do you think a *detritivore* is? What is another name for this kind of organism?
4. Create a food chain of the African savanna, including lions, savanna grass, and giraffes.
5. Draw an ecological pyramid from the food chain that you created in Question 4.
6. Label each trophic level in your ecological pyramid from Question 5 as a producer, herbivore, omnivore, or carnivore.
7. Where do omnivores fit on an ecological pyramid?
8. Sketch out a food web for the African savanna including the following organisms: savanna grasses, apricot trees, giraffes, wildebeests, lions, cheetahs, termites, anteaters, and side-striped jackals.
9. How would you respond to a person who says, "The natural world shaped by evolution is a brutal place where animals prey on other animals. How could a loving Creator make a world like this?"
10. Complete the table below to show the symbiotic relationships between two different organisms. For each organism, indicate whether the relationship is helpful (+), harmful (-), or neutral (0). The first row has been done for you as an example.

Symbiosis	Organism 1	Organism 2
competition	-	-
predation		
parasitism		
mutualism		
commensalism		
neutralism		
amensalism		

CHAPTER 3

REVIEW QUESTIONS

T Key Terms	
biosphere	45
ecology	45
biodiversity	46
biome	47
ecosystem	47
habitat	47
niche	47
abiotic	47
biotic	47
population	47
vertical zonation	54
producer	56
consumer	56
competition	56

(continued)

CONCEPT REVIEW

1. Why is astrobiology such a popular new field in science?
2. What factors limit the extent of the biosphere?
3. Do ecologists ever study individual organisms? Explain your answer.
4. Why is biodiversity a sign of a healthy ecosystem?
5. Place the following terms in order of increasing land area: biome, biosphere, ecosystem, and habitat.
6. An ecologist is studying a group of emperor penguins in winter, each of them a father sheltering a solitary egg on Antarctic ice while the mothers are out fishing. Is the ecologist studying an ecosystem, community, population, or individual? Explain.

Use the case study below for Questions 7–15.

CASE STUDY: TIDE POOL ECOLOGY



3-17

The lowest levels of tide pools always have water. The highest levels are most exposed to air and wave action.

Near Acadia National Park in Maine, waves buffet the rocky coasts. In this place where land and water meet, living things abound because of plentiful sunlight, fresh water, and a good supply of nutrients. An added benefit for the animals that live here is all the nooks and crannies to hide in. But life isn't always easy for the constantly battered starfish, sea anemones, snails, crabs, and mussels that call this place of transitions home. When the tide is out, they can be left high and dry for creatures to snack on. Animals find a way to cling onto the rocks to endure periods of exposure. Some fish called killifish live in areas of the tide pool where there is always standing water. These fish can gulp air from the surface when the tide is low and there is no fresh supply of oxygen in the water. They can also jump out of the pool and flop across land to find a new pool! Mussels, snails called limpets, and barnacles in the tide pool snack on algae and larval sea creatures called plankton. Mussels and limpets are eaten by starfish and crabs. These crabs could be the next meal for herring gulls or otters.

7. Name three abiotic factors in the tide pool.
8. Name three biotic factors in the tide pool.
9. Is a tide pool an example of a biome, ecosystem, or habitat? Explain.
10. How do you think temperature would affect the tide pool?
11. How do you think rainfall would affect the tide pool?
12. Do you think that tide pools might have their own small version of a vertical zonation? Explain.
13. Create a food chain from the information in the case study using algae, limpets, crabs, and otters.
14. Use your food chain from Question 13 to make an ecological pyramid. Label the trophic levels with producer, herbivore, omnivore, and carnivore.

15. Draw a food web for the tide pool including mussels, barnacles, algae, plankton, crabs, limpets, starfish, herring gulls, and otters.

16. Using the major lines of latitude, locate the temperate biomes and climate zones on the globe. See Figure 3-8.
17. Using the major lines of latitude, locate the tropical biome and climate zones on the globe. See Figure 3-8.
18. List the biomes of the world that have low precipitation (rain, snow, hail, sleet).
19. The coniferous forest biome has sufficient precipitation for many trees. Why does it support few grasses?
20. Why do the things that live and grow on a mountain change with elevation?
21. Honeybees get food from apple trees and also pollinate them, which enables the trees to produce fruit and seeds for propagation. What kind of symbiosis is this?

Key Terms (continued)

detritus	57
decomposer	57
food web	57
ecological pyramid	57
symbiosis	58
parasitism	58
mutualism	58
commensalism	59
neutralism	59
amensalism	59

TRUE OR FALSE

22. No physical part of the earth's surface lies outside the realm of ecology.
23. The biosphere is limited to Earth's surface.
24. Varying the types of plants growing in a garden or yard would increase its biodiversity.
25. A honey badger, a ferocious and tough inhabitant of the African savanna, invades and raids beehives for their honey. This is an example of neutralism.



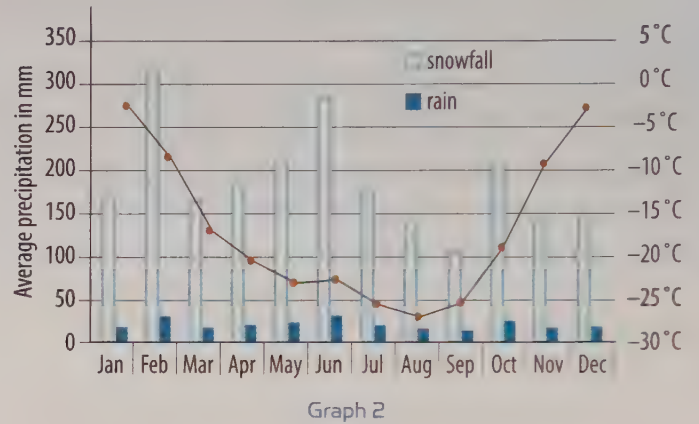
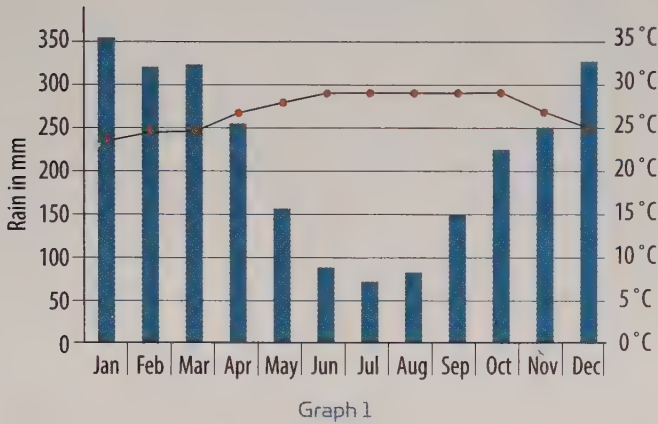
3-18

The honey badger, a member of the weasel family, is a rough-and-tumble inhabitant of the African savanna. Honey badgers have been known to fend off lions!

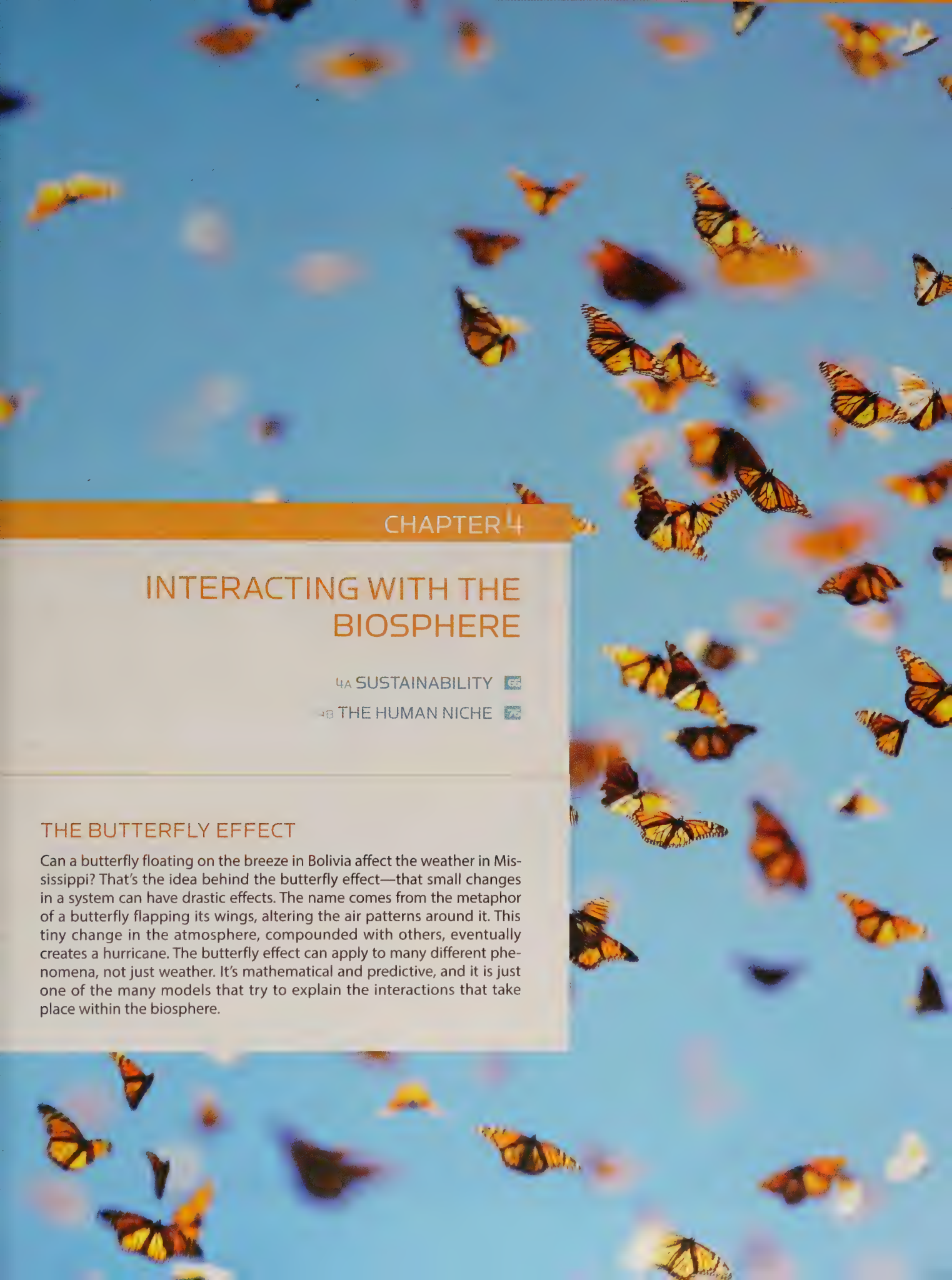
CRITICAL THINKING

- 26.** Do you think that Earth in its originally created form had the biomes that it has now? Why or why not?
- 27.** How do you think *freshwater* aquatic biomes are different from *oceanic* aquatic biomes?
- 28.** Create a food chain and an ecological pyramid that include a producer, herbivore, omnivore, carnivore, and decomposer from the same biome.

Use the graphs below to answer Questions 29–34.



- 29.** What kind of climate does Graph 1 represent: tropical, temperate, dry, or polar? How do you know?
- 30.** Is this climate zone in the Northern or Southern Hemisphere? How do you know?
- 31.** Do you think that Graph 1 represents a climate that can support a high biomass and great biodiversity? Why or why not?
- 32.** What kind of climate does Graph 2 represent: tropical, temperate, dry, or polar? How do you know?
- 33.** Is this climate zone in the Northern or Southern Hemisphere? How do you know?
- 34.** Do you think that Graph 2 represents a climate that can support a high biomass and great biodiversity? Why or why not?



CHAPTER 4

INTERACTING WITH THE BIOSPHERE

4A SUSTAINABILITY 

4B THE HUMAN NICHE 

THE BUTTERFLY EFFECT

Can a butterfly floating on the breeze in Bolivia affect the weather in Mississippi? That's the idea behind the butterfly effect—that small changes in a system can have drastic effects. The name comes from the metaphor of a butterfly flapping its wings, altering the air patterns around it. This tiny change in the atmosphere, compounded with others, eventually creates a hurricane. The butterfly effect can apply to many different phenomena, not just weather. It's mathematical and predictive, and it is just one of the many models that try to explain the interactions that take place within the biosphere.

4A Questions

- » How does matter flow through an ecosystem?
- » Why do some organisms survive in an environment, and others do not?
- » How does the environment recover after a disaster?
- » Why are ecosystems predictable and orderly?

biogeochemical cycles: the pathways of matter in the **biosphere** and **geosphere** (the earth's crust and atmosphere) on a **chemical** level

4-1

Cockroaches or any other animal or plant will never overwhelm the planet because God has designed the earth to keep itself in check.

4A

SUSTAINABILITY

How do living organisms and the nonliving environment interact?

4.1 THE CYCLES OF MATTER

Hurricanes, of course, aren't caused by butterflies (see opener), but small changes in the environment do add up. And if you love to eat oysters, then these small changes could be a big deal. Oyster populations in Maryland's Chesapeake Bay are declining due to overharvesting. Oysters filter large amounts of water, keeping it clean, but with fewer oysters comes dirtier water. As a result, fish and other parts of the Chesapeake Bay ecosystem are adversely affected, so Maryland has started a program to cultivate oysters and then release them to bring balance back to the bay.

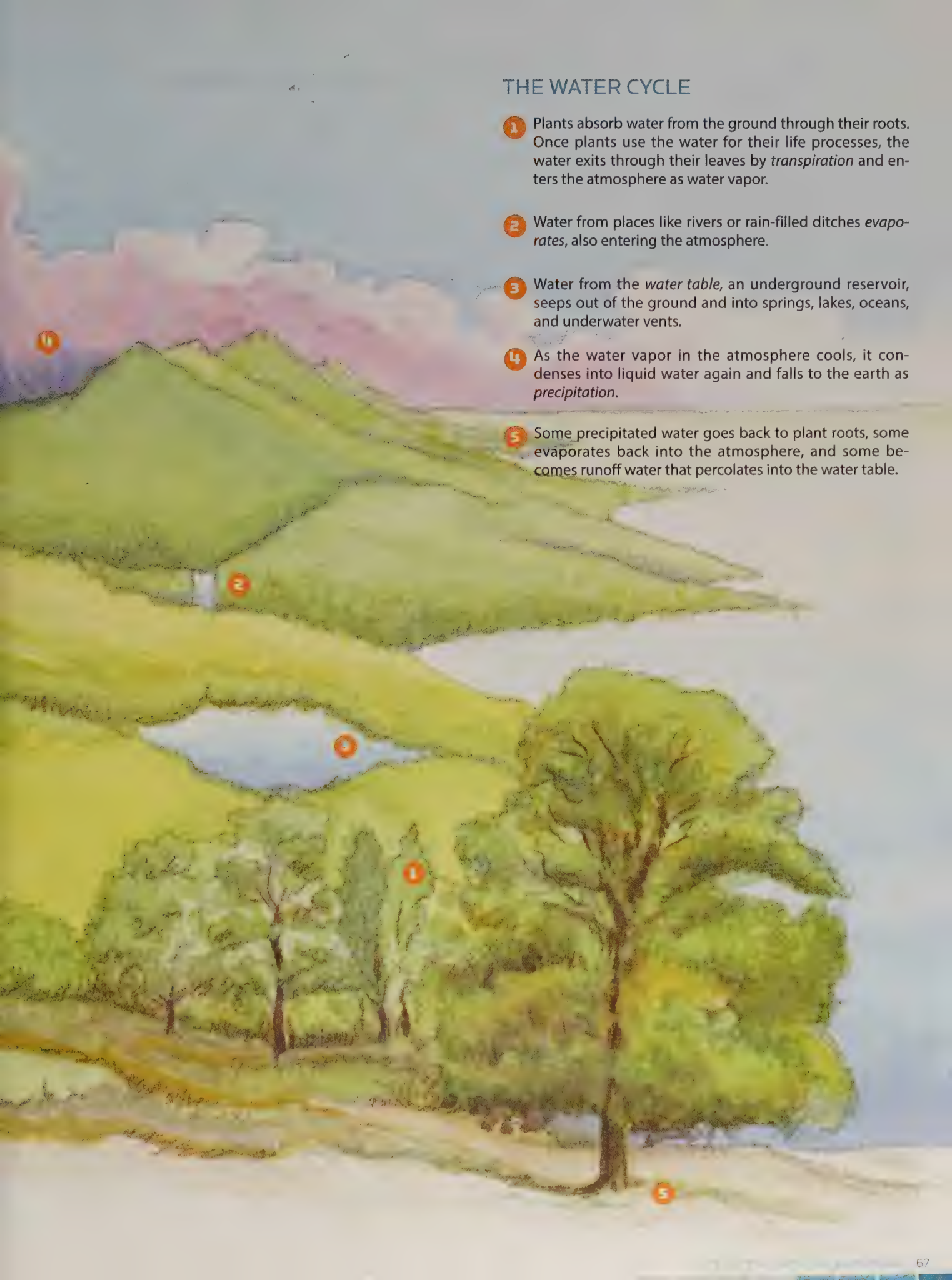
But people don't always have to lend a helping hand to either increase or decrease populations. We don't have to worry about cockroaches or mice taking over the earth or fast-growing weeds choking out all other plants. **Sustainability** is the ability of the biosphere to maintain its balance indefinitely, keeping lifeforms in check. God has built checks and balances into the earth that maintain the planet's productivity and diversity and prevent us from being overwhelmed as we try to manage the populations that really do need our help in a fallen world.

One way that the earth has been designed to sustain itself is through the cycling of matter. Water, oxygen, carbon, and nitrogen are constantly absorbed by organisms and released back into the environment. The movements and interactions of these materials are collectively known as **biogeochemical cycles**.



THE WATER CYCLE

- 1 Plants absorb water from the ground through their roots. Once plants use the water for their life processes, the water exits through their leaves by *transpiration* and enters the atmosphere as water vapor.
- 2 Water from places like rivers or rain-filled ditches *evaporates*, also entering the atmosphere.
- 3 Water from the *water table*, an underground reservoir, seeps out of the ground and into springs, lakes, oceans, and underwater vents.
- 4 As the water vapor in the atmosphere cools, it condenses into liquid water again and falls to the earth as *precipitation*.
- 5 Some precipitated water goes back to plant roots, some evaporates back into the atmosphere, and some becomes runoff water that percolates into the water table.



When Plants Flip the Switch

During the day, plants save a little oxygen for themselves to break down sugar for energy. At night, when plants have stopped photosynthesis, they absorb oxygen and release carbon dioxide to produce enough energy to get them through the night. This change every night doesn't really affect air-breathing organisms, but it can deplete the oxygen levels for fish in lakes or ponds that have lots of plants growing in them.

THE OXYGEN AND CARBON CYCLES

- 1 Most of the earth's oxygen is trapped in minerals in the earth.
- 2 Most free oxygen (O_2) is released by photosynthesis. Plants, along with the tiny phytoplankton floating in the oceans, take in carbon dioxide and expel oxygen during photosynthesis.
- 3 Bacteria, animals, and people take in oxygen and expel carbon dioxide (CO_2). Oxygen from the air also dissolves in water so that underwater creatures have the oxygen they need. Plants also produce carbon dioxide.
- 4 Most of the earth's carbon is trapped in the ocean or underground. But the largest reserve of usable carbon is in the form of carbon dioxide in the atmosphere.
- 5 Volcano eruptions and the combustion of *fossil fuels* (organic fuels such as oil, coal, and natural gas) contribute to the carbon in the atmosphere.



THE NITROGEN CYCLE

- 1 Most nitrogen is found in the atmosphere, but breathing it in doesn't incorporate nitrogen into your body. Animals and people receive their nitrogen by eating plants or plant-eating animals.
- 2 Through a process called **nitrogen fixation**, bacteria living in the roots of legumes (beans, peanuts, soybeans, etc.) can absorb nitrogen from the air and convert it into ammonia (NH_3).
- 3 Ammonia is broken down by water in the soil to form ammonium ions (NH_4^+), nitrates (NO_3^-), and nitrites (NO_2^-). These are absorbed by plant roots and are used to make nitrogen-containing products that plants need to grow.
- 4 Nitrogen fixation also occurs with bacteria that live apart from legumes. Farmers spread manure over their crops because it contains ammonia, which soil bacteria break down into the nitrogen ions that plants need.
- 5 During a lightning strike, atmospheric nitrogen around the bolt of lightning is converted to nitrogen compounds that fall to the earth in raindrops and enter the nitrogen cycle.



1

5

4

2

3

4.2 POPULATION GROWTH AND BIODIVERSITY

Sometimes after a heavy rain, fertilizers from a farm wash into a nearby lake—your grandpa's favorite fishing spot. The fertilized lake quickly becomes covered with a thick green blanket of algae. All that green looks incredibly healthy, but when you and your grandpa arrive at the lake for a fishing trip, the fish aren't biting. If you could push aside the algae and look into the water, you would see why—there are no more fish in the lake!

eutrophication (you troph i KAY shun): (Gk. *eutrophos*—well-nourished); the condition of a nutrient-rich body of water leading to the uncontrolled growth of algae



The algae have a high **population density**—the number of individuals in a certain amount of space. In a process known as *eutrophication*, the algae are disrupting the flow of carbon and oxygen beneath the water and lowering the lake's biodiversity. With more algae comes a higher algae death rate. Bacteria in the water begin to multiply as they eat the dead algae, producing lots of carbon dioxide in the process. Without a way to eliminate built-up carbon dioxide and infuse fresh oxygen into the lake, the fish die. The excess carbon dioxide and the lack of oxygen are known as **limiting factors**—factors that limit the growth of a population.

Limiting factors cause populations to grow or shrink in two ways. The first involves the ratio of birthrate to death rate. When the *birthrate* within a population is greater than the *death rate*, a population grows. When the ratio switches, the reverse is true. Sometimes the ratio holds steady, but the size of the population still fluctuates. This is because of the second way that a population can change size: outside individuals joining the population (*immigration*), or members of the population leaving (*emigration*).

BIODIVERSITY

Nothing looks nicer than a lush green lawn. It takes a lot of work to create a uniform field of grass—you may have observed one of your neighbors on his hands and knees, picking out each weed that dares to pop up. Why is so much effort required to keep just one kind of plant growing in a lawn? Because the earth is designed to support diverse populations.

As populations vary, the biodiversity of an area changes. If algae kill all the fish populations in a lake, then the insect populations that the fish once ate will grow. Insect-eating birds from other areas may discover this new insect buffet and move closer to the lake. Fish-eating bird populations will leave and find a new lake. This ripple effect is the result of one population—the algae—becoming unbalanced.

A change in biodiversity can be natural, or it can result from four major human factors:

- » habitat loss
- » overuse of resources

4.2

Sometimes the only way that fish can get oxygen in a green pond is through the air bubbles produced when birds kick their feet in the water.



4.2

The human population growth in Brazil has created a population decline for many rainforest species. How can Brazilians wisely use the land for themselves while preserving the rainforest?

- » introduction of a species to a new area
- » overuse of chemicals such as fertilizer

Though these types of situations can't always be avoided, it is part of our responsibility here on the earth to understand how we might be limiting the growth and diversity of populations.

EXPONENTIAL GROWTH

Limiting factors don't fully explain why a population can't continue to grow until it takes over the planet. Think about a tropical rainforest, filled with water, warmth, and nutrients. In theory, a population living there could grow endlessly. This rapid rate of growth is known as **exponential growth**. A square foot of algae in a pond turns into 2 square feet, then 4, then 8, then 16 square feet. In a tropical rainforest, 2 orchids in a tree that reach maturity in a month could exponentially grow to 4000 orchids covering the tree in a year. But you'll never find a tree with that many orchids on it because every population has a carrying capacity.

Carrying capacity is the maximum number in a population that an area can sustain. For example, orchids depend on tall trees to help them get closer to the rainforest canopy and reach sunlight. If orchids started multiplying and exceeded their carrying capacity, their tree would quickly be overwhelmed by the orchids and die. A dead, crumbling tree would drop its orchids on the ground, and since the orchids depend on the tree's height to get sunlight, the orchids would soon die. Algae in the fertilizer-tainted pond have temporarily exceeded the pond's carrying capacity as well. As the algae use up the fertilizer and the nutrient levels return to normal, algae will begin to die off due to the competition for declining resources.

Therefore, a more realistic model for growth is *logistic growth*, which accounts for the limiting factors and carrying capacity of a population. But even logistic growth can't perfectly predict how a population will change because of the huge number of factors that interact in the biosphere.

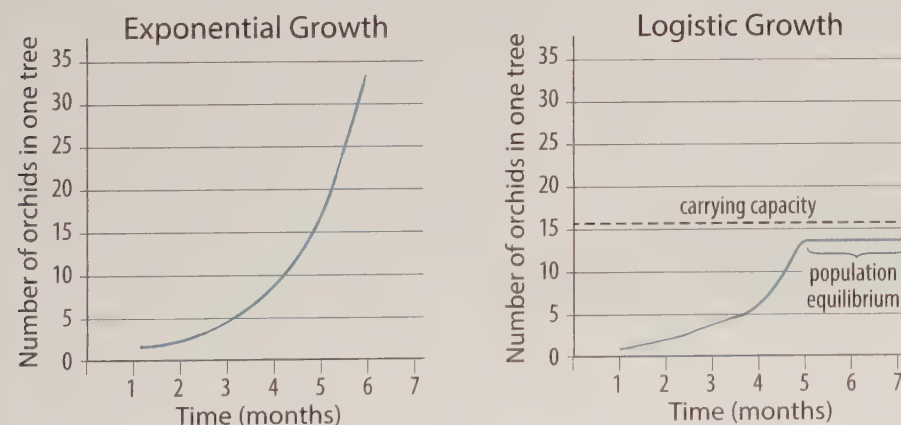


4-4

If these two orchids grew exponentially, their offspring would demolish this tree within a year.

4-5

Exponential growth, which is theoretical, and logistic growth, which is more realistic



CASE STUDY: FERRETING OUT THE GROWTH RATE



The black-footed ferret has come back from the grave not once, but twice. This member of the weasel family was thought to have gone extinct prior to 1964, but in that year a remnant population was discovered in South Dakota. Some of those ferrets were caught and used in an attempt to establish a captive breeding population. The attempt ultimately failed. When the last wild South Dakota ferret died in 1974, followed by the death of the last captive ferret in 1979, the black-footed ferret was once again thought to be extinct.

But in 1981 a rancher discovered another remnant population in Wyoming. Scientists studied this population, but diseases were quickly taking their toll on the ferrets. In 1987, the remaining ferrets were taken into captivity. This tiny remnant, eighteen ferrets in all, became the founding stock of a successful captive breeding program, whose offspring were eventually released back into the wild as part of a carefully managed ferret recovery plan initiated by the US Fish and Wildlife Service. Starting with the reintroduction of 42 young ferrets in 1991, the recovery plan hoped to have 1500 adult ferrets in the wild by 2020. By 2009, there were an estimated 448 adult ferrets back in the wild. Were the scientists on track to reach their goal of 1500 ferrets?

To estimate the growth rate of a population, wildlife biologists use the equation

$$P = P_i(1 + r)^t,$$

where P is the final population, P_i is the initial population, r is the rate of growth, and t is the time interval between the two population values. Using 18 as the value for t would give the

biologists the growth rate of the ferret population for the 18 years between 1991 and 2009. Follow the steps below.

In the wild, approximately 40% of young ferrets survive to reproductive age, so we will assume that about 16 of the original 42 survived and reproduced. So the initial equation looks like this:

$$448 = 16(1 + r)^{18}$$

Divide both sides by 16.

$$28 = (1 + r)^{18}$$

Take the 18th root of both sides.

$$1.20 = 1 + r$$

Solve for r .

$$r = 0.20$$

The growth rate is usually expressed as a percentage, so $0.20 \times 100\% = 20.0\%$. This means that during the first eighteen years of the recovery plan, the adult ferret population increased by an average of 20% each year. At that rate, the ferret population should have reached the target population of 1500 adults by 2016, well ahead of the 2020 target date.

At a growth rate of 20% per year, there should have been about 774 adult ferrets in 2012, but there weren't. In fact, in 2012 the adult ferret population had declined to 274. What happened? Think through the following questions to see whether you can figure out what is going on with the ferret growth rate.

1. Use the population growth equation to calculate the growth rate of the ferrets between 2009 and 2012.
2. What are some possible reasons why the ferret population declined between 2009 and 2012?
3. Calculate a new long-term (from 1991) ferret population growth rate using the 2012 population of 274 adult ferrets.
4. Which of the two growth rates you calculated, the rate based on 2009 population data or the one based on 2012 data, do you think is a more reliable estimate? Explain.
5. On the basis of your 2012 growth rate, can the ferret population still reach the 2020 target of 1500 adult ferrets?

Modeling nature and trying to predict the course that nature will take are difficult tasks. So the plan to increase the black-footed ferret population isn't a failure. It's a workable plan that can be adjusted as ecologists learn more about black-footed ferrets and the environment in which they live.

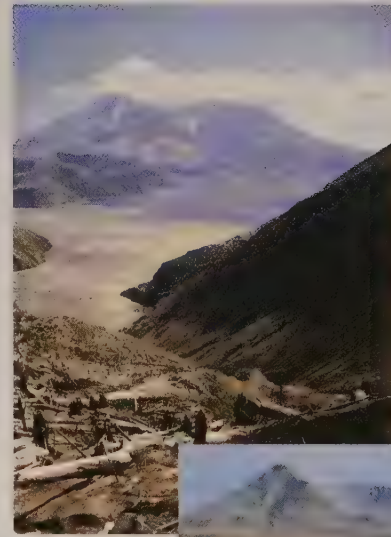
4.3 | PIONEERING ECOSYSTEMS

When Mount St. Helens blew its top in 1980, the ash from the erupting volcano could be seen in eleven surrounding states. The scorching heat from the pyroclastic flows that raced down the side of the mountain destroyed everything in its path. Once the volcano was spent, one side of it was nothing but bare rock. Fast forward to today, where the bare rock has been replaced with a thriving community of plants and animals. How does a devastated ecosystem bounce back like that?

This change of a biotic community over time is known as *succession*. Succession that begins with a barren landscape is **primary succession**. This is the type of succession that Mount St. Helens underwent—in several places around the mountain, there was nothing but ash and hardened lava covering the ground with no soil left for plants to grow in. As birds flew over these areas, leaving nutrient-rich droppings and seeds behind, a few plants began to reappear. Insects and other small creatures moved into the crevices of the lava rocks, and as they died, their bodies decomposed to form another rich layer of organic material. Plants and animals that are the first to return to an area are known as **pioneer species**. They tend to be short-lived as other species come along and replace them.

Succession in a disturbed landscape that already has soil is **secondary succession**. This type of succession follows primary succession. It also takes place when a farm field or lawn is abandoned. Seeds enter the field's habitat and grow unchallenged. The new kinds of vegetation in the field attract new animals. Soon, small trees begin growing, offering shelter to even more kinds of plants and animals. If left alone for about a hundred years, the habitat will become an old-growth forest filled with **climax species**—stable, long-lived species that mark the end of succession.

Succession doesn't necessarily follow a step-by-step path from primary to secondary succession. In the case of the Mount St. Helens eruption, the pioneer species and climax species were often growing at the same time. Eventually, if the area is not disturbed again, the climax species will take over, and the pioneer species may no longer grow there.

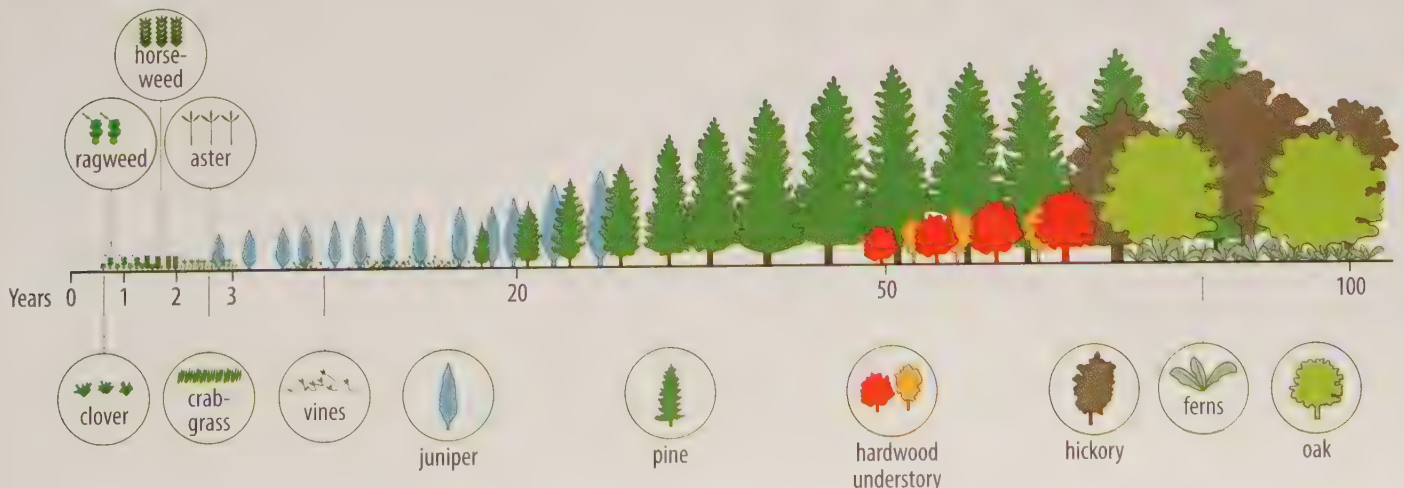


4-6 |

Through primary succession, the debris fields around Mount St. Helens began to host little populations of plants after just a few years.

4-7 |

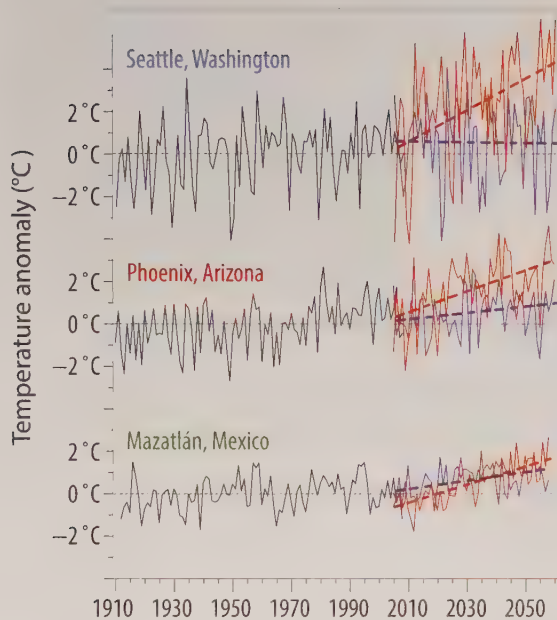
Succession from grassland to a climax forest in the southeastern United States



4.4 FINDING ORDER IN CHAOS

What Is a System?

A **system** is a part of the universe under study. Researchers put an invisible boundary around a system to analyze it and the factors that affect it. For example, you can define a population of puffer fish as a system while you study them. Everything outside this population is outside the system that you have defined.



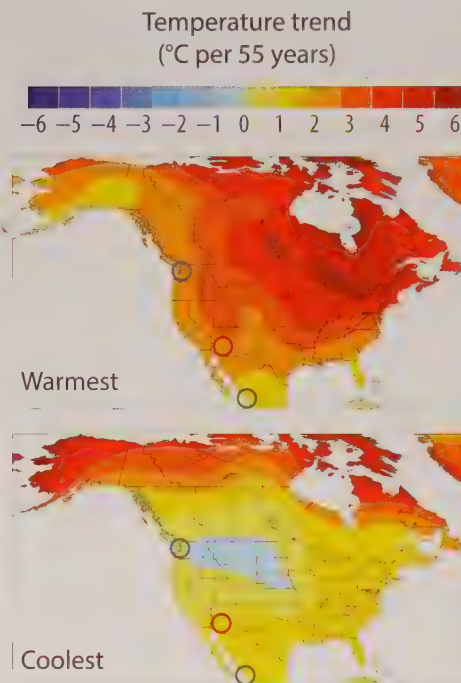
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4.3

The black lines above represent fluctuations in temperature that have been observed. The red and blue lines are high and low predictions. This model can't account for every factor that influences temperature and so predicts two possible outcomes—one warmer and one cooler. This is an example of the butterfly effect.

The cycles of matter through the biosphere and the delicate balance between populations are very complex **systems** that can appear chaotic and random at times. The butterfly effect is sometimes also viewed as a random process that allowed life to evolve from nonliving material in the oceans. Evolutionists view the butterfly effect this way because it does show us that we can't completely model nature. But does a model that appears chaotic really prove that we are the products of chaos and that we will evolve into something else in the distant future? The answer to this question has three parts.

First, human models are limited because the systems they attempt to model are incredibly complex. There are thousands of tiny variables that our finite models can't handle.



Second, as scientists have improved their models, they have discovered that the world is more orderly and predictable than it might appear. For example, in the "boom and bust" cycle of populations, a population seems to randomly swell (the "boom") and then quickly shrink (the "bust"). Ecologists are beginning to create models that help explain this roller-coaster cycle. And limited as they are, the models are still useful. Farmers found that a particular fungus caused their crops to bust. So they planted a new variety of fungus-resistant crops. The crops would boom until another fungus attacked the crops and caused them to

bust again. After studying the boom-and-bust model of crops and fungi, plant breeders developed varieties that resist several different kinds of fungi.

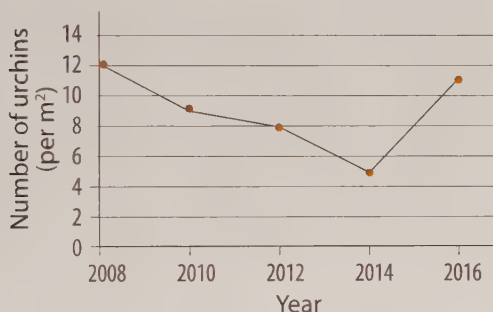
Third, a person's view of chaos in nature ultimately reflects his worldview. Where a naturalistic worldview interprets randomness, chaos, and even cruelty as evidences for evolution, a biblical worldview sees results of the Fall. The lack of order we see doesn't mean that we evolved from less-ordered creatures. We can still see God's order and design, but it has been broken because of sin. We can therefore predict that all our descendants will be people just like us.

CREATION'S CATASTROPHES

How does the quick recovery of the Mount St. Helens area support a biblical view of the changes to the earth's surface (see Figure 4-6)? Many evolutionists claim that after a cataclysmic event that wipes out life, it may take millions of years for populations to recover. That is one reason why they criticize the idea of a recent worldwide flood. But the eruption of Mount St. Helens has evolutionists reconsidering the effects of catastrophes on our planet. Populations reestablished themselves surprisingly quickly, and the destroyed side of the mountain already has several climax species. God created a resilient world that in His grace comes back in decades, not eons.

4A REVIEW QUESTIONS

1. How do biogeochemical cycles contribute to the earth's sustainability?
2. Even if oxygen is added to the water in an oxygen-poor lake, the fish in the lake will sometimes still die. What needs to be removed from the water to keep the fish alive?
3. Sea urchins love to eat algae. When the population density of algae becomes too high, the population density of sea urchins increases to over 10 per square meter. According to the graph below, in which years were the algal populations too high?



4-9

Large populations of algae usually accompany large populations of sea urchins.

4. Research some ways to encourage biodiversity.
5. What is the difference between primary succession and secondary succession?
6. Fireweed is a common pioneer species that grows after a forest fire. Do you think that a climax species like a birch tree can ever grow at the same time as fireweed? Explain your answer.
7. Is the recovery of populations after the eruption of Mount St. Helens more consistent with a biblical worldview or a naturalistic one? Explain your answer.
8. The flow of materials through an ecosystem is difficult to model, but why should people try to model it anyway?
9. How will people with a biblical worldview view nature? How does this view of nature affect their view of models?

4B Questions

- » Why should we take care of God's creation?
- » How is ecology connected to other fields of science?

THE HUMAN NICHE

How do people interact with both the living and nonliving worlds?

4.5 VIEWS OF ECOLOGY

You probably hear terms like *ecological footprint* and *climate change* all the time in the news, but what do they mean? Often, these ecological terms sound scientific, but at their heart is a worldview that doesn't see God as the Sustainer of the earth or people as His image bearers. Let's define some of these common claims in ecology and use the Bible to bring these views of ecology into focus.

GREENHOUSE GASES

Many of the compounds that move through the biogeochemical cycles are **greenhouse gases**—gases in the atmosphere that trap heat. Greenhouse gases are necessary for life because they keep the earth warm and absorb harmful radiation from the sun. The most common greenhouse gases are carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), water vapor (H_2O), ozone (O_3), and gases that contain fluorine such as chlorofluorocarbons (CFCs).

Many scientists believe that as these gases build up in the atmosphere and trap heat, they cause the earth to heat up in a process called *global warming*. They often say that human activities, such as burning fossil fuels or wood, increase our *carbon footprint*, or the amount of greenhouse gases that people release when they burn carbon-containing fuels. Scientists project that the earth's temperature will soon increase as we burn more carbon-containing fuels and cut down more carbon-absorbing trees.



1-10

Burning fossil fuels **1** contributes about 4 gigatons of carbon a year to greenhouse gases. On the other hand, plants **2**, decomposers, and the ocean **3** contribute a whopping 210 gigatons a year!

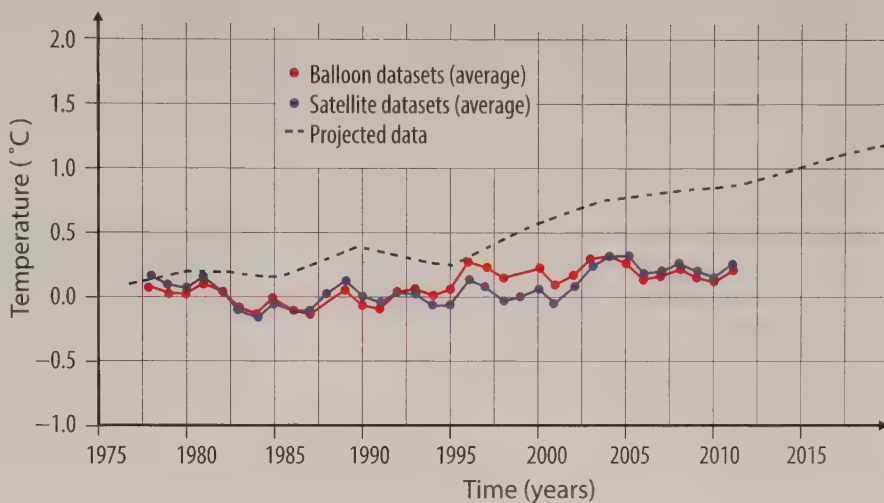
Evaluation

Temperature data suggests that the earth's temperature has risen about half a degree over the past 50 years, a very small change. Predictions of a great temperature increase in the future, based on a small increase in the past, are projections—not observations—and thus may not be reliable.

Though human industry does produce greenhouse gases, natural processes are responsible for most of the greenhouse gases released into the atmosphere. When greenhouse gases reach a certain level in the atmosphere, bacteria, algae, and plants flourish, taking in these gases and removing them from the atmosphere. This doesn't give people license to carelessly release nitrogen and carbon into the environment—part of fulfilling the Creation Mandate is to manage the byproducts of human industry. We should monitor the amount of greenhouse gases that we produce, improve our technology to produce less of them, and use trees wisely. But we can be assured that the fear of destroying our world with greenhouse gases is unfounded. God designed His earth to recycle its byproducts, including greenhouse gases.

4.11

This graph compares temperatures observed with weather balloons and satellites to temperatures predicted with models over the past three decades. Notice how much higher the predicted temperatures are than the actual temperatures.



ECOLOGICAL FOOTPRINT

How we humans relate to the carrying capacity of the earth is sometimes called our **ecological footprint**. This idea was developed in 1992 as a measure for how many resources people use and how quickly the earth can replenish those resources. According to the ecological footprint idea, 0.021 km² (5.2 acres) of land and water supports one person, but on average each person uses 0.027 km² (6.7 acres), meaning that humans are using up the earth faster than it can sustain itself and releasing greenhouses gases in the process. But is this true? Is our ecological footprint too big?

Evaluation

Ecological footprint calculations are generally faulty on a large scale for two reasons. These calculations don't consider the complexity of modeling human interactions with the environment. A single calculation cannot accurately capture each factor involved. They also don't take into account things like improving technology or recycling of greenhouse gases. Even as the human population has increased exponentially (between the 1960s and today, world population has doubled), we haven't exponentially increased the amount of land we use because gains in technology have helped us grow more food in less space.



4.12

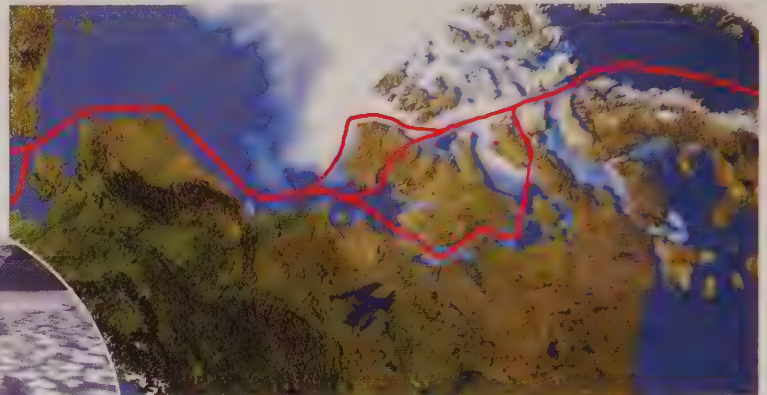
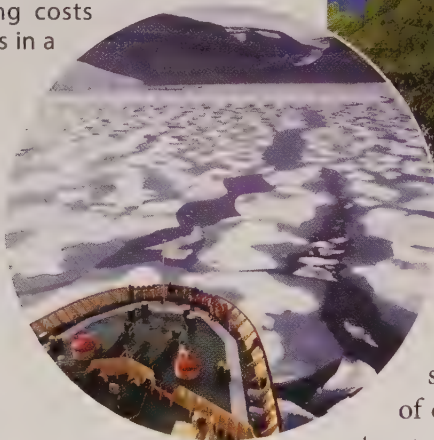
The ecological footprint model compares an area's used natural resources—cropland, fish resources, forests, developed land, and pasture land—to the amount of natural resources it generates.

Finding Footprints

The carbon footprint is just a small part of the ecological footprint. Becoming familiar with both footprints on a local scale can be useful; knowing your effect on the environment can motivate you to recycle your trash and use water wisely. But when it comes to calculating global footprints, many ecologists admit that both footprint models are limited because of the many factors that must be considered.

4-13

Melting glaciers have the potential to be helpful to people. The Northwest Passage, an ocean corridor above Canada that links the Atlantic and Pacific Oceans, is typically blocked by ice. Over the past few years, the ice has melted enough to allow a few shipping routes through the Passage, cutting shipping costs and connecting continents in a whole new way.



CLIMATE CHANGE

Scientists have observed fluctuating temperatures, such as a warm decade leading to a cooler one. And changes such as melting glaciers are hard to ignore. These are part of **climate change**, which is the change of global temperatures and weather patterns over time. Once again, scientists blame people for the shifting climate of the earth and its effect on plant and animal populations.



4-14

Many animals that are usually carnivores, such as polar bears, can adapt to climate change by acting as omnivores.

Evaluation

Most of the fears surrounding climate change are based on melting ice and snow, rising ocean levels, and increased rainfall. These changes are observable, and some people see them as the first steps toward the earth's destruction.

According to a biblical worldview, the earth has gone through at least one major change in its climate during its approximately 7000-year history. The Flood, followed by the Ice Age, drastically changed the face of the earth, but in God's grace the earth has rallied to replenish itself. And changing climate might be a sign that the earth is still recovering from the Flood. Also, God promised us after the Flood that seedtime and harvest, cold and heat, summer and winter, and day and night would continue without fail (Gen. 8:22). So we can be confident that melting glaciers and changing temperatures, though they may change the landscape and populations, will never drastically change the patterns of nature that God has designed for the earth.

Over the decades that scientists have studied climate change, they've found two realities: climate change is an extremely complex issue that cannot be explained or fixed easily, and it is mostly caused by forces that people can't control. One theory that tries to account for these two ideas is that the sun's activity is responsible for it. Some scientists have suggested that El Niño, which is a global weather event that occurs every few years, affects climate. But other scientists continue to propose theories that people cause climate change and should be the ones to fix it before we destroy our planet.

We are charged by God to learn as much as we can about the earth's changes, model them, and act wisely on what we learn. If we can wisely control our impact on the earth's climate, then we should. But we must be careful not to get caught in the hype of popular theories that seek to leave out God's promises and His control over and intricate design of the earth.

EXTINCTION RATES

The pygmy three-toed sloth is on the verge of extinction. It lives on several islands off the coast of Panama. No humans live on these islands, but locals harvest trees from the islands to build their homes, destroying the sloth's habitat in the process.

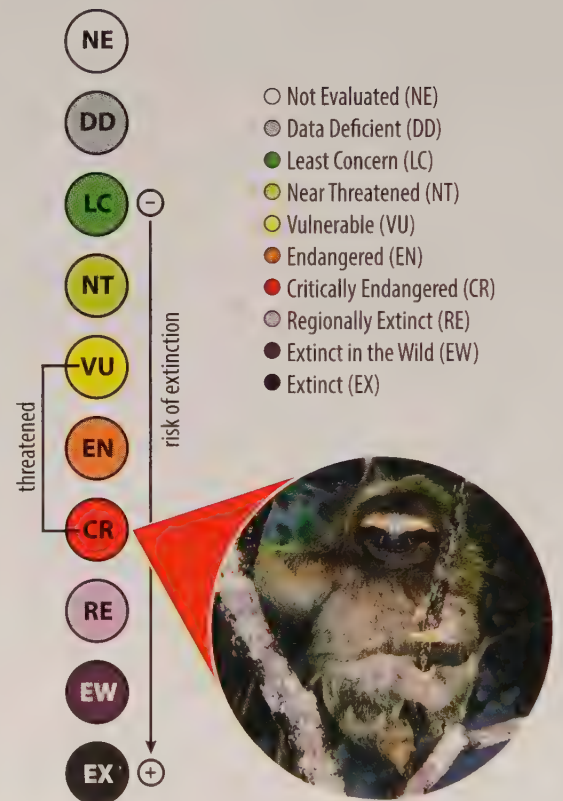
Many evolutionary biologists view the demise of the pygmy three-toed sloth as an example of the ever-growing decrease in the number of species. And they accuse the earth's dominant species, humans, for this decline. These biologists assume that

- » millions of years ago before humans evolved, only 10 species went extinct each year,
- » the earth today is losing thousands of species each year, and
- » there were many more species in the distant past (over a billion species) than there are now (almost 1.5 million cataloged species).

These assumptions lead people to think that increasing extinction rates will wipe out diversity in a few decades. These biologists have concluded that the biggest reason for all this extinction is the growth of the human population. Is this true?

Evaluation

If we use God's Word as our authority, then we know that God created the kinds of creatures that He wanted on the earth, and they quickly filled every corner of the globe. Then God sent the Flood about 4000 to 5000 years ago, which caused a mass extinction of life on the earth. We see evidence in the fossil record of the great variety of life before that worldwide event. After the Flood, the only species left were the land animals that Noah brought on board the ark and the plants and water animals that survived in the floodwaters.



4-15

The Red List, created by the International Union for the Conservation of Nature, is a scale that shows how close species are to extinction. The pygmy three-toed sloth above is listed as critically endangered.

Through Noah, God preserved each kind of creature so that they could repopulate the earth. Therefore, a biblical worldview assumes that the number of species has been increasing since the Flood. And that seems to fit current observations. Researchers are discovering many new species every year!

Because of their naturalist worldview, evolutionists interpret the massive extinction they see in the fossil record as part of a normal cycle of extinction in earth's history. So they believe that today's species are beginning another extinction cycle. They then inflate the actual extinction rate to make it higher than the rate of species discovery. What is the actual extinction rate? In the past 500 years, about 1000 species have gone extinct. That's about 2 species every year. The number may be higher than that, but scientists haven't observed thousands of species going extinct every year.

Should we care about killing off a species? Some argue that if the building of a home destroys the habitat of an endangered species like the pygmy three-toed sloth, then the home shouldn't be built. Others argue that sloths don't matter and people should build whatever they want. The answer lies somewhere in between. We should not willfully destroy a species if possible, but neither should we let plants and animals run the earth—that's not their role. Our responsibility is to watch over threatened species, fill the earth with more of God's image bearers, and provide for people above all other creatures.

Hunting the Hunters

There are many endangered animal species in the Florida Everglades, the United States' only tropical wetlands. Many of these animals have been tagged so that wildlife researchers can track their daily and seasonal patterns. Soon after the Burmese python hijacked the food resources in the Everglades, the data from tagged animals became erratic. Puzzled, researchers decided to track down one of the strange signals coming from a tagged woodrat. They followed the signal to the spot where the woodrat should be, but all they found was a Burmese python basking in the sun. They captured the snake and found the woodrat's tag—and the woodrat—in the snake's stomach.

This incident launched the beginning of the Python Patrol, a group that teaches people in python-plagued communities how to identify, safely capture, and transport pythons to wildlife management areas.

4.6 CONNECTING TO ECOLOGY

Issues in ecology branch out and touch many areas of life, and it takes more than ecologists to solve ecological problems. One example of different groups coming together to solve a problem has to do with **invasive species**, which are organisms that move into a habitat where they are not native and then compete with native species for resources.

The Burmese python, a snake native to Southeast Asia, is popping up more and more in parts of Florida. The pythons were introduced to the Florida environment by a python breeder whose shop was destroyed in 1992 by Hurricane Andrew and by people who bought them from pet stores and then released them once they got too big. These giant snakes are thriving in Florida's Everglades, but they're disrupting the native species. Wildlife biologists knew that they were no match for the growing numbers of pythons, so they began to work with other people, such as researchers at a local natural history museum, park rangers, hunters, volunteers, government agencies, and even the police to combat the snakes. Together these groups are working to solve an invasive problem that affects Florida's ecosystems and economy.



Another ecological problem—oil spills—may have found a solution. **Bioremediation** is a technique that uses organisms to remove or neutralize hazardous materials. In 2010, the largest oil spill in US history released millions of gallons of oil into the Gulf of Mexico. People used physical barriers called *booms* to manually gather the oil floating on the surface as well as chemicals to break down the oil, but it was still spreading throughout the Gulf. So scientists deployed their last hope: booms filled with fertilizer and oil-munching bacteria and fungi. The fertilizer gave the microbes enough nutrients to help them multiply, and the rest of their nutrition came from the oil. Groups from around the country donated materials for the booms, and volunteers helped scientists construct them and get them afloat. There's still oil along the Gulf coast, but the microbes are doing their part to clean it up.



4-16

It takes more than scientists for science to be truly useful. Getting these booms into the water to control the oil spill in 2010 took an entire community working together.

The command to care for the earth sounds simple, but carrying it out is complicated. For every wise decision we make about ecology, we often make a foolish one. But that doesn't mean we should give up. Though managing the earth is a difficult balancing act between preserving resources and using them to help people, we can learn how to face these tough ecological situations with God's wisdom.

4B REVIEW QUESTIONS

1. What are two ways that bacteria help keep the earth's processes in check?
2. What do ecological footprint calculations *not* take into account?
3. (True or False) There is a chance that rising ocean levels due to climate change might destroy life on the earth.
4. People with a naturalistic worldview say that species are generally (growing/declining) _____. Those with a biblical view say that species are generally (growing/declining) _____.
5. A swampy patch of land next to a town has become a haven for mosquitoes. The townspeople want to drain the swamp to get rid of the pests, but the area is protected by the government because it's home to an endangered frog. What are some solutions for this problem?
6. Do some research and write a paragraph on an example of bioremediation being used to combat an invasive species. Include at the end of your paragraph whether the effort solved the problem or created a new one.
7. How could a high-school student in Florida team with wildlife biologists to help control the Burmese python population?

WORLDVIEW SLEUTHING: CREATURES AND CLIMATE CHANGE



4-17

As sea lions were going farther and farther out to find food, their young were wandering away from their rookeries, ending up in some unusual places.

Introduction

Several years ago it was reported that malnourished baby sea lions off the coast of California were coming onshore in droves. What caused this odd behavior?

Task

Choose a migrating animal, such as a specific bird, butterfly, or sea creature, and try to figure out whether there's a connection between the animal's behavior and climate change. Then decide whether humans should be part of the solution for helping it get back on its feet.

Procedure

1. Once you've chosen an animal, research to find out the following information about it:
 - » typical migration patterns, eating habits, and habitat preferences
 - » new or changing migration patterns, eating habits, and habitat preferences
 - » possible causes for the changing behaviors
 - » ways that people are helping it recover

Pay attention to words such as *predicted*, *projected*, *forecasted*, and *potential*. Many statistics that you'll find about the effect of climate change on animals may be projections into the future and not observed data.

2. Create a map that compares the animal's migration pattern in the past (10–20 years ago) and its migration pattern now. Include on your map a summary of the research that you did.
3. Suggest a possible way that your animal can be helped. For example, there are now several sea lion rescue groups in California that nurse baby sea lions back to health and then release them. There are also new fishing restrictions to help increase the fish populations that sea lions like to eat.
4. Include a few sentences about how worldview might affect people's interpretation of data. Base your sentences on the two questions below.
 - » Why do many scientists believe that changing migration patterns are caused by humans?
 - » What is the biblical role of people when it comes to fulfilling the Creation Mandate?

Conclusion

It makes sense that as the earth's climate changes, animal populations will change too. We should try to help struggling animals as much as we can because they are resources that are under our care. We should also keep in mind that the earth is the Lord's and that He is in control of every change.

REVIEW QUESTIONS

CONCEPT REVIEW

1. What is sustainability?
2. What are the four major biogeochemical cycles?
3. List two ways that water leaves the earth and enters the atmosphere.
4. Which two biogeochemical cycles are most closely tied together? Why are they linked?
5. Which creatures give off oxygen? Which give off carbon dioxide?
6. Describe the flow of carbon through the biosphere.
7. Identify the three ways that nitrogen can be made usable for plants.
8. Draw a simple diagram showing the flow of nitrogen from a peanut plant to a rabbit and back to a peanut plant.
9. A population of bacteria in a petri dish will grow rapidly and then begin to shrink even if the bacteria are well fed. What causes the bacterial population to shrink?
10. If a population's death rate is higher than its birthrate, then the population will (grow/shrink) _____.
11. If a population's emigration rate is higher than its immigration rate, then the population will (grow/shrink) _____.
12. What is the biblical role of people in sustaining the living and nonliving aspects of the environment?
13. Give an example of God's orderly and predictable design in the way that succession takes place in an abandoned field.
14. When a scientist finds that she cannot accurately model the behavior of a herd of elephants, should she assume that their behavior is too chaotic to model or that there may be more variables to include in her model? Explain your answer, including how worldview affects the assumption that you choose.
15. What is responsible for most of the greenhouse gases in the atmosphere?
16. Some scientists predict that if the climate continues to change, we may no longer have seasons. How can we know that seasons will continue on the earth?
17. According to a naturalistic worldview, why is climate change such a big concern?
18. Should Christians ignore climate change data? Explain your answer.
19. On what assumptions do evolutionists base their extinction rates for species?
20. Why is it difficult to figure out how fast species form today?
21. Why are invasive species harmful?
22. What is bioremediation?
23. How does bioremediation help fulfill the Creation Mandate?
24. List several branches of science that may be involved in cleaning up an oil spill.

Key Terms

sustainability	66
biogeochemical cycle	66
nitrogen fixation	69
population density	70
limiting factor	70
exponential growth	71
carrying capacity	71
primary succession	73
pioneer species	73
secondary succession	73
climax species	73
greenhouse gas	76
ecological footprint	77
climate change	78
invasive species	80
bioremediation	81

TRUE OR FALSE

25. Transpiration could be considered a type of evaporation.
26. The nitrogen that your body needs comes from breathing it in.
27. A high population density can be harmful to other populations.
28. Biodiversity remains steady as long as populations stay balanced.
29. Pioneer species are never found where climax species are growing.
30. Primary succession begins in places that have no usable soil.
31. Because the earth can recycle carbon so well, we shouldn't be concerned about the amount of carbon our industries release into the atmosphere.
32. We will soon exceed the earth's carrying capacity if the human population continues to increase.
33. The earth has experienced climate change during its history.
34. Since species on the earth are generally increasing, we shouldn't worry about extinguishing them.

CRITICAL THINKING

35. Ecologists understand why algal populations in a lake follow a "boom and bust" cycle—they grow to their environment's carrying capacity and then shrink once they run into a limiting factor. Why do you think some scientists choose to ignore this model of population change when they try to explain similar "boom and bust" cycles on a global scale?
36. How might an artist who frequently draws birds be able to help researchers track down a new species of bird?
37. People around the world are working on creative ways to use invasive species, such as turning kudzu vines into biofuel. Do some research and write a paragraph about one of the interesting ways that people are using an invasive species.

Use the table below and the following information to answer Questions 38–45.

The table shows the land area covered by colonies of monarch butterflies that migrate to Mexico in the winter.

Monarch Colonies Migrating to Mexico

Year	Area (acres)	Year	Area (acres)
1993	15.39	2004	5.41
1994	19.30	2005	14.60
1995	31.16	2006	16.98
1996	44.95	2007	11.39
1997	14.26	2008	12.50
1998	13.74	2009	4.74
1999	22.16	2010	9.93
2000	9.46	2011	7.14
2001	23.13	2012	2.94
2002	18.63	2013	1.65
2003	27.48		

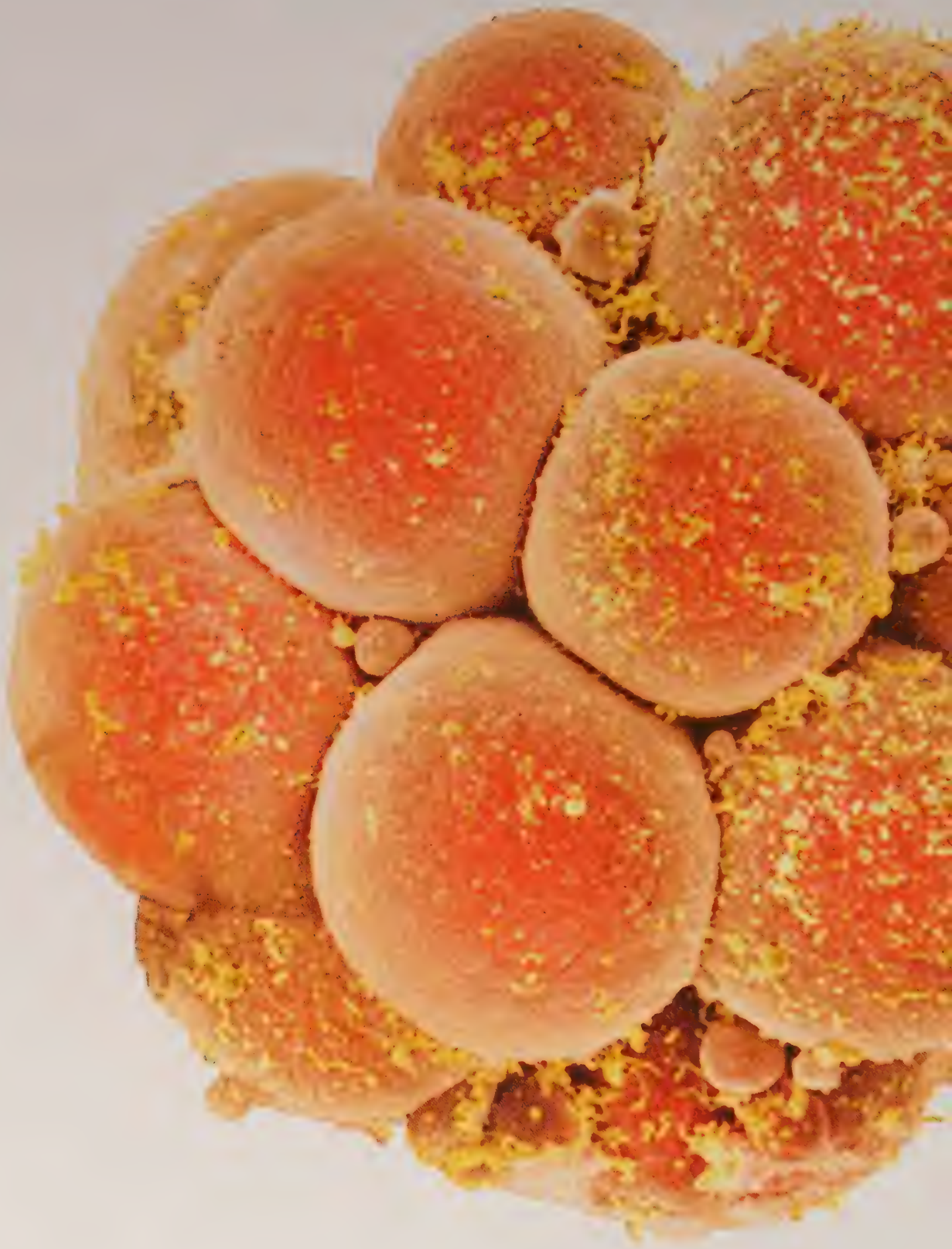
- 38.** How do you think ecologists collected this data?
- 39.** Why would ecologists use land area instead of actually counting the monarch butterflies?
- 40.** Graph the table data, placing the year on the x axis and the land area in acres on the y axis. You can use a graphing calculator or a spreadsheet program. Then find the equation that best fits the trendline on your graph.
- 41.** How does the equation of your trendline compare to the equation used in the Case Study on page 72?
- 42.** What is happening to the number of monarchs making it to their winter hibernating grounds?

Monarchs make their winter colonies in the fir and pine trees in the mountains of Mexico. They have one of the longest migrations of any insect, gathering energy for their migration by drinking from milkweed along the way.

- 43.** List a few reasons why monarch butterflies are struggling to migrate.
- 44.** What can ecologists do to help the monarch butterfly population recover?
- 45.** How do the actions that you suggested in Question 44 align with the Création Mandate in Genesis 1:28?

It is not medicine we should fear, but the folly of mankind. Every day . . . our ability to change nature by using its own laws [increases]. But using this power wisely is what each generation must learn in its turn. We are certainly more powerful today than ever before, but we are no wiser: Technology is cumulative, wisdom is not."

JÉRÔME LEJEUNE (1926-94),
FRENCH GENETICIST WHO DISCOVERED
THE CHROMOSOME THAT CAUSES DOWN
SYNDROME



2 THE PATTERN OF LIFE

CHAPTER 5
CYTOLOGY 88

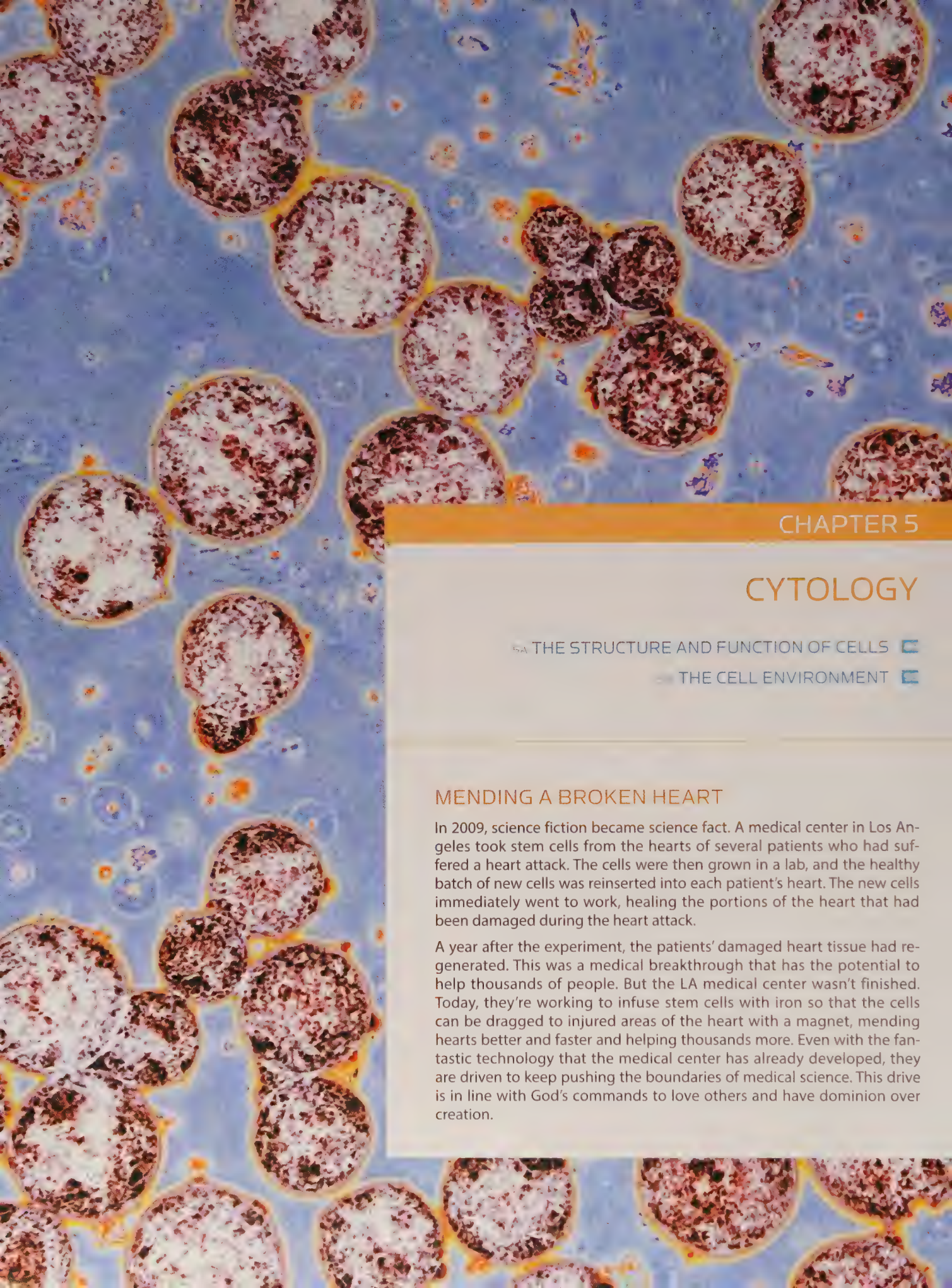
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CHAPTER 8
BASIC GENETICS 131

CHAPTER 9
ADVANCED GENETICS 156

CHAPTER 10
WHEN WORLDVIEWS COLLIDE 177

A microscopic image showing numerous cells, likely red blood cells, with a granular, reddish-brown interior and a lighter, yellowish-orange outer ring. They are scattered across a light blue background with some smaller, less distinct cellular structures.

CHAPTER 5

CYTOLOGY

SA THE STRUCTURE AND FUNCTION OF CELLS 

SA THE CELL ENVIRONMENT 

MENDING A BROKEN HEART

In 2009, science fiction became science fact. A medical center in Los Angeles took stem cells from the hearts of several patients who had suffered a heart attack. The cells were then grown in a lab, and the healthy batch of new cells was reinserted into each patient's heart. The new cells immediately went to work, healing the portions of the heart that had been damaged during the heart attack.

A year after the experiment, the patients' damaged heart tissue had regenerated. This was a medical breakthrough that has the potential to help thousands of people. But the LA medical center wasn't finished. Today, they're working to infuse stem cells with iron so that the cells can be dragged to injured areas of the heart with a magnet, mending hearts better and faster and helping thousands more. Even with the fantastic technology that the medical center has already developed, they are driven to keep pushing the boundaries of medical science. This drive is in line with God's commands to love others and have dominion over creation.

THE STRUCTURE AND FUNCTION OF CELLS

What are cells, and how do they contribute to life?

5.1 MODELING THE CELL

The idea of the cell, the basic unit of life, hasn't always existed. When biologists first peered into their newly invented microscopes in the 1600s to study plants and animals, they weren't exactly sure what they were looking at. What they saw didn't fit with their current theories of *spontaneous generation*, the formation of a living thing from nonliving materials, and *preformation*, the idea that eggs and sperm contain miniature people that simply increase in size after conception. Being able to see an actual cell under a microscope dispelled those theories.

Over the centuries, biologists have assembled the tiny puzzle pieces of the cell to create the picture of the cell that we have today. And the discoveries aren't finished; new puzzle pieces are still turning up! In the future, scientists may unveil a never-before-seen part of the cell and completely change how we understand cells. Until then, the ideas we have about cells have proved useful in predicting how they function.

It wasn't until 1665 that the Englishman Robert Hooke used the word *cell* to describe the tiny box-like structures he saw in a piece of cork under a microscope. This was just the beginning of *cytology*—the study of cells. In 1682, Dutch scientist Antonie van Leeuwenhoek discovered that blood is made of cells. He also studied the cells of sperm, bacteria, and larvae under his microscope, which led him to two ideas: each cell had a central part, and living cells didn't arise from nonliving materials or contain mini versions of adult organisms. The model of the cell was taking shape.

One hundred and fifty years went by before scientists revisited this model. In 1831, the British botanist Robert Brown named the central cell part that Leeuwenhoek and others had described—he called it the nucleus. Just a few years later, the ideas of four young German scientists came together to complete the model of the cell. In 1837, botanist Matthias Schleiden and zoologist Theodor Schwann met for dinner to discuss an idea that they had both been thinking about: that all plants

5A Questions

- » Where did the idea of a cell originate?
- » How are the cells in an organism similar? How are they different?
- » How do the parts of a cell work together?

Robert Hooke, Renaissance Man

Robert Hooke did more than study cells under a microscope—he was an artist, mathematician, architect, and astronomer. He created the beautiful drawings in his book *Micrographia* when he was 30 years old. He also studied gravitation and laid the foundation for Isaac Newton to develop the law of gravity. The grid layout of streets used by many large cities such as Paris and New York was created by Hooke.

Because of his contributions to science and society, scientific laws and schools are named after him and awards are given in his honor. He even has an asteroid and craters on the moon and Mars that bear his name.



5.1

Hooke's *Micrographia* contained giant fold-out drawings like this one of a flea. His writing style and drawings were so popular that his book became a bestseller.

Bi Something from Nothing: Spontaneous Generation and the Origin of Life

Until the cell theory became widespread in the mid-1800s, many people believed that organisms spontaneously came into existence with the right combination of materials. For example, many thought that if you mixed a sweaty shirt with a handful of wheat in a box, you'd get mice! And scientists designed experiments that seemed to prove this theory.

As science progressed, these experiments were shown to be wrong. People learned that life comes from life, not from someone's dirty laundry. But the theory of evolution requires life to come from something that was never alive. Just as scientists tried to do centuries ago, evolutionists today try to design experiments to prove their something-from-nothing view of life, despite our observations of how life works. The only life that came from nothing was miraculously created by God, not by a chance combination of chemicals.

and animals are made of cells. Then in 1855, Robert Remak discovered that cells divide, producing new cells. Three years later, Rudolf Virchow expanded on the ideas of Schleiden, Schwann, and Remak by declaring that all cells come from preexisting cells.

Years later, the work of these scientists and others after them has led to the modern **cell theory**:

1. Cells are the structural and functional units of all living things.
2. Cells come only from other preexisting cells.

These two simple statements contain a lot of information. Ideas such as heredity (the flow of information), metabolism (the flow of energy), and chemical composition (the makeup of cells and their products, information, and energy) are all included in these statements.

The cell theory is a very reliable and predictable model that people use every day to understand cells. But since cells are big enough to observe under a microscope, why do we need a model for them? Biologists still have to explain what they observe about how cells handle energy and information and interact with their environment. As scientists continue to study cells and their environment, cell theory has changed. And one day, it may be replaced completely. That's okay, because a theory is useful to scientists only when it can explain what we have already observed, make predictions, and be modified to account for new observations.

5.2 ORGANIZING WITH CELLS

Your body is made of an estimated 37 trillion cells that are working together to keep you going. Exactly how these cells work together is one way that biologists classify organisms. An organism that is made of only one cell is called a **unicellular organism**. Bacteria and protozoans are typically unicellular, as are several algae and fungi. A unicellular organism can fully function without help from other cells.

5.2

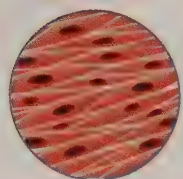
The colony on the left, known as *Volvox*, contains unicellular algae. The single cells all secrete a gel-like substance to form a clear, protective sphere around them. The petri dish on the right contains many bacterial colonies.



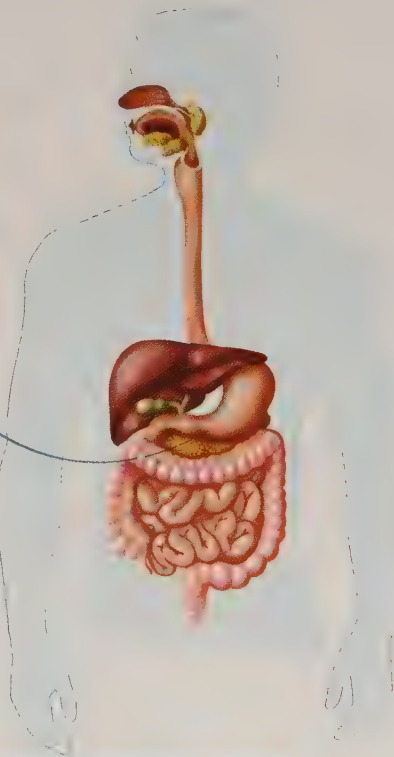
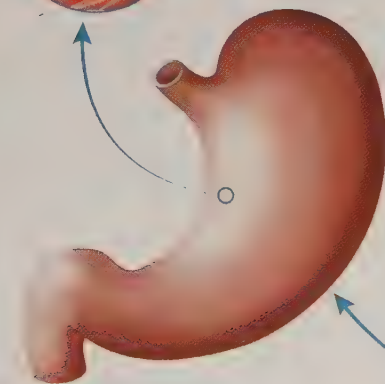
Some unicellular organisms work together in a **colony**. Within the colony, the single cells take on specific tasks—some are involved in reproducing, moving the colony, removing wastes, and so on. But the cells can break away from the colony and function on their own.

A **multicellular organism** is made of two or more cells that depend on each other to function. Some algae and fungi are multicellular, and so are all plants, animals, and humans. Most cells in a multicellular organism are highly specialized and cannot function without the support of other cells. For example, your blood cells have a completely different role than your skin cells do, but one can't function without the other.

In multicellular organisms, cells are organized into **tissues**. These muscle cells form muscle tissue.



Different tissues that work together to perform a specific function are **organs**. The stomach is made of muscle, skin, and gland tissues.



Why Are Cells So Small?

The genetic information inside a cell governs its size. But even if that information were turned off, a cell would still stay tiny. Why? The cell's surface area must be similar to its volume.

The nutrients that a cell needs enter the cell through its surface. Whenever the surface area of an object increases, its volume increases even more, creating more volume inside a cell than can be taken care of by the cell's surface.

To illustrate this, consider that the average cell has a surface area of $314 \mu\text{m}^2$ and a volume of $524 \mu\text{m}^3$, a ratio of 1.7:1. The largest cells have a surface area of 0.031 mm^2 and a volume of 0.52 mm^3 , a ratio of 16.8:1. So a large cell's volume is 16.8 times greater than its surface area. That much volume requires a lot of nutrients, so the surface of a large cell is a very busy place and would shut down completely if the cell were any bigger.

An **organ system** is a group of organs that work together. The stomach is just one organ in the digestive system.

5.3 THE CELL'S PARTS AND PURPOSES

There's another way that organisms can be classified other than as unicellular or multicellular—by the kinds of parts they have. The parts inside a cell are called **organelles**, which literally means "little organs." Many organelles are surrounded by a membrane, and an organism with cells that contain membrane-surrounded organelles is **eukaryotic** (yoo KEHR ee AHT ik). Humans, animals, plants, fungi, and protists fall into this category. An organism whose organelles lack surrounding membranes is **prokaryotic** (PROH kehr ee AHT ik). A bacterium is an example of this type of organism.

eukaryotic: eu- (Gk.—good or true) + -karyotic (Gk. *karuotos*—having a central part)

prokaryotic: pro- (Gk.—before) + -karyotic

Evolutionists chose the prefix *pro-* for prokaryotic organisms because it expresses their belief that prokaryotes evolved *before* eukaryotes.

STRUCTURE AND FUNCTION IN CELLS

Typical bacterial cell (prokaryote)

1 cytoplasm—consists of everything within the cell membrane except the nucleus; contains *cytosol*, the fluid in which the organelles are suspended; has molecules used for building structures in the cell

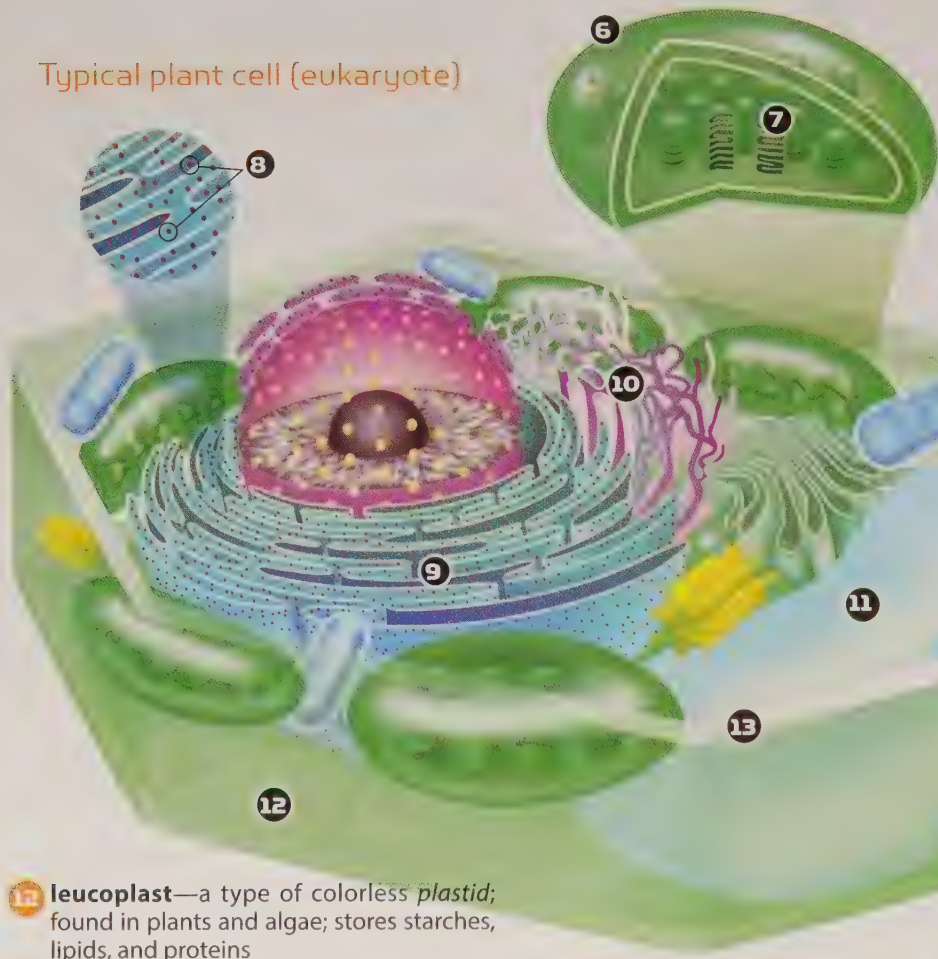
2 cytoskeleton—a system of fibers in the cytosol that helps maintain the cell's shape and provides protein motors and a track to move substances around the cell in a process called *cytoplasmic streaming*

3 capsule—found in bacteria outside the cell membrane and cell wall; protects the cell; contains water to keep the cell from drying out, often making it feel slimy

4 nucleoid—found in prokaryotes; contains the genetic material for the cell; floats freely in the cytosol

5 flagellum (pl., flagella)—extension of the cytoskeleton; usually only one or a few on a cell; propels the cell through its environment using a protein motor

Typical plant cell (eukaryote)



6 chloroplast—a type of pigmented *plastid*; found in plants and algae; converts light energy from the sun into chemical energy

7 granum (pl., grana)—found inside chloroplasts; made of stacks of thylakoids, which contain the green pigment *chlorophyll* to carry out photosynthesis

8 ribosome—found in both prokaryotes and eukaryotes because it's not surrounded by a membrane; contains proteins and RNA; lines up amino acids to make proteins; either attached to the endoplasmic reticulum or floating in the cytosol

9 rough endoplasmic reticulum (rough ER)—transports compounds around the cell and helps maintain the cell's shape; is studded with ribosomes and processes the proteins made by ribosomes

10 smooth endoplasmic reticulum (smooth ER)—transports compounds around the cell and helps maintain the cell's shape; processes fats and breaks down toxic substances in liver cells

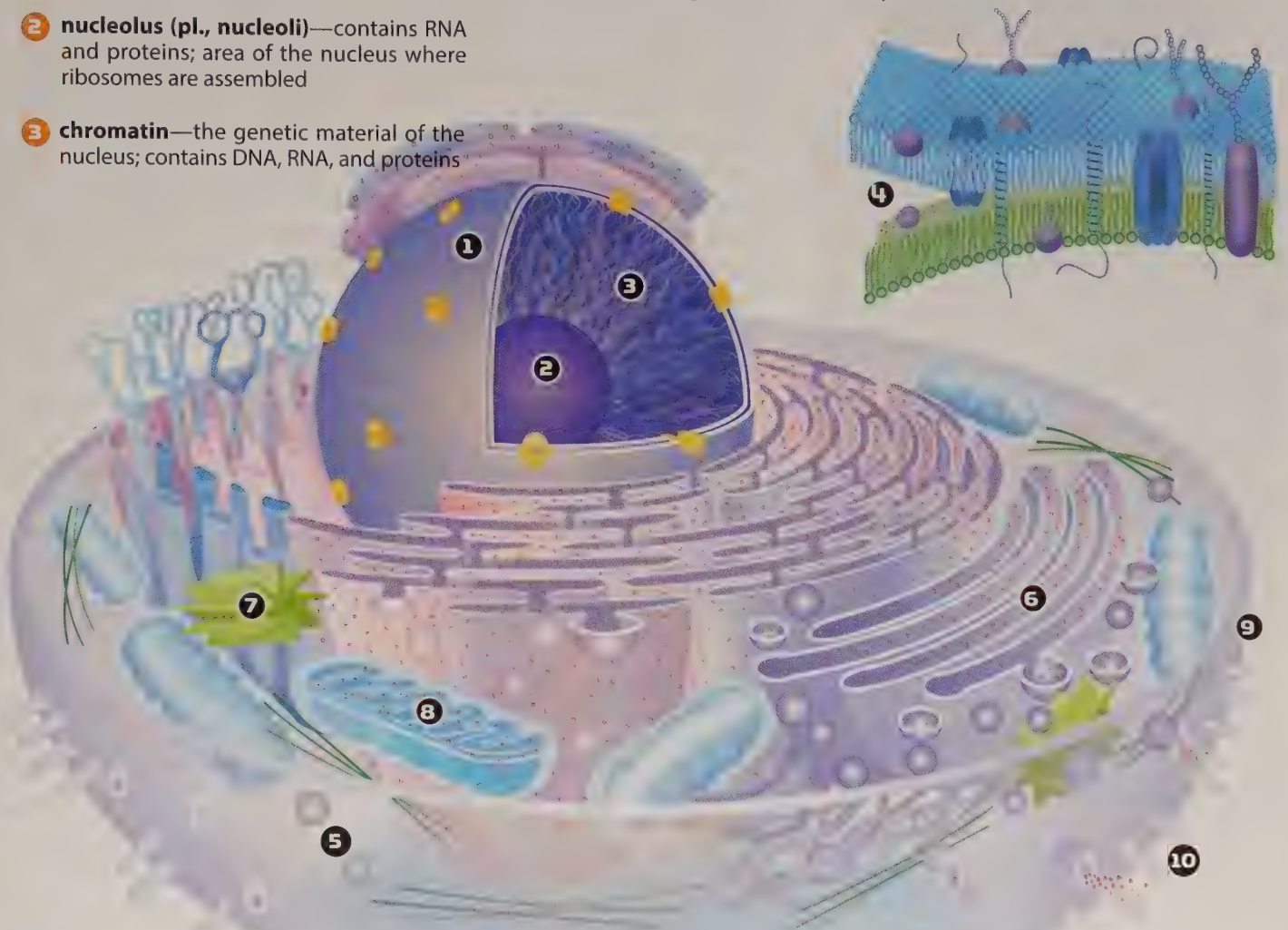
12 leucoplast—a type of colorless *plastid*; found in plants and algae; stores starches, lipids, and proteins

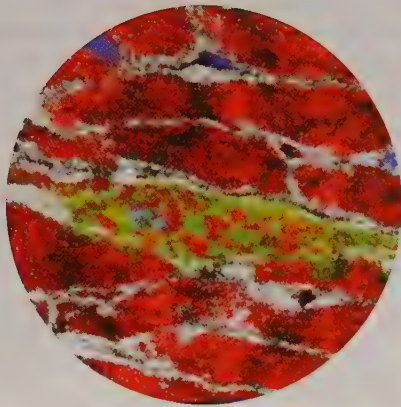
13 cell wall—found in plants, fungi, algae, and bacteria; provides strength and rigidity to the cell; contains pores so that materials can pass through it

11 central vacuole—found mostly in plants; stores water, salts, sugars, and proteins; maintains **turgor pressure**—the water pressure inside the central vacuole that keeps the cell rigid

Typical animal cell (eukaryote)

- 1 **nucleus (pl., nuclei)**—found in eukaryotic cells; “control center” of the cell; controls the actions of the cell and contains its genetic material
- 2 **nucleolus (pl., nucleoli)**—contains RNA and proteins; area of the nucleus where ribosomes are assembled
- 3 **chromatin**—the genetic material of the nucleus; contains DNA, RNA, and proteins
- 4 **lipid bilayer**—Lipids have a hydrophilic (water-loving) end and a hydrophobic (water-fearing) end, so they arrange themselves into two layers—the hydrophilic ends facing the watery environments inside and outside the cell, and the hydrophobic ends facing each other to escape the water.
- 5 **lysosome**—a type of *vacuole*; found in human, animal, and animal-like cells (protozoans); contains digestive enzymes that digest food, kill bacteria and viruses, and recycle old cell parts; moves to the cell membrane by cytoplasmic streaming to release wastes outside the cell
- 6 **Golgi apparatus**—“post office” of the cell; receives substances from the ER and packages them into membrane sacs called *vesicles*; sends vesicles either to places within the cell or to the cell membrane to deliver their cargo outside the cell
- 7 **centrosome**—found in animal and human cells; builds parts for the cytoskeleton
- 8 **mitochondrion (pl., mitochondria)**—“powerhouse” of the cell; transforms energy from sugars into usable energy for the cell; has an inner membrane that contains folds (*cristae*), allowing for more surface area to increase energy output and more proteins to be embedded in the membrane; may have many or few *cristae* depending on how much energy a certain type of cell needs
- 9 **cell membrane**—surrounds each cell of both prokaryotes and eukaryotes; protects the cell and allows certain materials to move through it; contains proteins that perform several different functions for the cell
- 10 **cilia (sing., cilium)**—extension of the cytoskeleton; often cover an entire cell or a portion of a cell; shorter than flagella; propel the cell through its environment; move particles past the cell, such as moving mucus out of the lungs, into the throat, and down to the stomach





5-3

The green-colored cell is a stem cell that was added to a mouse's heart tissue. Researchers mark these added cells to see how they behave and whether they need improvement.

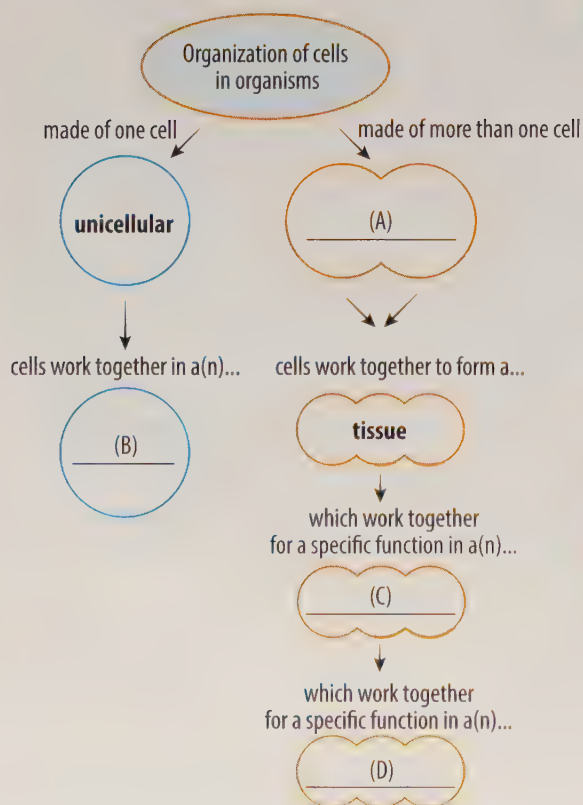
WHY STUDY CELLS?

The model of cells is still developing. For example, the vesicle in plant cells that makes unripe fruit taste bitter was discovered inside chloroplasts as recently as 2013. But why bother improving the cell theory? Does it really help us to fulfill the Creation Mandate and love others?

It was while studying cells that researchers in Los Angeles discovered a way to turn stem cells from a patient's bone marrow into heart cells. To do so, they had to tinker with each protein in the stem cell and see how the cell reacted. Once they figured out which proteins were essential for changing a bone cell into a heart cell, they began testing their discovery. This led to clinical trials where heart attack patients could benefit from this groundbreaking research. Patients were able to go back to work, walk farther without getting tired, ride a bike, and even play the trumpet again.

Non-Christian researchers do their work for the sake of improving people's lives, just as Christian researchers do. But a Christian has a bigger picture: to love people as Christ does, working for their benefit so that they might see Him. Christians can also view cell research as a way to obey God's command to manage the earth. If studying the tiniest and most insignificant parts of cells can save and improve people's lives, then we are bound by God's commands—managing the earth and loving others—to study the life-saving possibilities that are still locked inside the cell.

5A SECTION REVIEW



- Which part of the cell theory refers to the flow of energy through a cell? to the flow of information through a cell?
- (True or False) As discoveries were made that couldn't be explained by spontaneous generation, scientists came up with an updated version of the spontaneous generation model.
- Fill in the concept map to the left on your own paper to organize the information on the different levels of organization of cells.
- How are organelles in a prokaryotic cell different from those in a eukaryotic cell?
- Would a muscle cell that works hard every day have many or few cristae in its mitochondria? Explain your answer.
- Since ribosomes are found in bacterial cells, do ribosomes have a membrane around them? Why or why not?
- Some diseases cause people to become extremely tired. They don't seem to have any energy. What organelle might be damaged in their cells? Research and describe a few treatments that are being used to help people who have this damaged organelle.
- How does a biblical worldview direct a Christian researcher's work?

THE CELL ENVIRONMENT

How do cells interact with their environment?

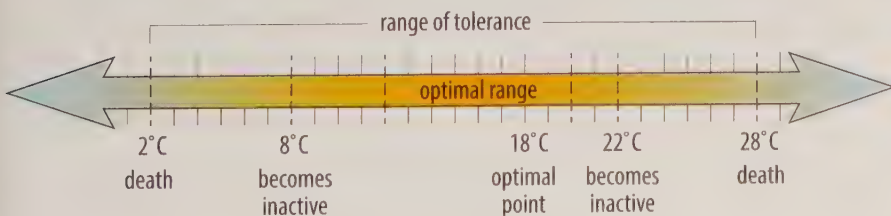
5.4 BALANCE IN THE CELL

It's always exciting to see a package you ordered show up on your doorstep. You rip the box open and happily pull out the book, shoes, or gadget that you've been waiting for. Have you ever thought about the massive effort required for something you purchased a thousand miles away to arrive at your house? It takes the coordination of huge shipping centers to process incoming and outgoing items and to ensure that your new shoes end up at your house and not your neighbor's.

That's how your cells work—they are the shipping centers of the body. They not only send products around the body; they also make the products. That's a lot of work for the tiniest parts of your body! To do this job every day, your cells must maintain **homeostasis**, which is the internal balance of a system that keeps conditions stable.

Another term used to describe this balance is **dynamic equilibrium**, the balance of changes and motions in a system. For example, a shipping center has enough space in its warehouse to hold 10,000 items. But if the warehouse has fewer than 3000 items, then the shipping center will close. Every day, items are shuttled into and out of the warehouse, and the warehouse manager makes continual adjustments to maintain the warehouse's dynamic equilibrium of more than 3000 items but fewer than 10,000.

In a cell, things like temperature, nutrition, and illness can affect homeostasis, so the cell is designed to constantly adjust to maintain an equilibrium. Under ideal conditions, cells may not have to work that hard. These conditions are in the **optimal range** for cells. But if conditions change, then cells leave the optimal range and enter the **range of tolerance**, a status that cells can handle with some extra work. If you get too hot or cold, your body does its best to stabilize itself and get back into the optimal range. When you're hot, you sweat to remove heat from your skin. When you're cold, you shiver to generate heat. But when conditions go beyond what cells can handle, called the **limit of tolerance**, the cells die. Frostbite and sunburn are the result of cells reaching the limit of their tolerance.



5B Questions

- » How does a cell maintain balance in different environments?
- » How does a cell send and receive materials?



5-4

This shipping center requires a high level of organization and a balance between incoming and outgoing products.

homeostasis: homeo- (Gk. *homos*—same) + -stasis (Gk.—standstill)

dynamic equilibrium: dynamic (Gk. *dunamis*—power, motion) + equilibrium (L.—balance)

5-5

Changes in temperature affect a soil microbe.

GETTING FEEDBACK

How do cells regulate the speed of processes or even start and stop them when needed? Signaling occurs through two important processes: positive feedback and negative feedback.

Positive feedback occurs when a substance involved in a cellular process causes the process to speed up. For example, when you breathe in air, the oxygen must move from your lungs to all the cells of your body. Remember from Chapter 2 that each type of protein has its own unique shape that enables it to do its job. Red blood cells contain a protein called *hemoglobin*, which has four subunits that can bind with oxygen molecules. In their natural shape, the subunits have only a low attraction for oxygen, so it would take a long time for oxygen molecules to bind to all four subunits. However, when oxygen enters the bloodstream from the lungs, an oxygen molecule will usually bind to at least one of the subunits. This makes the other three subunits change shape so that they quickly bind to oxygen molecules, guaranteeing that every hemoglobin molecule carries a full load of oxygen to the cells.

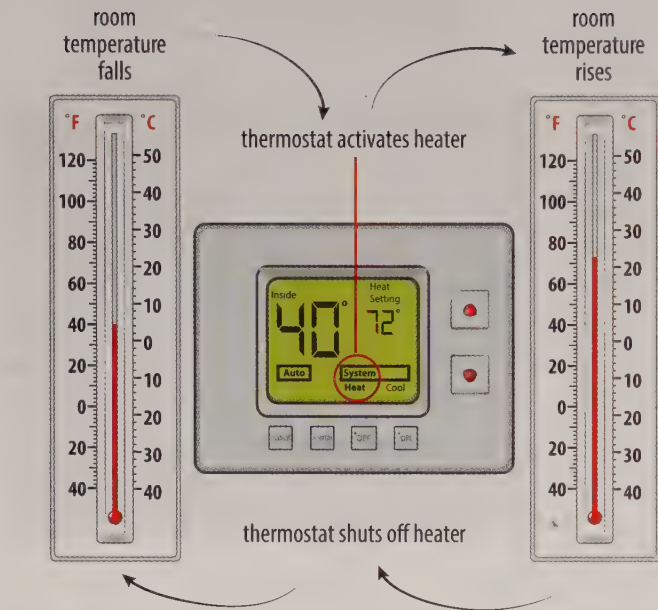
Negative feedback occurs when a substance produced by a cellular process causes the process to slow down or stop.

For example, mitochondria provide cells with usable energy in the form of a molecule called ATP. One of the many enzymes involved in this process is PFK. When the cell needs energy because the number of ATP molecule is low, PFK swings into action. However, as the number of ATP molecules rises, they begin binding to PFK, deactivating it. Thus, the product (ATP) brings the process to a halt until the cell begins to run low on ATP again.

5.5 SOLUTIONS AND THE CELL

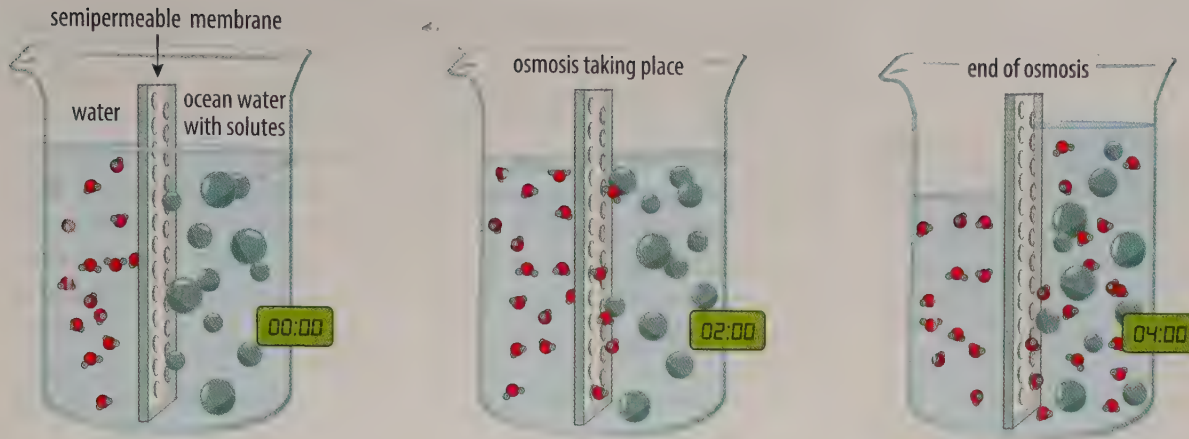
Cells are always in some sort of solution. The air we breathe and walk through and the water we drink and swim in are solutions that affect cells. You experience the chemistry of solutions when you put lots of salt on your French fries. You end up feeling thirsty, because the cells in your mouth and digestive system get depleted of water. The same thing happens when a person gets lost at sea and drinks ocean water out of desperation. He'll be dead in a few days! But why?

Remember from Chapter 2 that the amount of solute dissolved in a solvent is called the *concentration* of a solution. Water is the solvent in both the ocean and a person's cells. Ocean water contains a lot of solutes, being about a 3.5% salt solution. It is a more concentrated solution than a person's cells are, which are about a 0.9% salt solution. Also think back to the discussion in Chapter 2 about diffusion—the spreading of solutes throughout a solution until they reach equilibrium. But a person's cells are surrounded by a cell membrane to keep its contents in and everything else out. So something other than diffusion has to take place to move water into and out of our stranded sailor's cells.



5-6

A thermostat is an example of negative feedback because it maintains a certain temperature in a room.



What takes place is **osmosis**, which is the diffusion of a solvent through a **semipermeable membrane**, a membrane that allows certain substances to pass through it but not others. The cell membrane is a semipermeable membrane. When ocean water contacts the thirsty sailor's cells, the water in his cells travels through the cell membranes toward the greater concentration of solutes. This leaves the cells depleted of water and triggers a negative feedback response of "I'm thirsty!" so that the cells can reach equilibrium again. Instead he drinks more seawater. Poor guy.

5-7

Osmosis of water

Diffusion vs. Osmosis

In diffusion, solute particles spread from an area of higher concentration to an area of lower concentration to create a uniform solution. In osmosis, solvent particles move through a membrane from an area of lower solute concentration to an area of higher solute concentration, creating unequal concentrations in the solutions on either side of the membrane.

semipermeable: semi- (L.—half, partial) + -permeable (L.—able to pass through)

5-8

Osmosis is the reason why these fishermen can't drink the ocean water, no matter how thirsty they get. Water in their cells would be pulled out by the high concentration of salts in ocean water, making them even thirstier.

Ocean water is known as a **hypertonic** solution, a solution that is more concentrated than the cytoplasm of a cell. This difference in solute concentration causes water to flow out of the cells through the semipermeable membrane. When cells are in a solution that is less concentrated than their cytoplasm, they are in a **hypotonic** solution. For example, when cells are in pure water, there is more solute inside the cells, so the pure water passes through the cell membrane and into the cells, causing them to swell. When cells and the solution that they are in have the same concentration of solutes, they are **isotonic**. Your body works to keep most of its solutions isotonic.

hypertonic: hyper- (Gk.—over, beyond) + -tonic (Gk.—able to maintain tension); producing movement of water out of a cell that causes it to shrivel



hypotonic: hypo- (Gk.—under, beneath) + -tonic; producing movement of water into a cell that causes it to swell



isotonic: iso- (Gk.—equal) + -tonic; producing equal movement of water into and out of a cell that maintains its shape



PASSIVE TRANSPORT

When you drop a tea bag into a mug of hot water, what happens? The water enters the tea bag, mixes with the ground tea leaves, and then exits as a much tastier substance. You can speed up the process by using hotter water or by stirring, but ultimately the process of tea diffusing out of the tea bag happens without any help. This is known as **passive transport**—the movement of molecules across a membrane without the use of chemical energy. The particles' own natural motion causes them to move from an area of high concentration to an area of low concentration, and cells don't have to expend any energy to get these particles across their membranes.

Four factors determine whether a particle can be passively transported across a cell membrane.

1. *Particle size*—Very small particles like water, oxygen, carbon dioxide, and nitrogen can pass through the pores of a cell membrane easily.
2. *Particle shape*—Even if a particle is small enough, it may still not be able to pass through an opening in the cell membrane. A round particle will not fit into a square hole!
3. *Particle polarity*—Charged regions within a particle can let it in or keep it out. Oil and water don't mix because oil is nonpolar (contains symmetrical charges) and water is polar (contains asymmetrical charges). Likewise, the outer surfaces of a cell membrane's lipid bilayer are polar (hydrophilic), but the inner surfaces are nonpolar (hydrophobic). The nonpolar surfaces of a cell membrane repel polar substances, but the membrane allows nonpolar molecules to pass through easily. Only very small polar molecules like water can pass through the membrane using passive transport. Also, ions with their unbalanced charges cannot pass through the membrane passively.
4. *Membrane composition*—The lipid bilayer contains different proteins and different-size openings that affect what can get through a cell membrane. For example, because liver cells process toxins that enter the body, the openings in their cell membranes are very large to accommodate the different toxin particles that the liver cells need to absorb. But in the membrane around a liver cell nucleus, only particles that present a specific chemical "ticket" can pass through.

We've already discussed two types of passive transport—diffusion and osmosis. A third type is known as facilitated diffusion.



5.9

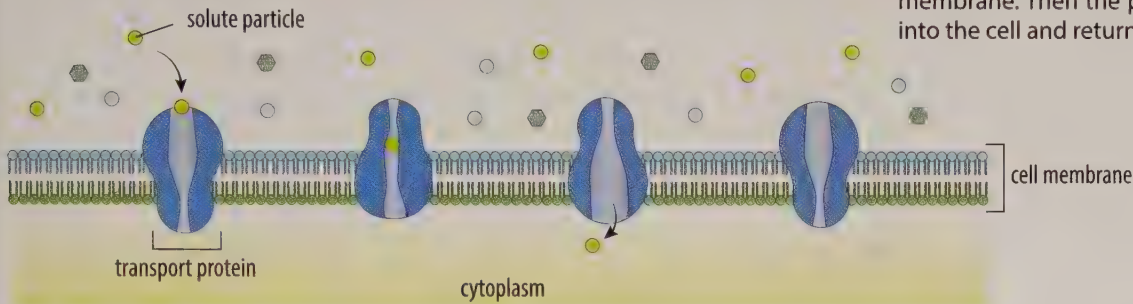
Passive transport is similar to a raft moving downstream. Once the raft is in fast-moving water, it is carried down the river with no need for paddling or any other use of energy.

Glucose, the sugar that your body uses for energy, is a large polar molecule. Yet in some cells, it can pass through the cell membrane without the cell expending any energy. How is that possible? In the process of **facilitated diffusion**, molecules move through the cell membrane with the help of *transport proteins*. These proteins respond to the concentrations of the solutions inside and outside the cell. When the concentration of glucose is higher outside the cell than inside, transport molecules automatically shuttle the glucose molecules into the cell without using any chemical energy.

Not all particles can passively diffuse through the pores in the cell membrane; sometimes the cell needs to use energy to actively bring in the particles that it needs.

5-10

In facilitated diffusion, the pressure of the higher concentration of particles outside the cell forces a particle into the transport protein. The protein changes shape to move the particle through the membrane. Then the protein releases the particle into the cell and returns to its original shape.



ACTIVE TRANSPORT

Whether a human is fighting a strong ocean current or a salmon is trying to swim upstream, it takes energy to move against the flow of water. This is a lot like **active transport**, the movement of molecules across a membrane using chemical energy. A cell often needs to move materials from an area of lower concentration to an area of higher concentration. How can the cell actively use energy to do that?

Molecules such as sodium ions attach themselves to transport proteins on the cell membrane, similar to facilitated diffusion. But the transport proteins don't automatically shuttle the ions into the cell. The cell must apply some energy to the transport protein before the protein will move the sodium ion across the membrane.

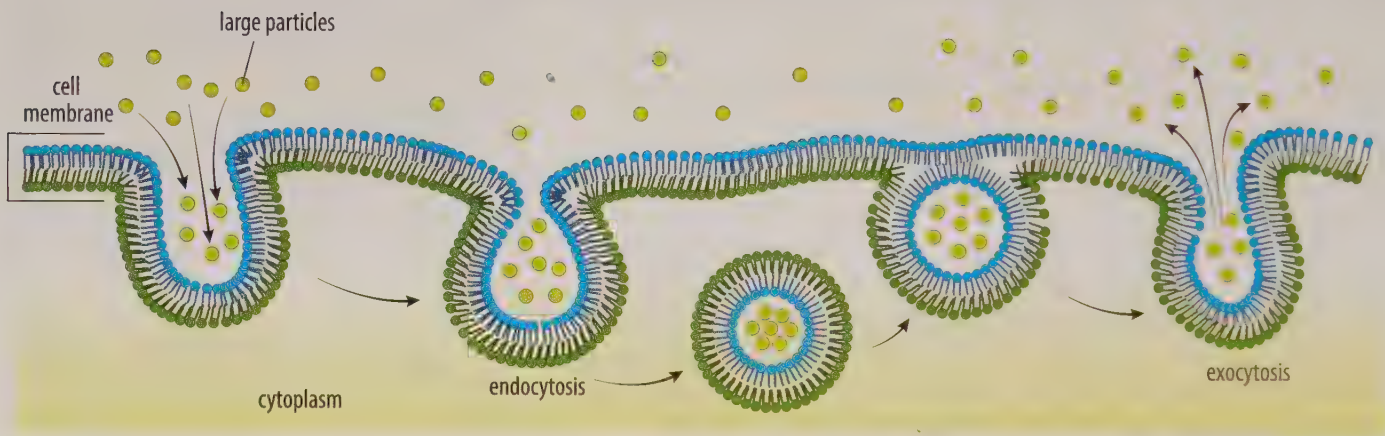
5-11

Active transport requires energy to move molecules across the cell membrane from an area of lower concentration to one that is higher. Notice the energy that comes in to activate the protein before the protein will change its shape.



Cells use two other kinds of active transport to handle really big particles. Instead of moving a particle across its membrane, cells can use energy to simply engulf the particle they want, a process known as *endocytosis*. During endocytosis, a molecule that comes in contact with the outside of the cell membrane is then surrounded by the membrane. The membrane forms a sack around the molecule and then pinches off to become a vesicle. Whenever you cut your finger, white blood cells rush to the wound to engulf any bacteria that may have entered your body. Without endocytosis, you wouldn't last very long in the battle against bacteria.

The opposite of endocytosis is *exocytosis*, which occurs when a vesicle fuses with the cell membrane to release its contents outside the cell. When your cells produce proteins, they are shuttled from the endoplasmic reticulum to the Golgi apparatus to be packaged into a vesicle. Once packaged, the proteins are sent to the cell membrane. Here, the vesicle fuses with the cell membrane, opens up, and releases the proteins into the solution around the cell for other cells to pick up and use.



5-12

Endocytosis engulfs particles; exocytosis releases them.

5B SECTION REVIEW

1. When you catch a cold, your body fights the cold virus and tries to eliminate it as quickly as possible. Why does your body react this way to a virus?
2. Two of the most important parts of your blood are red blood cells and plasma. They are usually isotonic. What would happen to the red blood cells if the plasma became hypotonic?
3. (True or False) Osmosis occurs when a solvent moves from an area of lower concentration to an area of higher concentration.
4. When cells are in a(n) _____ solution, they are maintaining homeostasis.

5. Even though sodium ions are tiny, they cannot cross a cell membrane using passive transport. Why not?
6. Sketch out a cell membrane that shows the four factors that can affect a particle as it tries to pass through a cell membrane.
7. Why is facilitated diffusion a type of passive transport?
8. Why are endocytosis and exocytosis kinds of active transport?

CASE STUDY: PASSIVE TRANSPORT AND KIDNEY STONES

Doubling over in pain, Jamal felt like someone was stabbing him with tiny knives in his lower back. Until the pain began, he was having a good day—he had a hard but fun soccer practice and a steak for dinner. His parents rushed him to the ER, where a physician quickly diagnosed the pain as a kidney stone. Jamal's mom mentioned to the ER physician that she had also had a few minor kidney stones recently. Could their cases be related?

Kidney stones can form in several different ways, one of which is through a defect in the transport proteins that carry amino acids from kidney cells to the blood, a condition called *cystinuria*. Amino acids enter the kidneys through active transport but exit the kidneys through passive transport. This means that if the transport proteins that carry the amino acids out are defective, the acids will build up inside kidney cells. One amino acid in particular, cystine, can build up so much that its molecules crystallize together to form stones in the kidneys.

The ER physician told Jamal that once he passed the kidney stone, he could bring it in to be tested. Two painful days later, Jamal passed the stone, and he dropped it off at the hospital lab. The lab analyzed it and found that it was made of cystine crystals. Armed with this knowledge, Jamal and his mom went to their family physician, who told Jamal that he had cystinuria, an inherited condition. The physician then told him a few ways to manage his newly discovered condition—drink plenty of fluids to help dilute the amino acids in the kidneys, especially when he's active. And eat fewer amino acids—that means less protein.

Think through these questions about Jamal's case:

1. Although cystinuria is an inherited condition, some people never know they have it until something triggers it. Judging by the treatments that Jamal's physician suggested, what do you think triggered Jamal's kidney stone?
2. What kind of passive transport is used by the kidneys to move amino acids into the blood? How do you know that?
3. Even though Jamal's mom has never been diagnosed with cystinuria, she decided to follow the physician's advice herself to drink more fluids and eat less protein. Her kidney stone problem quickly diminished. Without testing her kidney stones, how can you know that she has cystinuria?
4. Why do you think that a condition like cystinuria cannot be cured at this time?
5. How would searching for a cure for Jamal's cystinuria show obedience to God?

5-13

Cystine kidney stones like this one often have jagged edges and can be the size of a marble. They cause a lot of pain as the body moves them from a kidney to the bladder in a tube that's only 3 to 4 mm in diameter.



REVIEW QUESTIONS

Key Terms	
cell theory	90
unicellular organism	90
colony	91
multicellular organism	91
tissue	91
organ	91
organ system	91
organelle	91
eukaryotic	91
prokaryotic	91
cytoplasm	92
cytoskeleton	92
capsule	92
nucleoid	92
flagellum	92
chloroplast	92
granum	92
ribosome	92
rough endoplasmic reticulum	92
smooth endoplasmic reticulum	92
central vacuole	92
turgor pressure	92
leucoplast	92
cell wall	92
nucleus	93
nucleolus	93
chromatin	93
lipid bilayer	93
lysosome	93
Golgi apparatus	93
centrosome	93

(continued)

CONCEPT REVIEW

1. Not every part of an organism is made of cells; some parts are made from secretions or products of cells. Does this observation fit with the cell theory? Why or why not?
2. Suppose it's the year 2185 and scientists have discovered that something smaller than the cell is the foundation of all living things. How would this discovery affect the cell theory?
3. What is the difference between a colony and a multicellular organism?
4. Do unicellular organisms have tissues? Why or why not?
5. Why should Christians study cells?
6. Which kind of cell contains organelles with membranes around them?
7. List three structures that are found in all types of cells.
8. Draw a eukaryotic cell and include these organelles: nucleus, nucleolus, smooth endoplasmic reticulum, rough endoplasmic reticulum, Golgi apparatus, mitochondrion, lysosome, centrosome, ribosome, cytoplasm, and cell membrane. Label the organelles in your drawing.
9. List three organelles that cells use to move themselves or to move other substances.
10. Place these plant organelles in order from largest to smallest: granum, thylakoid, chloroplast.
11. Which organelle is most responsible for making proteins?
12. What do you think makes the rough endoplasmic reticulum look rough?
13. What are cilia and flagella made of? What function do they both have in cells?
14. Which two organelles in an animal cell are responsible for moving materials to the cell membrane to be released outside the cell?
15. Hair cells come from the same tissue layer that brain cells do. Because of this, researchers have begun to reprogram hair cells to turn them into brain cells in order to study them. How could this research be used to fulfill God's command to love others?
16. How is keeping a seesaw from touching the ground an example of a dynamic equilibrium?



17. When you don't get enough sleep, your body produces high levels of stress hormones to deal with the lack of sleep. Which range of conditions does this example represent? Explain your answer.

18. What is the difference between positive and negative feedback?
19. How are diffusion and osmosis different? How are they the same?
20. How could you turn a hypertonic solution like ocean water into a hypotonic solution relative to the cell?
21. If you add too much fertilizer to your houseplant's water, the plant will die. Why do you think this happens?
22. Which passively travels across the cell membrane more easily—a polar or a nonpolar molecule?
23. Since passive transport doesn't use any energy, how does a particle move from the outside to the inside of a cell?
24. Large molecules can enter a cell passively using _____ or actively using _____.
25. How is active transport different from facilitated diffusion? How are they the same?
26. In the case study on page 101, why can amino acids enter the kidneys but sometimes not exit?

Key Terms (continued)

mitochondrion	93
cell membrane	93
cilia	93
homeostasis	95
positive feedback	96
negative feedback	96
osmosis	97
hypertonic	97
hypotonic	97
isotonic	97
passive transport	98
facilitated diffusion	99
active transport	99

TRUE OR FALSE

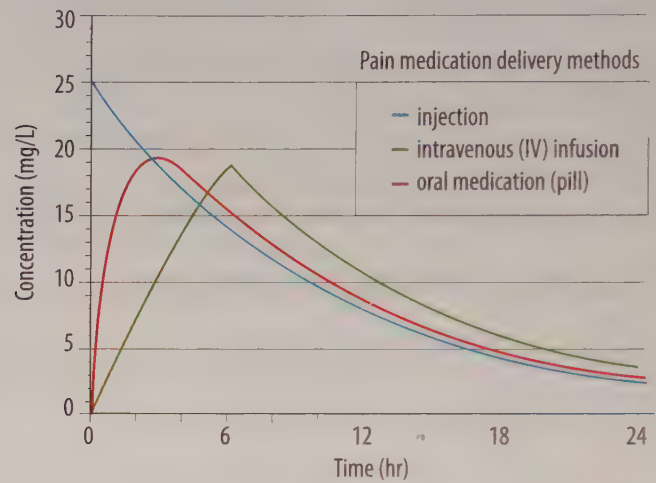
27. The cells that a microbiologist grows in his lab come from already existing cells.
28. The cell theory is so foundational to biology that it may not ever need to be changed.
29. Bacteria are both unicellular and prokaryotic.
30. The Golgi apparatus is the "post office" of the cell.
31. The nucleus is the "powerhouse" of the cell.
32. Both prokaryotic and eukaryotic cells contain genetic material.
33. Even though the current model of the cell is being used to create amazing treatments for people, scientists should continue to learn about the cell to create even better treatments.
34. When you're sick with the flu, your body raises its temperature, giving you a fever, which kills the flu virus. This is an example of a negative feedback.
35. When a cell is in an isotonic solution, the cell is in its optimal range.
36. Diffusion doesn't require any energy to transport materials across a cell membrane, but facilitated diffusion does.
37. Exocytosis uses energy to engulf particles for a cell.

CRITICAL THINKING

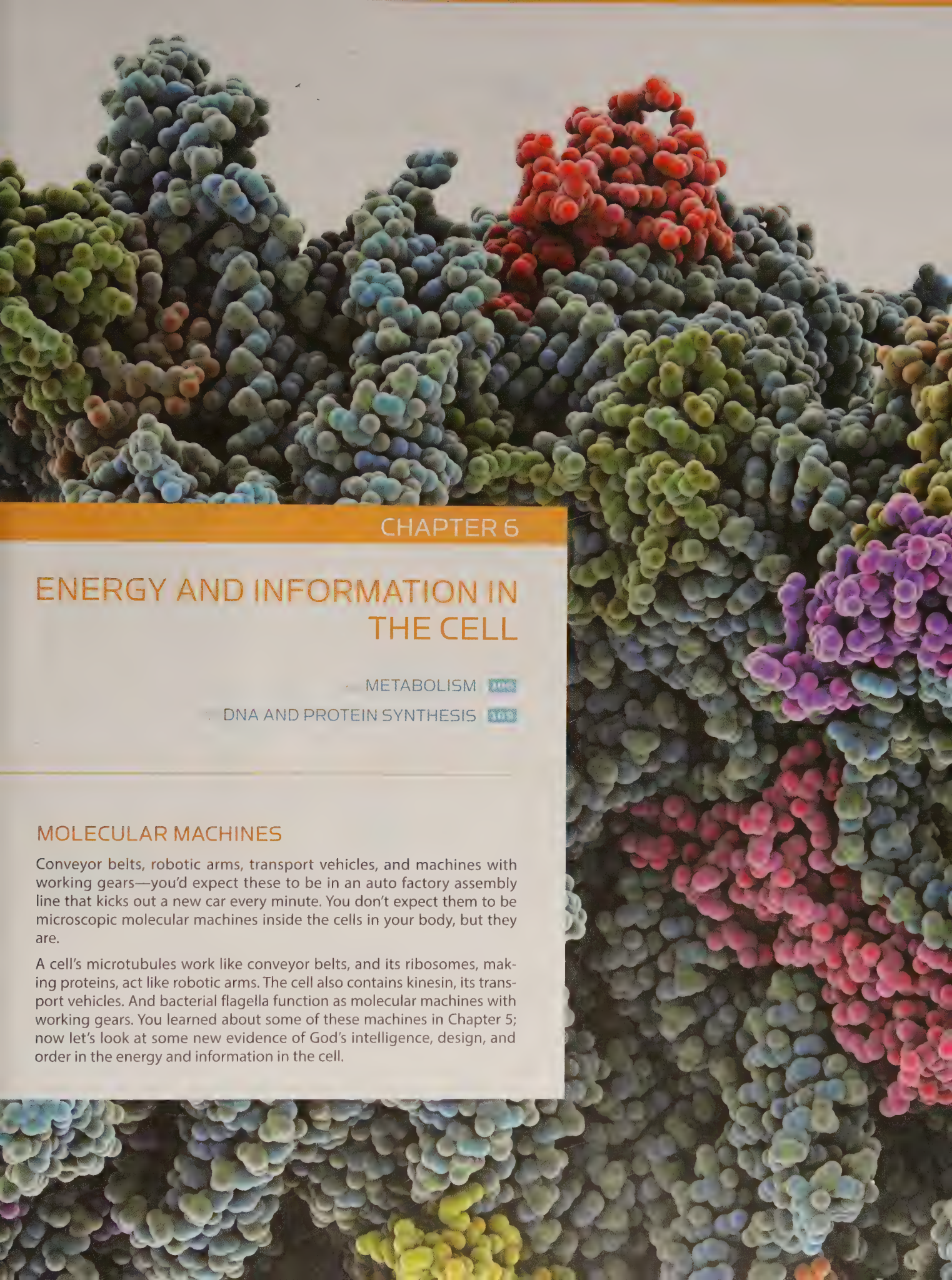
38. When a virus enters a plant cell, it hijacks the cell's nucleus and inserts its own genetic material into it to make more virus particles. This leads to the cell filling with virus particles and eventually dying. Thinking through how each organelle works, how do you think the virus's genetic material takes over and leads to cell death?
39. How are solutions and feedback signals in cells related?
40. Many single-celled organisms that live in a freshwater environment have an organelle called a *contractile vacuole*. This vacuole continually pushes water out of the cell. Why do these organisms need this organelle?

Use the graph below and the following information to answer Questions 41–44.

This graph shows how one kind of pain medication given to a patient in three different ways diffuses through the body. The higher the concentration of pain medication, the less pain the patient feels.



41. Which method of delivering pain medication works best after 14 hours?
42. Why do you think the pill form of the medication starts out with no concentration and the injection form starts out with a high concentration?
43. At what concentration does it appear that the medications are no longer diffusing through the body and are slowly being removed?
44. How could this information be helpful to a physician who has a patient in great pain?



CHAPTER 6

ENERGY AND INFORMATION IN THE CELL

METABOLISM 

DNA AND PROTEIN SYNTHESIS 

MOLECULAR MACHINES

Conveyor belts, robotic arms, transport vehicles, and machines with working gears—you'd expect these to be in an auto factory assembly line that kicks out a new car every minute. You don't expect them to be microscopic molecular machines inside the cells in your body, but they are.

A cell's microtubules work like conveyor belts, and its ribosomes, making proteins, act like robotic arms. The cell also contains kinesin, its transport vehicles. And bacterial flagella function as molecular machines with working gears. You learned about some of these machines in Chapter 5; now let's look at some new evidence of God's intelligence, design, and order in the energy and information in the cell.

6A Questions

- » Where does an organism's energy come from?
- » Where does a cell's energy come from?



autotroph

autotroph: auto- (Gk. *autos*—self) + -troph (Gk. *trophe*—nourishment)

heterotroph: hetero- (Gk. *heteros*—other) + -troph



autotroph



heterotroph

6A |

METABOLISM

What powers a cell?

6.1 | ENERGY AND LIVING THINGS

Staying alive is hard work! In Chapter 2 we learned that living things rely on energy found in their food. Chemical energy gets locked away and stored so that an organism can have it when it needs it.

Organisms that produce their own food are called **autotrophs**. Some living things—called **heterotrophs**—can't make their own food, so they have to get their energy from another living thing that has stored chemical energy. Herbivores, omnivores, carnivores, and parasites are all heterotrophs. Autotrophs are producers and heterotrophs are consumers.

Energy is like money. Autotrophs convert one kind of “money” into another kind by doing a currency exchange, similar to exchanging US dollars for currency in another country. Autotrophs transform energy from the environment into a different form. Likewise, heterotrophs get energy by taking it from another organism! Energy can be saved or it can be spent, but you can't use it any faster than you can get it—there aren't any energy credit cards! The law of conservation of energy reminds us that you can't create energy. Even autotrophs rely on energy transformations.



heterotroph

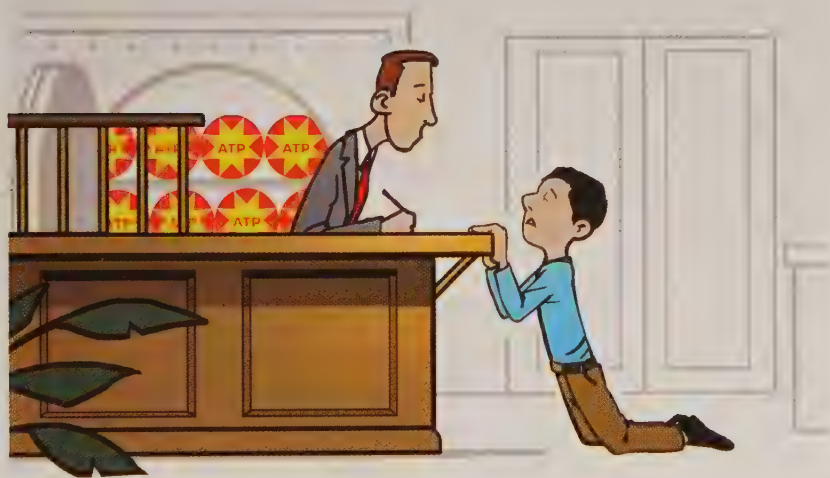
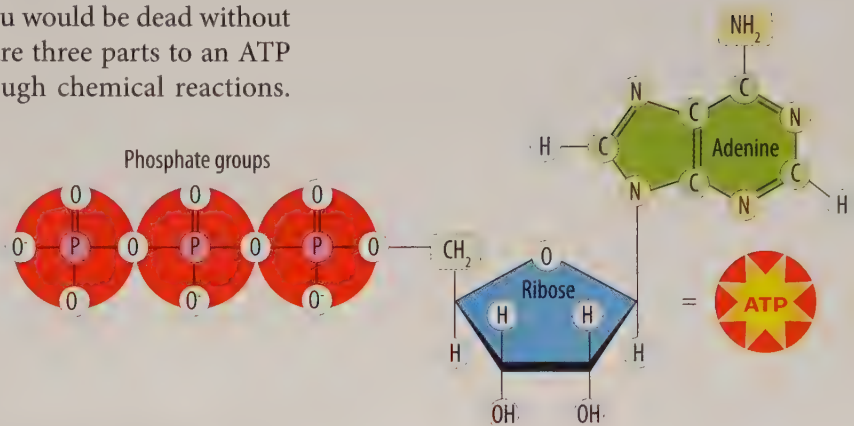
6.2 | ENERGY AND THE CELL

If living things want to store energy to use later, where do they store it? An organism's cells are its “energy bank.” Organisms have to get energy from their food or from light and store it in cells through chemical processes, called **anabolism** (a NAHB eh liz ehm). Living things then use stored energy to carry on life processes through chemical reactions called **catabolism** (kah TAB eh liz ehm). Anabolism combines small molecules to make larger ones that store energy, and catabo-

lism breaks down large molecules into smaller ones to release energy. Anabolism is like building a tower with blocks; catabolism is like tearing the tower down to use the blocks for something else.

The energy released during catabolism, usually in the form of heat, helps make chemical reactions happen in organisms by providing the activation energy needed for life-sustaining reactions to proceed. All the processes that get, save, and spend energy in an organism are called **metabolism**—the sum of the chemical processes that an organism uses to get energy from food to grow and function. The cells in organisms manage metabolism to maintain their homeostasis on the basis of food supply and other factors in the environment.

If energy is like money, then its currency is **adenosine triphosphate (ATP)** (uh DEN uh SEEN • try FOS FATE). You would be dead without this molecule! As you can see below, there are three parts to an ATP molecule. Two parts remain the same through chemical reactions. But the third part, the phosphate tail, is responsible for releasing and storing energy. Notice that all three of the phosphate groups are charged, which means that they push against each other. This is an unstable molecule. ATP is like a compressed spring ready to expand or a \$1 bill waiting to be spent.



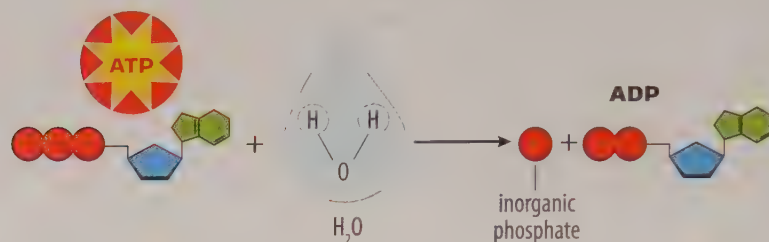
I need to make an energy withdrawal.

Here's how it works. Anabolic processes take small molecules in food like glucose molecules and use them to form large molecules such as starches and fats. This stores energy for long-term use in the form of chemical energy held in the many bonds of these large molecules. But there is too much energy stored here for cells to use all at once, like having just a \$20 bill and needing \$0.50 to buy a drink. If these bonds were all broken at the same time, the energy released would destroy the cell.

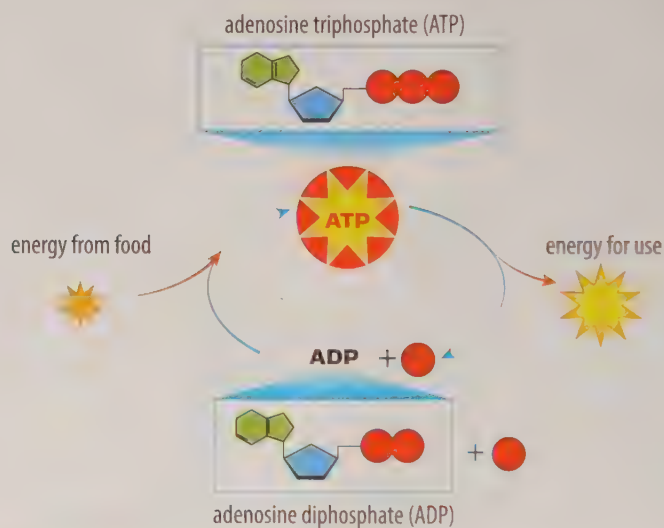
6-1

If energy is like money, then ATP is its currency.

Instead, cells store energy ready for immediate use in ATP. These are manageable packets of energy, or “pocket change” for the cell. When cells need energy, ATP reacts with water to chop off one of the phosphate groups, producing **adenosine diphosphate** (dy FOS FATE) (ADP), one phosphate group, and energy for the cell to use.



One of your muscles can use its entire reserve of ATP molecules in one minute, so what happens when there's no more ATP to power a muscle? Your body very capably recycles ADP. In a working muscle cell, 10 million ATP molecules are used and regenerated every second! The large molecules provide the energy to regenerate ATP. A phosphate group is linked to the ADP molecule, and once again, energy is stored in the bond, ready to be released when the cell needs it to maintain homeostasis. God's provision for life goes down to the molecular level.



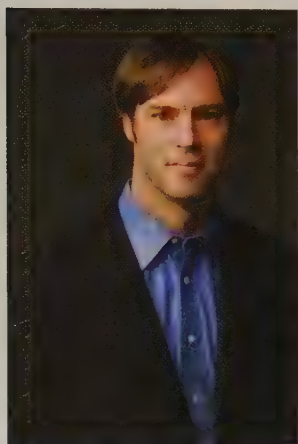
5A SECTION REVIEW

1. Do both heterotrophs and autotrophs have metabolic processes? Explain.
2. Explain how the sources of energy for heterotrophs and autotrophs are different.
3. Identify the structural difference between ATP and ADP.
4. Why can't organisms just use energy as soon as they get it without storing it in ATP?
5. How do ATP molecules store energy for the cell?
6. Explain what an organism does with the energy that it takes in from food or light.

WORLDVIEW SLEUTHING: *SIGNATURE IN THE CELL*

You pop a little chip into your computer, and documents and photos appear. Where did they come from? The information on that chip is stored in a code. Someone designed the chip that stored that code, and you created and saved the information.

You've been learning about the code that is built into cells, codes that can create the cellular machinery in the form of motors (flagella), dump trucks (Golgi bodies), and highway systems (microtubules). You don't question the intelligent design of the memory chip you put in your computer. So why do people question the intelligent design of cellular machinery? Both are the result of code.



Stephen Meyer is a scientist and philosopher, and is the director of Discovery Institute's Center for Science and Culture, the headquarters of the intelligent design (ID) research community. He wrote the book *Signature in the Cell* in which he argues that information always has an intelligent source. Then he demonstrates that DNA contains information—a remarkably complex kind of information. Therefore, DNA (and life itself) has come from an intelligent source.

Introduction

You are a writer for a Christian scientific journal, and you are writing a review of Meyer's book, a classic on ID.

Task

Your task is to write a 150–200 word summary of his book, examining his claims and analyzing them from a biblical perspective.

Procedure

1. Do a search on the title of the book, reading summaries and comments about it. Consider visiting the book's website. If you feel ambitious, you could consider reading parts of or all of the book.
2. Do some research on ID by using the words "intelligent design" in a keyword search.
3. Do a keyword search on ID on the Answers in Genesis website.
4. Plan, write, and revise your review.
5. Get another student or adult to proofread your review, and ask your teacher to publish it on a class website.

Conclusion

The existence of God and His involvement and care for creation extend to the molecular level. When we look at the code for creation, we are driven to see God's "signature in the cell."

6B

DNA AND PROTEIN SYNTHESIS

What guides a cell's growth and function?

6.3 THE CODE OF LIFE

If energy is like money, and ATP is like currency, then the cell is a whole Wall Street of buyers and investors! Though it seems chaotic, there is a carefully ordered flow of energy and information within the cell. Cells know just what to do to get energy out of storage and how to use it in metabolic processes to sustain life and maintain homeostasis. As the energy for life extends down to the molecular level, so also the information of life is coded in molecules in the cell. The molecule that is responsible for this is **deoxyribonucleic** (dee AHK see RYE boh noo KLEE ik) **acid (DNA)**. DNA is a nucleic acid made of a chain of nucleotides that stores information. This information is used to direct the metabolic processes of the cell and will also be copied and transmitted when a cell reproduces.

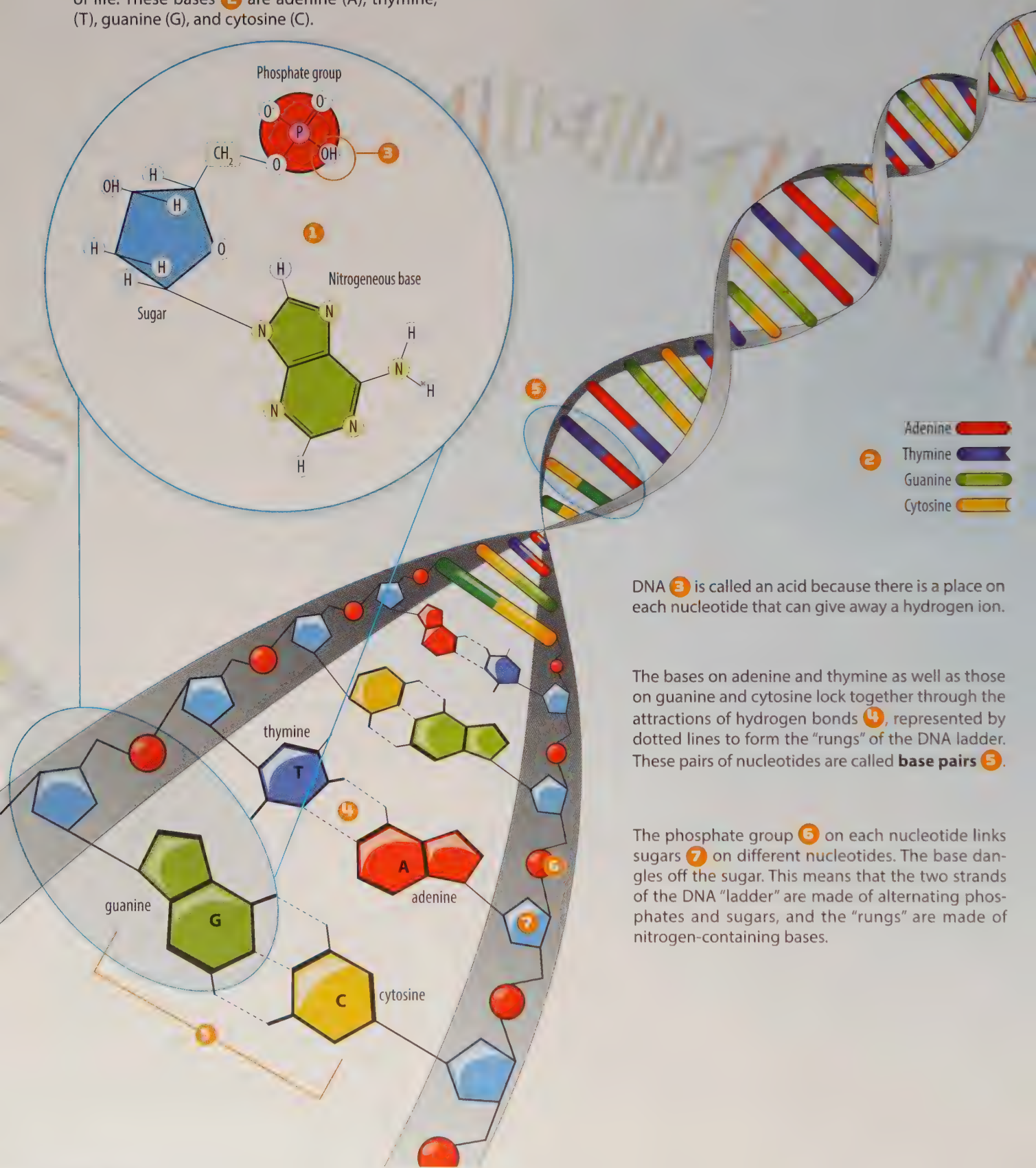
6B Questions

- » Where does a cell's information come from?
- » How does this information guide a cell's growth and function?

XNAs

Recently, scientists have been able to string together nucleotides in polymers that behave just like real DNA and RNA. These artificial polymers, called **XNAs**, have the potential to create artificial proteins and enzymes. Scientists have worked hard to make enzymes because they think that it proves that evolution can happen in other ways than through the work of actual DNA or RNA. What do you think? Suggest a better application of this science to help God's image bearers.

Nucleotides **1** have three parts—a nitrogen-containing base, a sugar, and a phosphate group. The phosphates and sugars in every DNA nucleotide are the same, but the nitrogen-containing base is different. There are four different types of bases, often represented with letters in the code of life. These bases **2** are adenine (A), thymine (T), guanine (G), and cytosine (C).



The two strands of DNA look like a twisted ladder, which scientists call a **double helix** **8**.

DNA can be copied when enzymes pull apart the base pairs to unzip **9** the DNA.

Actual photograph of DNA replication bubble **10**

Another enzyme called *DNA polymerase* **11** shuttles in nucleotides that match each unzipped part of the DNA. When the strands have been completely unzipped and matching nucleotides are linked together, two copies have been created in a process called **replication**. Mistakes in the replication process can cause **mutations** when a nucleotide is mistakenly inserted, deleted, or skipped altogether. The cells have repair enzymes to recognize and repair mistakes added during the replication process. This is a powerful evidence of design since, without these enzymes, mutations could have disastrous effects on an organism. However, some mutations persist, usually causing trouble for organisms.



6.4 BUILDING PROTEINS

Cells make copies of DNA for two reasons: to get a cell ready to divide, so that the new cell will have the information it needs to continue life processes, and to make proteins.

Proteins are the machines that help a cell do its job. DNA is like the blueprints for a skyscraper, and proteins are like the dump trucks, bulldozers, and cranes that turn the blueprints into an actual building. Enzymes are proteins that fulfill a specific purpose to make metabolic processes happen in living things. As we saw in Chapter 2, proteins are chains of smaller molecules called *amino acids*. These large chains fold into complex shapes that help a protein do its job.

So how does a cell use DNA to make proteins? The cell makes a copy of a section of DNA, but this copy has only one strand with a few

6-2

Transcription happens in the nucleus; translation happens in the cytoplasm.



modifications. This single-strand nucleic acid is called **ribonucleic acid (RNA)**. This process takes place in the nucleus and is called **transcription**.

1 RNA polymerase

First, the cell unzips DNA just as if it were undergoing replication. But instead of DNA polymerase stepping in, another enzyme called *RNA polymerase* begins to make one copy of one side of the chain.

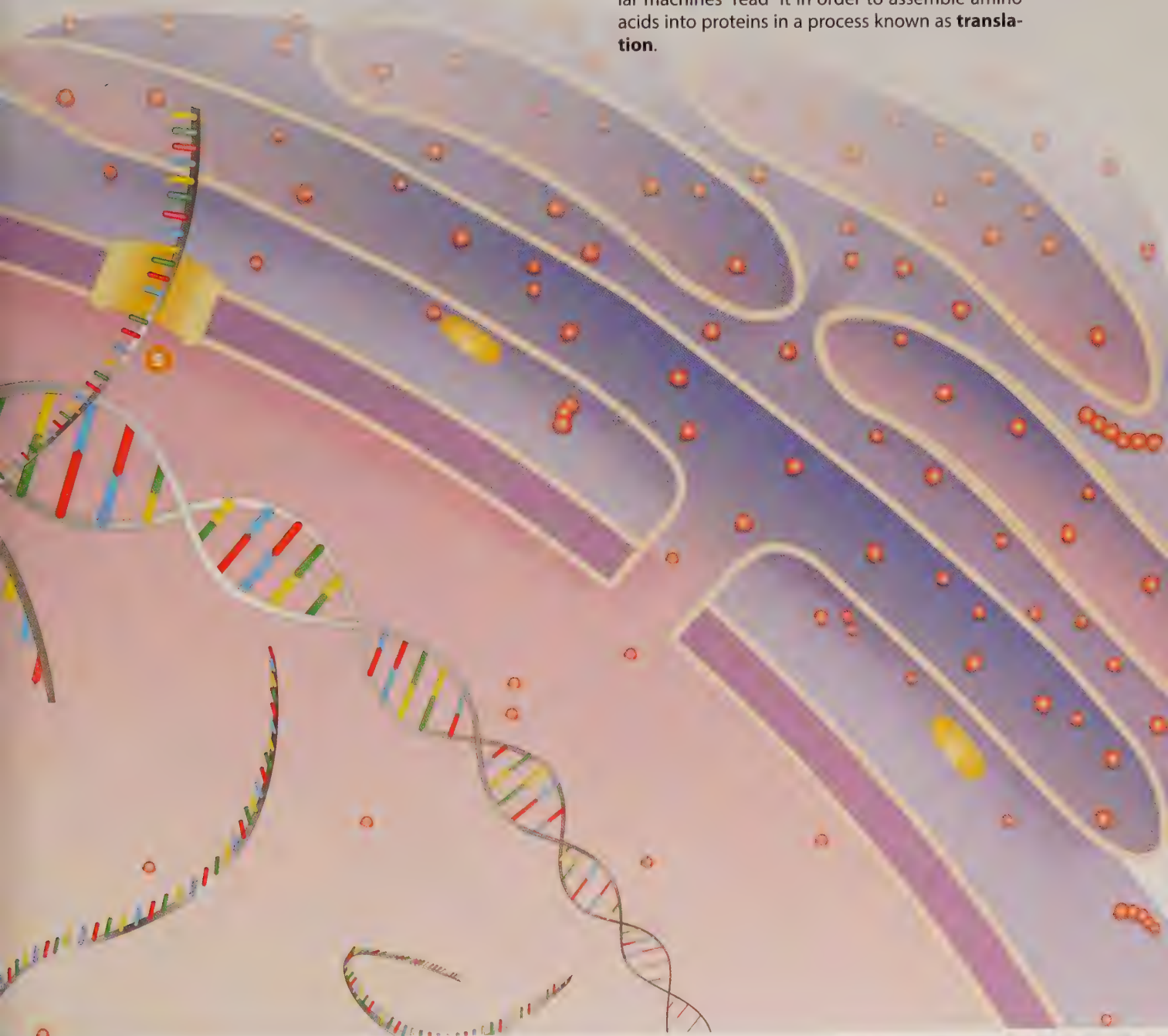
2 Differences between DNA and RNA

RNA is a single strand, rather than a double helix. In RNA strands, thymine is replaced by uracil (U). Also, the sugar part of the nucleotides in RNA is different than the one in DNA, having one extra oxygen.

Introns 3 are sections of the RNA transcript that don't contain information about the protein being produced. They are cut out of the RNA before it is sent from the nucleus to make proteins. Biologists are still exploring the not yet completely understood role of introns in the function of RNA.

Exons 4 are sections of the RNA that code for proteins, so they are included in the final version of RNA transcript that is sent out of the nucleus to be translated into proteins.

The newly transcribed strand of RNA leaves the nucleus 5 to go to the cytoplasm where cellular machines "read" it in order to assemble amino acids into proteins in a process known as **translation**.



TRANSLATION

1 Nuclear pore

After transcription, the final version of RNA leaves the nucleus for the translation process. This RNA is specifically referred to as *messenger RNA (mRNA)* because of the purpose it fills—to carry the code from the nucleus to the cytoplasm.

2 rRNA

The cellular machine that links the amino acids brought to it by tRNA to be linked into a protein is called a *ribosome*. It contains another type of RNA called *ribosomal RNA (rRNA)* that is used to make proteins. The messenger RNA runs through the ribosomal RNA like dental floss runs between teeth.

3 Ribosome

There are three active sites on the ribosome. Two hold tRNAs with their amino acids, and a third is the exit site for tRNAs that have already lost their amino acid to the protein chain.

4 tRNA

Another type of RNA, *transfer RNA (tRNA)*, picks up amino acids in the cytoplasm. On one of the four prongs of tRNA are three unattached bases called **anticodons**, which align with codons on the mRNA strand to properly position amino acids for the new protein chain being built. The tRNA is assembled and released from the nucleus just as mRNA is.

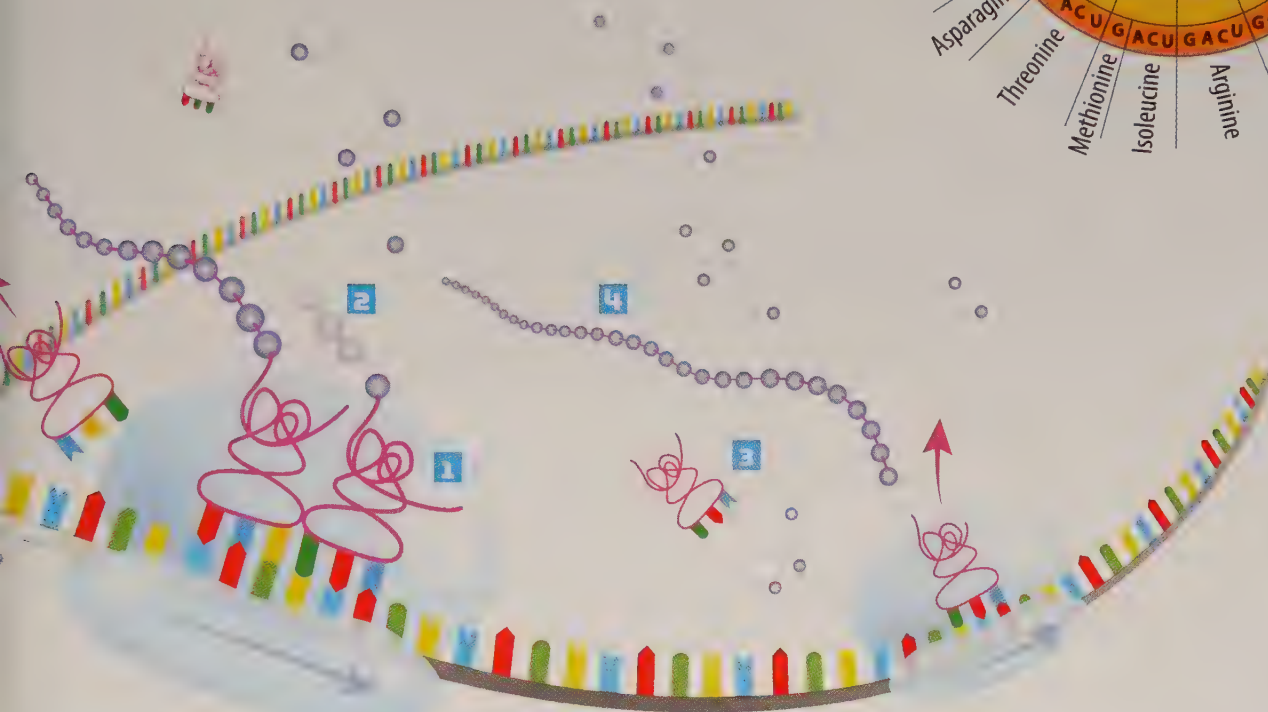
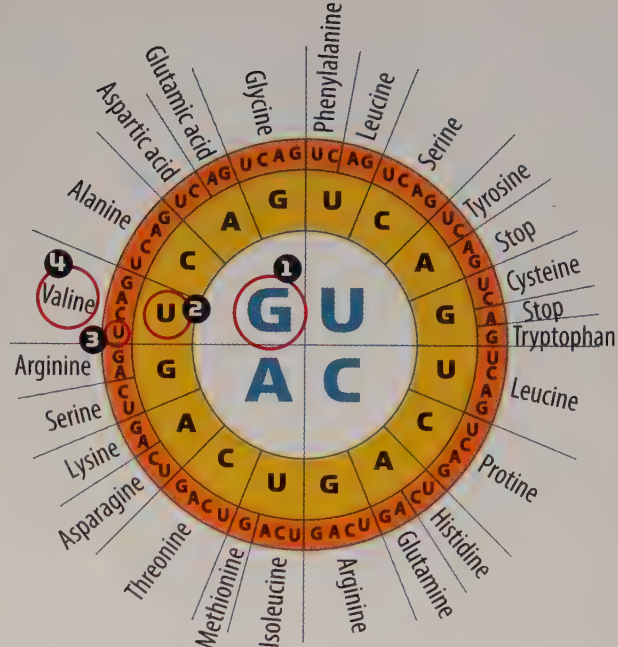
5 Protein chain

When two anticodons are lined up with their corresponding codons, they dock to form a *peptide bond* between their amino acids in a process called **protein synthesis**. As protein builds, it forms its own signature folds and turns on the basis of chemical interactions.



Reading Codons

Like using letters to form words, three consecutive nucleotides form **codons**, which are triplets of nucleotide bases in the RNA transcript that provide the code for an amino acid during translation. The combination of bases in a codon codes for one of 20 possible amino acids to add onto a protein chain. For example, in the codon GUU, the first letter represents guanine **1**, the second is uracil **2**, and the third is uracil **3**. That codon codes for valine **4**. Valine is an amino acid that can be used to build a protein, which you can see below.



6B SECTION REVIEW

1. How does DNA contain information?
2. In your own words, describe the DNA replication process.
3. Compare DNA and RNA. You may choose to use a graphic organizer like a T-chart (see Appendix B).
4. How does the information in DNA help a cell grow and function?
5. Name the three types of RNA and give their purposes.
6. Create a process map relating the terms DNA, RNA, protein, amino acid, transcription, and translation. Show which processes happen in the nucleus and which happen outside the nucleus (see Appendix B).
7. What happens when there is a mistake in the transcription or translation process? What do we call this phenomenon?
8. After learning about the energy and information in the cell, how would you respond to the quote below by Richard Dawkins, a biologist and one of the world's most outspoken atheists?

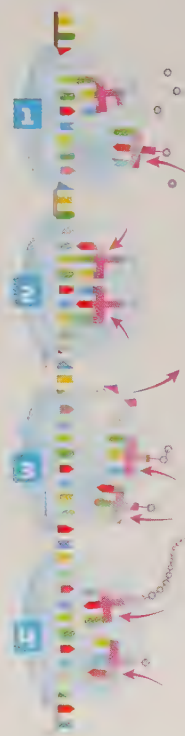
"We are machines built by DNA whose purpose is to make more copies of the same DNA. . . . This is exactly what we are for. We are machines for propagating DNA, and the propagation of DNA is a self-sustaining process. It is every living object's sole reason for living."

A tRNA carries an amino acid to the ribosome. If its anticodon fits with the codon, it docks to form base pairs with the messenger RNA strand.

A second tRNA carrying a matching anticodon docks. This loosens the tRNA's grip on the amino acids. These amino acids form bonds with the addition of energy from ATP to form a peptide bond.

The ribosome moves down the mRNA to read a new codon, and the tRNA that has transferred its amino acid to the protein chain exits so that another can take its place.

The protein forms its own signature folds and turns as it is manufactured.



T

Key Terms

anabolism	106
catabolism	106
metabolism	107
adenosine triphosphate (ATP)	107
adenosine diphosphate (ADP)	108
deoxyribonucleic acid (DNA)	109
base pair	110
replication	111
mutation	111
ribonucleic acid (RNA)	113
transcription	113
translation	113
anticodon	114
protein synthesis	114
codon	115

CHAPTER 6

REVIEW QUESTIONS

CONCEPT REVIEW

1. How are the two types of metabolic processes related?
2. Why do living things need both anabolic and catabolic processes?
3. Where is energy stored in ATP?
4. Draw a process diagram that shows the relationship between ATP, ADP, energy, and a free phosphate group.
5. What smaller units make up DNA?
6. Which parts of a nucleotide form the backbone and rungs of the double helix?
7. What holds a base pair together?
8. What unzips DNA for replication?
9. List three ways RNA is different from DNA.
10. What is the difference between transcription and translation?
11. Explain how a protein comes from DNA.

TRUE OR FALSE

12. Living things get their energy from ATP.
13. When living things eat, they take in ATP from their food.
14. Adenine is an example of a nucleotide.
15. During DNA replication, the cell makes a perfect copy every time.
16. Codons are the three parts of a nucleotide.
17. The different types of RNA are the same strand of RNA in different places in the cell.
18. There are three types of RNA involved in making proteins.

CRITICAL THINKING

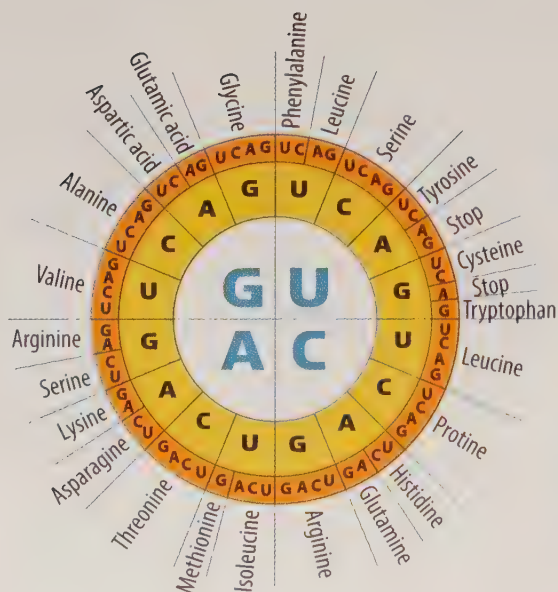
19. Using the codon circle chart on the left, decipher the code below and name the three amino acids that it represents.

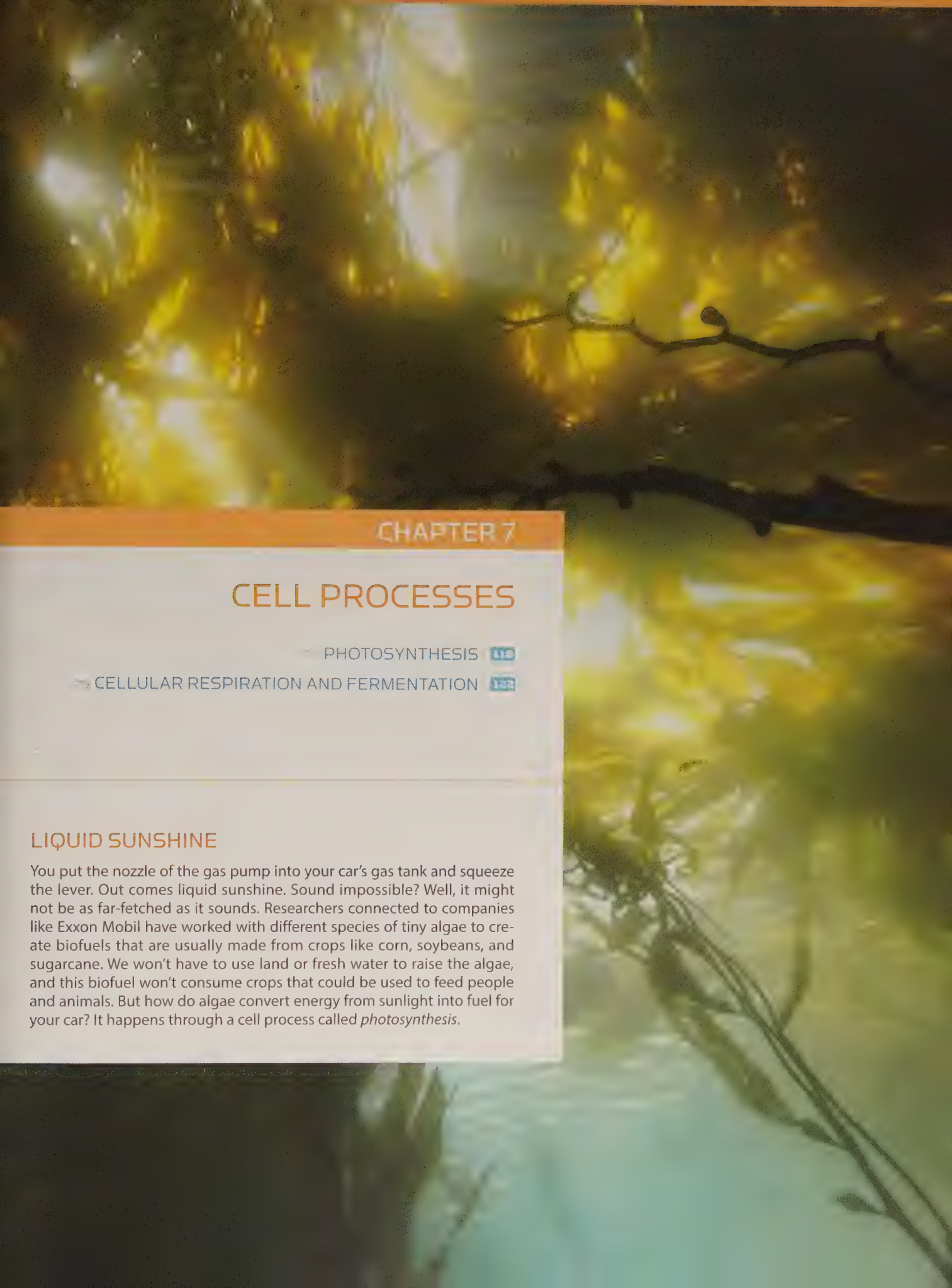
GGU GGA UGG

For Questions 20–22, use the code of bases from a single strand of DNA shown below.

GGAATCGGACTATGGGT

20. Make the second strand of DNA.
21. Make the second strand of DNA that includes one mutation.
22. Make a strand of RNA.





CHAPTER 7

CELL PROCESSES

PHOTOSYNTHESIS 110

CELLULAR RESPIRATION AND FERMENTATION 122

LIQUID SUNSHINE

You put the nozzle of the gas pump into your car's gas tank and squeeze the lever. Out comes liquid sunshine. Sound impossible? Well, it might not be as far-fetched as it sounds. Researchers connected to companies like Exxon Mobil have worked with different species of tiny algae to create biofuels that are usually made from crops like corn, soybeans, and sugarcane. We won't have to use land or fresh water to raise the algae, and this biofuel won't consume crops that could be used to feed people and animals. But how do algae convert energy from sunlight into fuel for your car? It happens through a cell process called *photosynthesis*.

7A Questions

- » How can a cell generate its own energy?
- » What happens to photosynthesis when factors in the environment change?

PHOTOSYNTHESIS

How does a cell convert light energy into chemical energy?

7.1 HARVESTING LIGHT

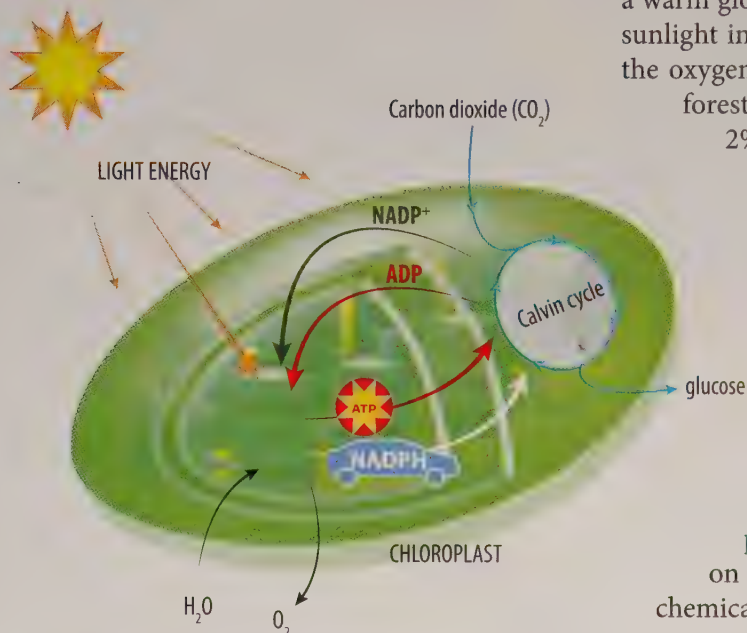
A kelp forest sways in the undulating current of an ocean bay. Its leaf-like colonies bask in the sunlight that fills the green waters with a warm glow. The same process that grows kelp also helps algae turn sunlight into biofuel. What you might not expect is that 70–80% of the oxygen that we breathe comes from algae in the oceans! Rainforests produce the other 20–30%, but they cover only about 2% of the earth's surface, though 50% of the organisms on our planet make their home there. Compare that with the oceans, which cover 71% of the earth's surface. You can see why algae are pretty important to the rest of life in the world.

So why don't you make your own energy like algae do when you go out into the sun? It would definitely save on grocery bills! The reason is that you don't have the right information or organelles in your cells to pull off this feat. It takes specially designed cells and special enzymes to turn sunlight into food through the process of **photosynthesis**. Without photosynthesis, widespread life on Earth wouldn't be possible. In Chapter 2, we studied the chemical reaction that describes the process of photosynthesis.

Just as there are two parts to the *word* photosynthesis, meaning “light” and “forming,” there are two stages to the *process* of photosynthesis. The first involves capturing the energy from sunlight, called the **light-dependent phase**. The second involves changing that energy into a form that an organism can use by making special chemicals—the **light-independent phase**. These two phases of photosynthesis take place in different parts of a cell's chloroplast.

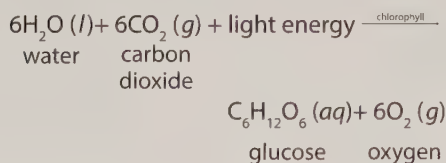
As you study the following images that show the process of photosynthesis, make sure that you look for two pairs of chemicals to see what's happening to the energy in these reactions. You already know about one pair of chemicals—ADP and ATP. When ATP is produced, the process stores energy. When ADP is produced, the process releases energy.

The other pair of chemicals to keep your eyes on is $NADP^+$ (*nicotinamide adenine dinucleotide phosphate*) and NADPH. $NADP^+$ is like an electron shuttle, and when it captures hydrogen ions and electrons, $NADP^+$ bonds with hydrogen ions and takes up electrons. It also links a phosphate group with ADP to form ATP. Without these two pairs of molecules, photosynthesis won't happen at all.



7-1

The two stages of photosynthesis that take place in different parts of a cell's chloroplast are the light-dependent and light-independent phases.



photosynthesis: photo- (L. *photo*—light) + -synthesis (L. *synthese*—to make)

Photosynthesis Phase 1: Light-Dependent Phase

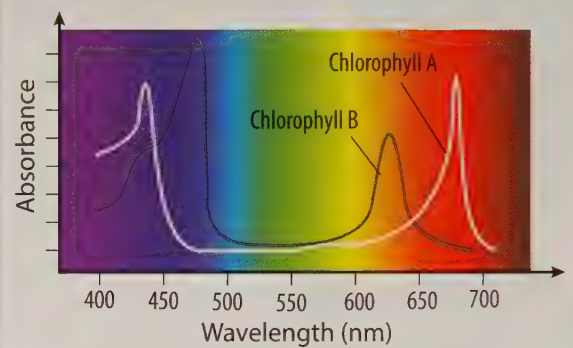
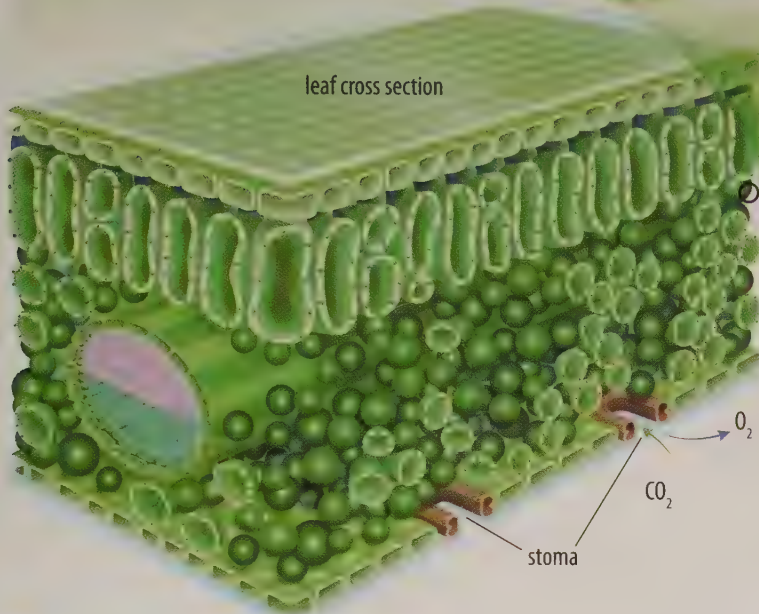
1 During the first phase of photosynthesis, the light-dependent phase, cells gather energy from light. For plants, water comes from the roots, and carbon dioxide comes in through the tiny openings called *stomata* (s. stoma) on the undersides of leaves. As a byproduct of photosynthesis, stomata also release the oxygen that we breathe.

chloroplast

2 Sunlight enters the chloroplasts in plant cells, passing through the clear fluid in the chloroplasts called **stroma**.

3 In the interior of the chloroplasts are *grana* (s. granum), stacks of green sacks called **thylakoids** (THY luh KOYDS). Each thylakoid is a membrane-bound compartment.

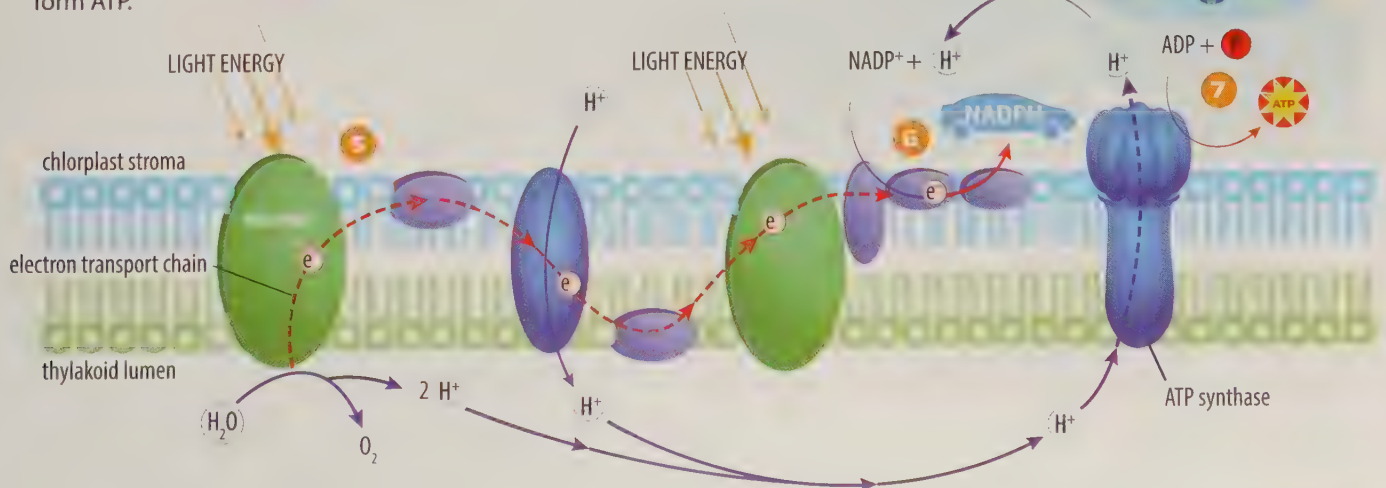
4 Thylakoid membranes contain **chlorophyll** embedded in strategic places. Chlorophyll is a chemical, a *pigment* that absorbs energy from sunlight to produce its green color. It uses sunlight to energize electrons, which kick off photosynthesis. Without chlorophyll, photosynthesis doesn't happen!



Chlorophyll appears green and makes plants and algae look green because it absorbs all the other colors of light and reflects green light.

5 When chlorophyll reacts with light, it splits water molecules to produce high-energy electrons and hydrogen ions (H^+). These electrons fall through a series of protein molecules like water over a water wheel in a system called the **electron transport chain**. Energy from the electron transport chain increases the H^+ in the thylakoid and decreases H^+ in the chloroplast stroma.

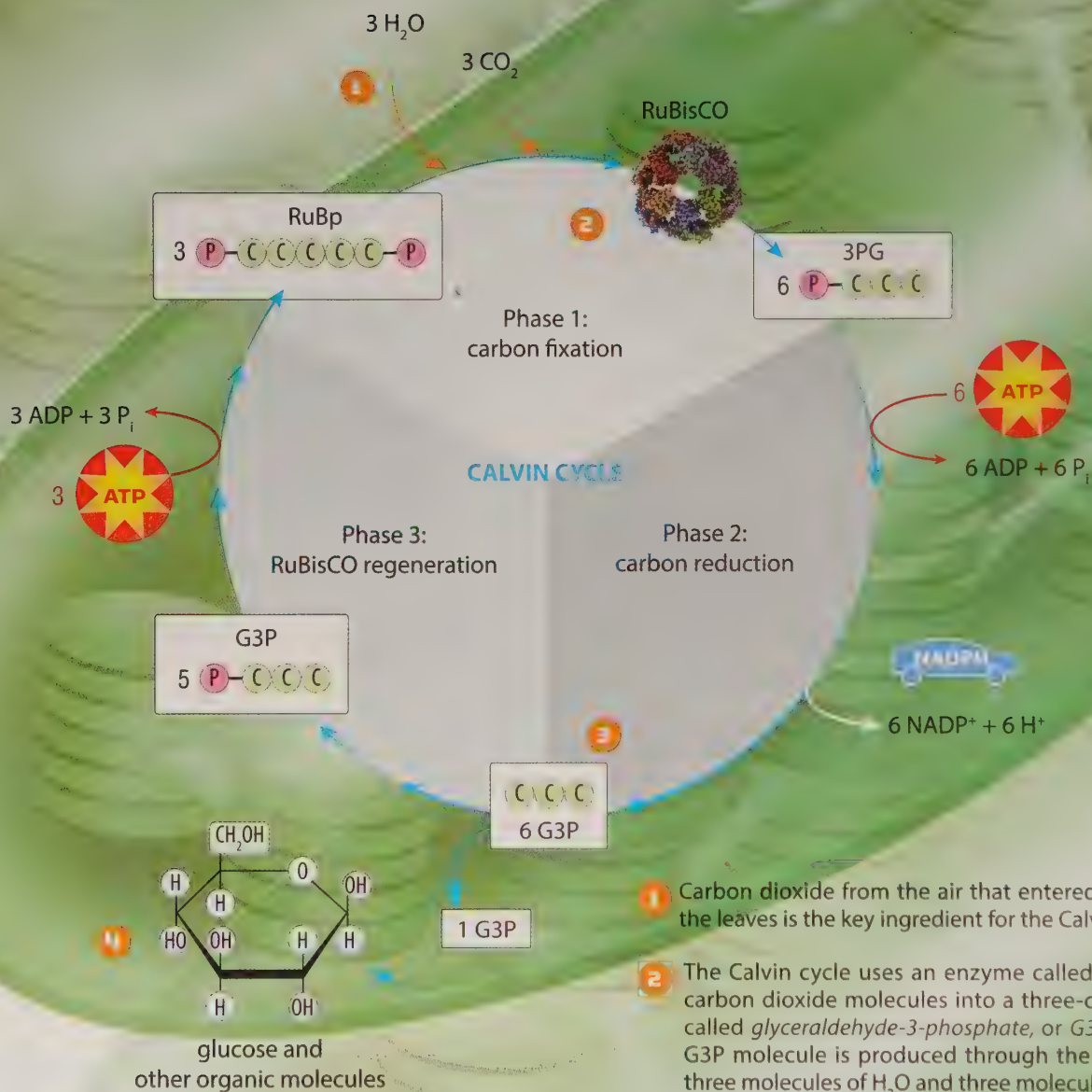
6 The hydrogen ions and electrons are released into the stroma through a protein that turns the molecule $NADP^+$ into $NADPH$. $NADP^+$ is like an electron shuttle in the stroma. When hydrogen ions and electrons enter the stroma, $NADP^+$ bonds with the hydrogen ions and takes up electrons. $NADP^+$ keeps the electron chain going. ATP synthase **7** links a phosphate group with ADP to form ATP.



Photosynthesis Phase 2: Light-Independent Phase

Now the second phase of photosynthesis begins. It does not rely on sunlight, and so is called the light-independent phase. NADPH and ATP from the electron transport chain enter the stroma to fire up the Calvin cycle in order to make food.

In the **Calvin cycle**, ATP provides energy to turn carbon dioxide and water into glucose. NADPH provides electrons to keep this cycle going. Note the number of carbons at each step in the Calvin cycle, showing how carbon dioxide with one carbon becomes glucose with six carbons.



- Carbon dioxide from the air that entered the stomata of the leaves is the key ingredient for the Calvin cycle.
- The Calvin cycle uses an enzyme called *RuBisCO* to link carbon dioxide molecules into a three-carbon molecule called *glyceraldehyde-3-phosphate*, or *G3P*. Only one *G3P* molecule is produced through the Calvin cycle for three molecules of H_2O and three molecules of CO_2 . All the other molecules are fed back into the Calvin cycle to continue the process.
- Cells use *G3P* molecules to make glucose for food and other sugars like cellulose for structure. It takes nine ATP molecules and six NADPH molecules to produce one *G3P* molecule. It takes two *G3P* molecules to make one glucose molecule.

7.2 ENVIRONMENT AND PHOTOSYNTHESIS

In the photosynthesis diagram in Figure 7-1 on page 118, notice that plants and other photosynthetic organisms need light, carbon dioxide, and water to make glucose. Plants usually have enough carbon dioxide and light to undergo photosynthesis. But in some biomes, like the desert and chaparral, water can be scarce. So how do plants cope to maintain homeostasis?

Most plants are called C3 plants, which means that they use the Calvin cycle to produce a three-carbon precursor of glucose, G3P. These G3P molecules can also be used to create starch, cellulose, sucrose (table sugar), and fructose for plants.

But when it gets hot and dry, as plants open their stomata to take in carbon dioxide, they lose water. When there's not enough water, the Calvin cycle can't make G3P molecules. Instead, it *uses up* oxygen and *produces* carbon dioxide, opposite of the way the cycle normally works. This process is called *photorespiration*. But photorespiration is a kind of survival mechanism for plants, not normal operating procedure!

To get around photorespiration, some plants, called *CAM plants*, open their stomata only at night when it is cooler so that they can take in carbon dioxide without losing water to their environment. Instead of creating G3P, they create other compounds that can be made into glucose. But these processes are not as energy efficient as the Calvin cycle. They cost more ATP molecules to make glucose. Succulents like pineapples, cacti, and orchids are CAM plants.

Another option is for plants to just continue the Calvin cycle with less carbon dioxide. Instead of creating a three-carbon G3P precursor to glucose, these plants create a four-carbon molecule, though it requires more energy. Because of this, these plants are called C4 plants. Corn and sugar cane are examples of C4 plants. Both operate like C3 plants within limits when conditions are more favorable for the Calvin cycle to produce G3P.

Now let's step back and see how photosynthesis affects the biosphere. Light energy is the only significant source of energy in many ecosystems. Plants absorb only about 50% of the total light energy available to them. The rest is reflected or lost as heat. Of the absorbed light energy, about 2% is actually stored in sugar. Of that energy stored in sugar, the plants use about 50% for their own metabolism. This means that, of all the light energy available to plants, only about 0.5% is available to the first consumer. It's amazing that the rest of the biotic community can thrive on such a small percentage of the energy from the sun. Ultimately, the sun is responsible for sustaining life on Earth.

7-2

Pineapples take in carbon dioxide at night, producing a chemical that can be stored in vacuoles and used during the day to complete photosynthesis.



7A SECTION REVIEW

1. According to Genesis 1:29–31, how does God use photosynthesis to provide for life all over the world?
2. How can people exercise good and wise dominion over the process of photosynthesis for God's glory?
3. Diagram the chemical reaction of photosynthesis, using red circles to symbolize oxygen, white circles to symbolize hydrogen, and black circles to symbolize carbon. Use the chemical reaction to determine how many molecules you need.
4. Why are plants and algae green?
5. God has designed the stroma to be a clear fluid. Explain what could happen if the stroma was opaque to light.
6. List the two stages of photosynthesis and describe where they take place.
7. Create a process map that shows the different steps of photosynthesis. Make sure to account for all reactants, catalysts, and products in the chemical equation for photosynthesis. Also make sure that you show the flow of energy in this process. (See Appendix B.)

7B

7B Questions

- » How does a cell use energy?
- » What is the role of oxygen in cellular respiration?
- » How does cellular respiration help in the cycling of matter and energy through the environment?

CELLULAR RESPIRATION AND FERMENTATION

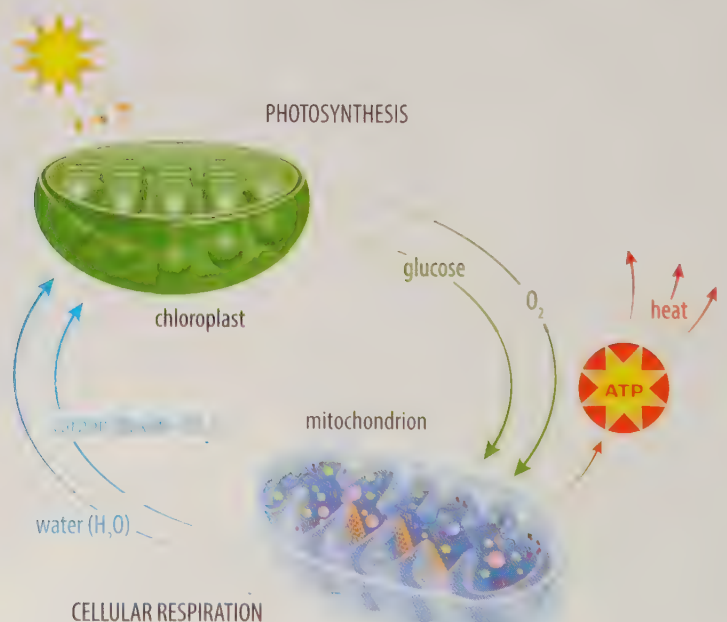
How does a cell free up chemical energy in sugar?

73 CELLULAR RESPIRATION

You already know that people and animals eat to get energy from their food. In the last section we saw how plants and other photosynthetic organisms make food from the water, carbon dioxide, and sunlight in their environment. Both producers and consumers get energy from energy-containing molecules in their food through a different process—**cellular respiration**. It's a meal of molecules!

7-3

Photosynthesis uses light energy and happens in the chloroplast; cellular respiration happens mostly in the mitochondrion and produces ATP.



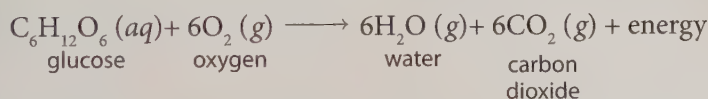
These energy-containing molecules are glucose or other sugars, lipids, and even proteins. Cellular respiration produces energy in the form of ATP that can be used to fuel the processes of life for both producers and consumers.

Cellular respiration is similar to the chemical process of photosynthesis but in reverse. Photosynthesis takes place in the chloroplasts of photosynthetic organisms; cellular respiration occurs in the mitochondria, and most eukaryotic cells have these organelles (see Figure 7-3).

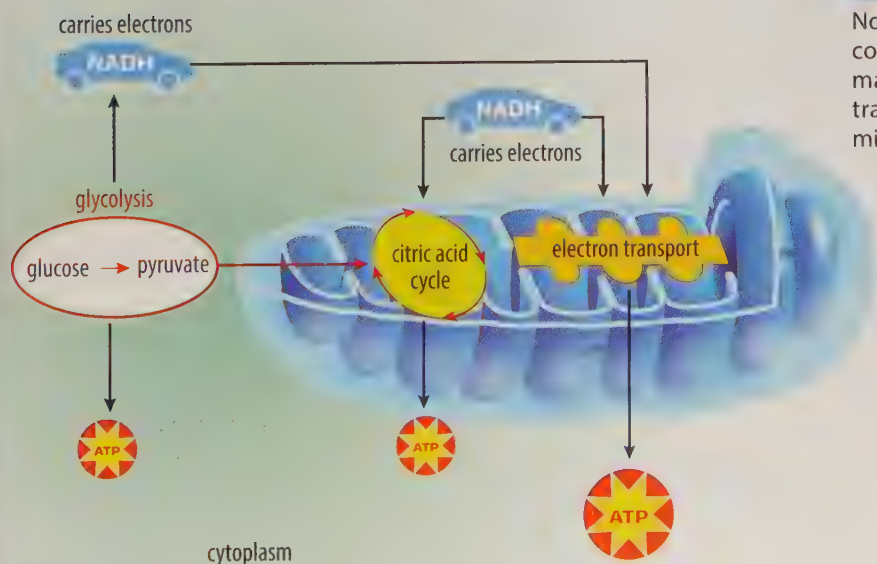
The energy from photosynthesis is stored in the bonds of glucose. When plants need energy for cell processes, they can break down glucose in a series of steps called **glycolysis** to release the energy and form ATP. When herbivores and omnivores eat plants, they get the glucose and other energy-containing molecules that plants store. This means that other organisms besides plants can carry out glycolysis.

Cellular respiration is very much like burning fuel. It usually requires oxygen, so it is an **aerobic** process. We'll see later on that fermentation can occur without oxygen in what are called *anaerobic processes* (see the next subsection), but less energy is produced.

There are three phases of aerobic cellular respiration: glycolysis, the citric acid cycle, and the electron transport chain. Glycolysis occurs in a cell's cytoplasm, and the citric acid cycle and electron transport chain take place in the mitochondria. The **citric acid cycle** takes smaller molecules produced by glycolysis and uses them to form citric acid. The cycle then gradually takes atoms from this 6-carbon molecule to produce ATP, NADH, and carbon dioxide. The main function of the citric acid cycle is to harvest high-energy electrons to feed into the electron transport chain. This process occurs in the mitochondria as the last phase of cellular respiration. See the chemical reaction for cellular respiration below.



aerobic: aero- (Gk. *aero*—air) + -bic (Gk. *bios*—life); requiring air to live



7-4

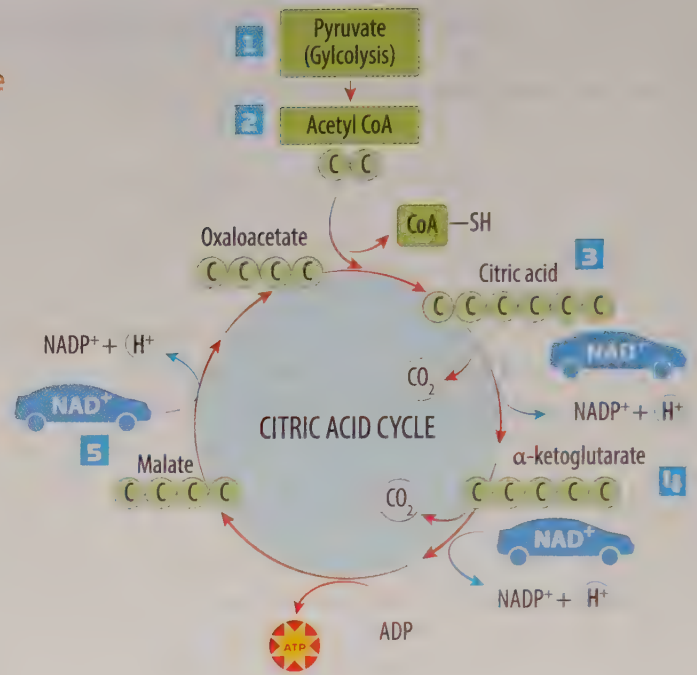
Notice the three parts of cellular respiration: glycolysis in the cytosol, the citric acid cycle in the matrix of the mitochondrion, and the electron transport chain in the inner membrane of the mitochondrion.

Cellular Respiration Phase 1: Glycolysis

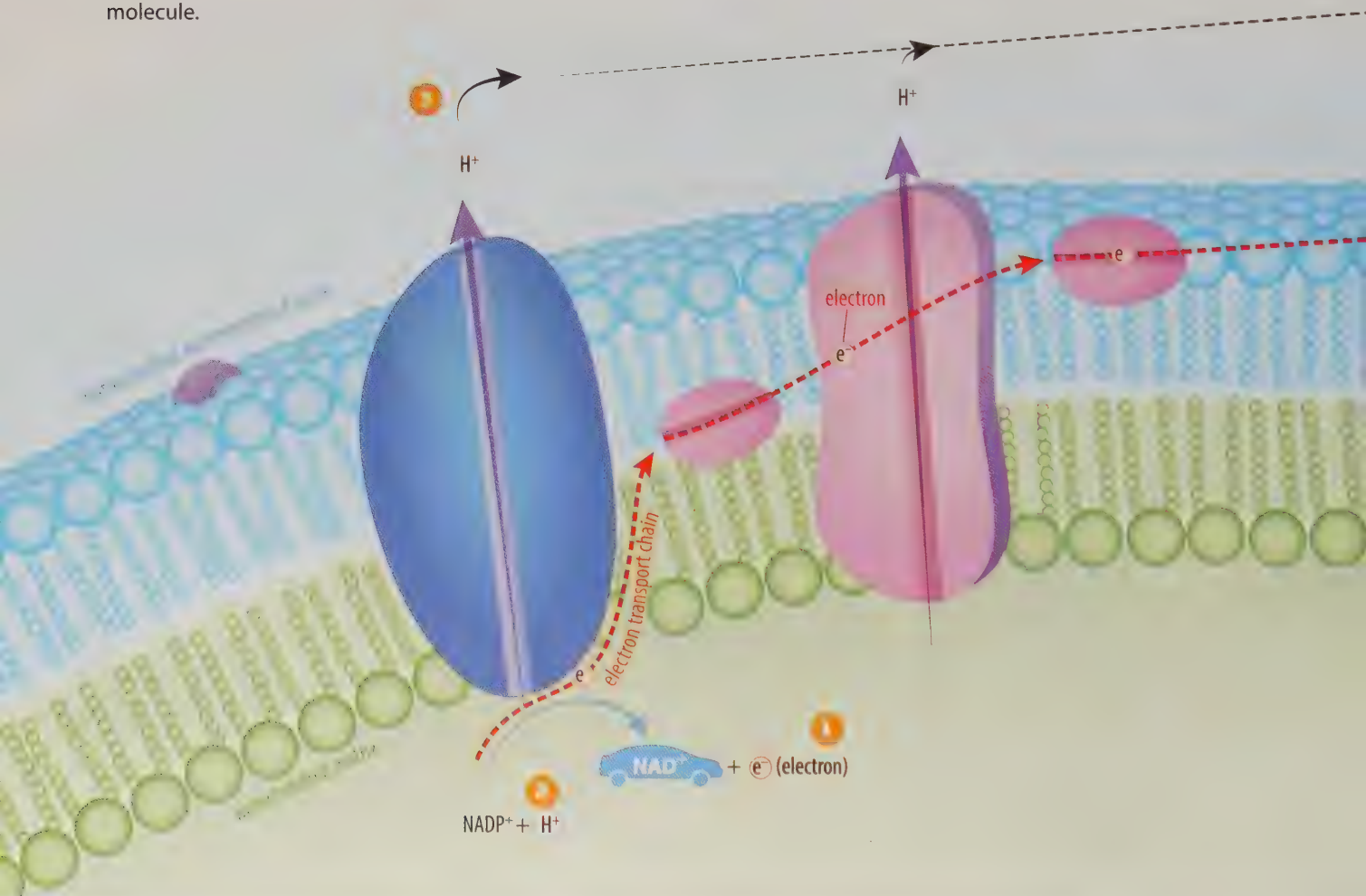
Cellular Respiration Phase 2: Citric Acid Cycle

The citric acid cycle happens in the fluid of the innermost part of each mitochondrion, called the *matrix*. It releases carbon dioxide, which can be exhaled or simply allowed to diffuse back into the environment, and energy, which an organism can use. Overall, the citric acid cycle produces one molecule of ATP each time around. It takes pyruvate from glycolysis to drive the citric acid cycle so that it can transport high-energy electrons to the electron transport chain that will eventually produce large amounts of ATP.

- 1** Pyruvate from glycolysis migrates into the mitochondrion, where one carbon breaks off to form carbon dioxide and a 2-carbon coenzyme called *acetyl CoA*.
- 2** Acetyl CoA combines with a 4-carbon molecule to form citric acid, which has six carbons like glucose.
- 3** Citric acid loses a carbon to carbon dioxide, generating one molecule of NADH in the process and a 5-carbon molecule called *α-ketoglutarate*.
- 4** The 5-carbon molecule from the previous step loses another carbon to carbon dioxide, generating another NADH molecule and one molecule of ATP. It forms a four-carbon molecule.



- 5** The last step of the citric acid cycle turns four-carbon molecules into oxaloacetate, which retains all four carbons. Oxaloacetate will combine with more pyruvate from glycolysis to start the cycle all over again.



Cellular Respiration Phase 3: Electron Transport Chain

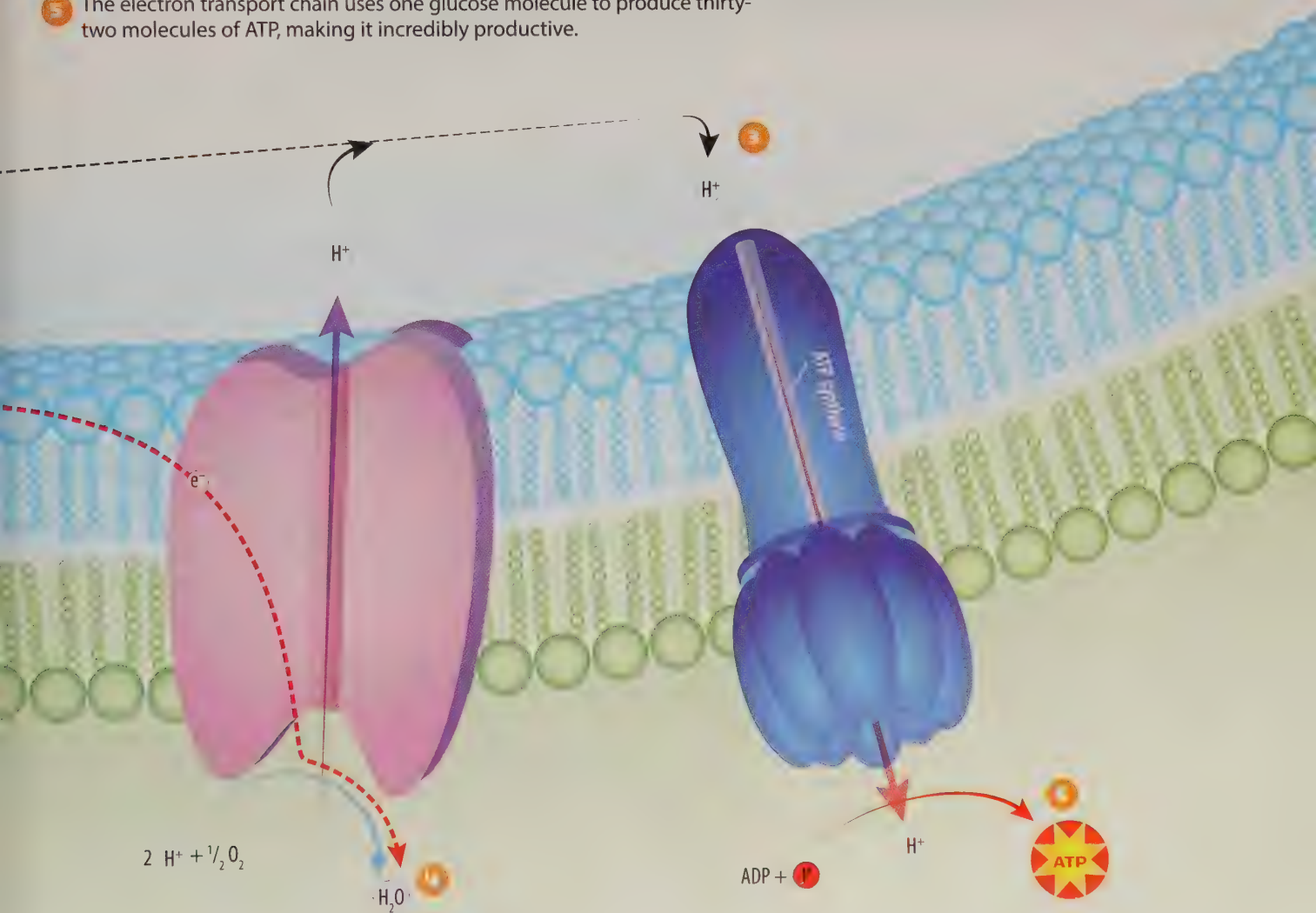
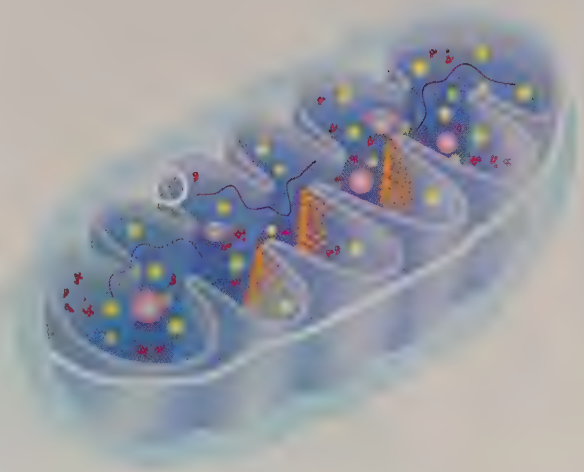
The electron transport chain in the mitochondria uses the NADH of the citric acid cycle to produce large amounts of ATP. Compare this figure with the electron transport chain in photosynthesis on page 119.

NADH releases electrons **1** and hydrogen ions **2**. The electrons pass through the electron transport chain indicated by the red arrow. Hydrogen ions are actively transported into the intermembrane space of the mitochondrion because of the difference in charges between these two areas.

3 Hydrogen ions pumped into the intermembrane space during the electron transport chain pass back into the matrix through an enzyme at the end of the electron transport chain called *ATP synthase*. The diffusion of hydrogen ions passing from a higher to a lower concentration catalyzes ATP formation. This process is called *chemiosmosis*.

4 The electrons donated from NADH in Step **1** and the incoming hydrogen ions from chemiosmosis **2** combine with oxygen to form water. Since oxygen is required for this process, it is aerobic.

5 The electron transport chain uses one glucose molecule to produce thirty-two molecules of ATP, making it incredibly productive.



Glycolysis happens in the cytoplasm and doesn't require oxygen. It gets all the materials ready for the citric acid cycle. Glycolysis uses several different enzymes to jumpstart the different steps that break glucose down into a three-carbon molecule called *pyruvate*, producing two ATP and two NADH electron carrier molecules in the process. Again, tracking these molecules in the preceding diagrams will help you understand the flow of energy in the process.

So what does the whole process of aerobic cellular respiration provide for living things? Glycolysis produces two ATP molecules, the citric acid cycle produces two ATP molecules, and the electron transport chain produces thirty-two ATP molecules, giving us a grand total of thirty-six ATP molecules. This process has about a 40% efficiency rate, with the rest of the energy released as heat. Even this thermal energy is still useful to keep us warm. But this is one of the most efficient energy processes we know of. Consider that the engine in your car is only about 20% efficient. The cell is a marvel of engineering!

7.4 FERMENTATION

In two of the three steps of cellular respiration—the citric acid cycle and the electron transport chain—oxygen is necessary, making this aerobic cellular respiration. However, sometimes oxygen isn't available, like in the muddy waters of marine estuaries or in the deepest regions of the ocean. This can happen even in your body when you exercise strenuously. Does that mean that necessary cellular processes can't occur in these places to give energy?

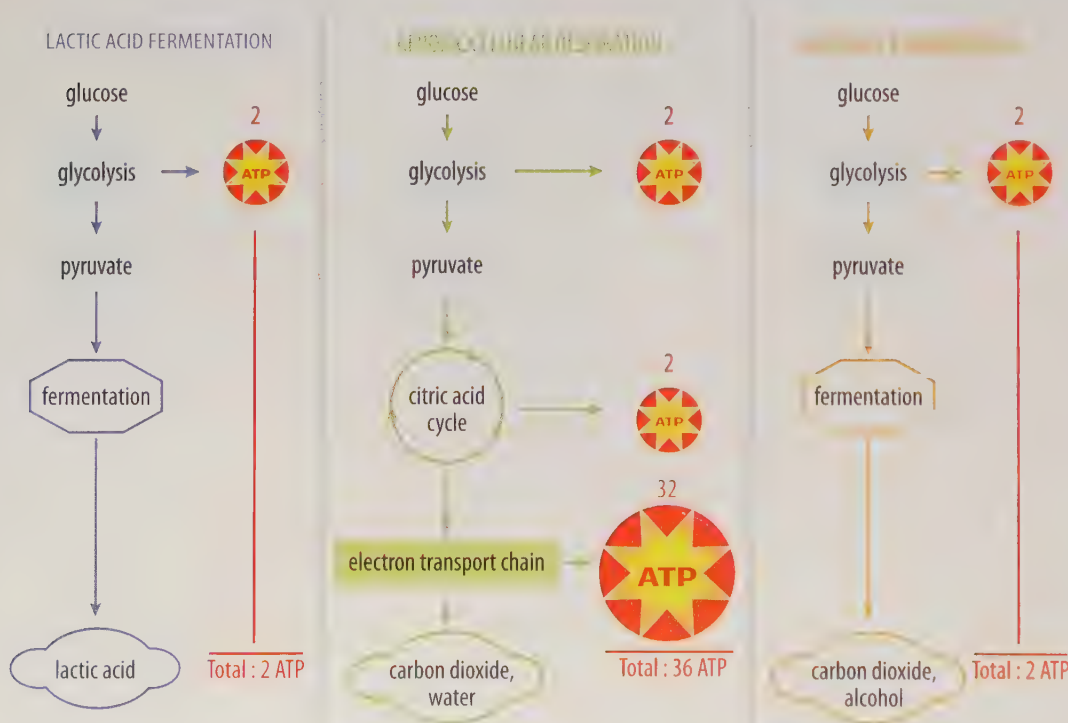
Though cellular respiration can't happen in these situations, other processes can provide energy in a way that doesn't require oxygen. These are called **anaerobic** processes. Without these, your muscles would shut

down when you run out of oxygen! Releasing energy by anaerobic processes requires two steps—glycolysis and **fermentation**. Since glycolysis doesn't require oxygen, fermentation can use glycolysis just as aerobic cellular respiration does. Not so with the citric acid cycle and electron transport chain, since both require oxygen. Fermentation happens in the cytoplasm. We saw that the electron transport chain is the most productive part of aerobic cellular respiration, so we would expect that fermentation would produce many fewer ATP molecules.

anaerobic: an- (Gk. *an*—without) -aero- + -bic

7.5

Compare the energy yields of lactic acid fermentation, aerobic cellular respiration, and alcoholic fermentation.

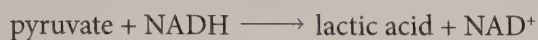


There are multiple kinds of fermentation that produce two ATP molecules during the glycolysis step. During the second step of fermentation, NADH is recycled back into NAD⁺ so that glycolysis can continue. Without this, the cell would die.

In *alcoholic fermentation*, pyruvate from glycolysis is changed into alcohol using NADH. The fungus *yeast* uses alcoholic fermentation to process sugar. Bread rises and alcoholic beverages are bubbly because of the release of carbon dioxide in alcoholic fermentation. See the chemical reaction below.



Bacteria use another type of fermentation called *lactic acid fermentation*. This fermentation process is used to make cheese and yogurt. In one step, pyruvate forms lactic acid as it reacts with the enzyme NADH.



The reactants are the same as in alcoholic fermentation, so what makes the difference? Different organisms or parts of an organism have environments that are favorable to different enzymes. These enzymes allow the different types of fermentation to take place and produce different products. Lactic acid fermentation happens in your muscles when you exercise vigorously. Notice that this doesn't produce any carbon dioxide.

You can see from the equations above that both alcoholic and lactic acid fermentation produce NAD⁺, which can be recycled back into NADH. This electron-carrying molecule is necessary to keep glycolysis going, producing energy. Without fermentation, glycolysis stops.

Cell theory is a model—it is a simplified representation of reality that describes or explains the cell in a workable and useful way. You may be used to thinking of force, energy, and atoms as being parts of science that you can't directly observe. But the cell is another black box in science. Scientists can't slice open a cell and watch it work. We can experiment with cells and watch how they respond and make inferences about the processes that cause these responses.

Cell processes—metabolism, DNA replication, protein synthesis, photosynthesis, cellular respiration, and fermentation—are incredibly complex. Depending on the food supply and environment, cells can adjust to run different processes in order to maintain homeostasis. The interconnectedness and flexibility of cell processes leave us baffled. Scientists are still working to grasp the intricacies of the cell with models that are simplified representations of this wonderfully designed unit of life. Though we know so much about the cell, it remains a mystery. Even as we learn more, we uncover more questions waiting to be answered.



7-6

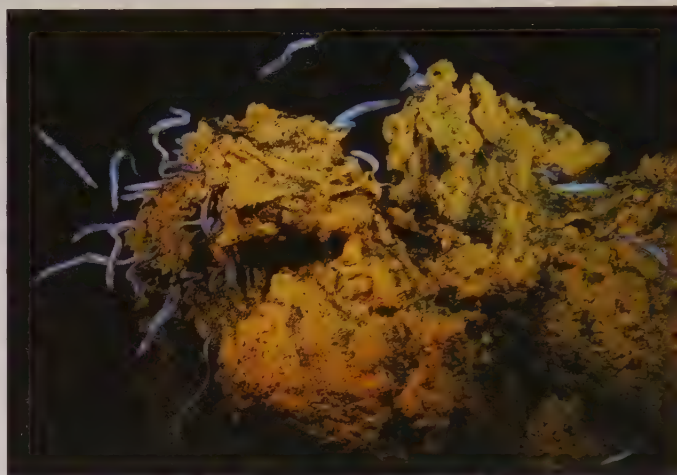
The cheesemaking process relies on lactic acid fermentation.

EEL CITY

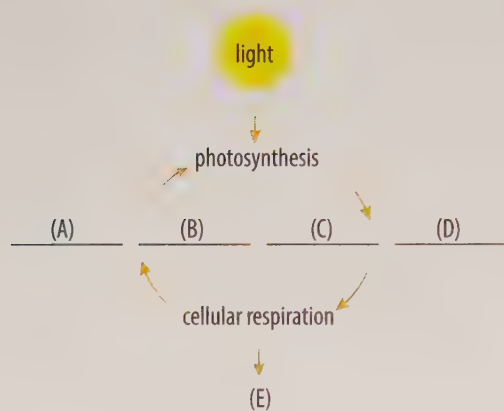
Off the coast of American Samoa in the Pacific lies an underwater volcano called Vailulu'u that rises almost 14,000 feet from the ocean floor. You'd think that nothing could live in the inky black, scorching waters there, right? Wrong! In 2005, marine biologists and geologists were stunned to find a population of foot-long greenish eels thriving in the dark, hot, acidic waters near the Nafanua cone of Vailulu'u, called "The Crater of Death."

An ecological community thrives there, and at the base of the food chain are bacteria that use a process called *chemosynthesis*, similar to photosynthesis, to pull nutrients from the water to make their own food. In chemosynthesis, bacteria absorb toxic hydrogen sulfide, oxygen, and carbon dioxide from water emitted from the volcano. The bacteria use these nutrients to get energy and make food. They grow in mats and are eaten by other organisms such as shrimp, clams, and giant tube worms (*Riftia pachyptila*) that can reach 7 feet long. The community near Vailulu'u is unusual because it is home to a large population of deep-sea eels, the first that has ever been discovered near an underwater volcano. Scientists are still unsure what

the eels are eating, but they suspect that chemosynthetic bacteria are related to the eels' unusual presence in this seemingly inhospitable place.



7B SECTION REVIEW



1. Why does the phrase "burning carbs" or "burning fat," used in connection with exercise, make sense in light of what you've learned about cellular respiration?
2. Fill in the process map to the left, relating photosynthesis, cellular respiration, water, carbon dioxide, oxygen, glucose, and ATP.
3. Why must glycolysis happen at the beginning of cellular respiration?
4. What is the difference between aerobic cellular respiration and fermentation? Include in your contrast the reactants, parts, and products.
5. Why does fermentation take place at all in cellular respiration if it produces only a small amount of energy?
6. Think about a person who is exercising more than normal. Why does fermentation even happen in the muscles since it doesn't produce very much energy? Is this a beneficial or harmful thing?
7. Compare the two types of fermentation.
8. Do a keyword search on the Internet for "human metabolic map." Find the citric acid cycle, which should look like a circle. Where is it on the map? What does this map show you about the processes in the cell?
9. What goes through your mind as you look at this metabolic map?

REVIEW QUESTIONS

CONCEPT REVIEW

1. How is photosynthesis part of God's good design for life in light of Genesis 1:29–31? How can we use it?
2. What is the role of NADP⁺ and NADPH in cellular processes?
3. What is the role of ATP and ADP in cellular processes?
4. Write the overall chemical reaction for photosynthesis, giving the names of the reactants, products, and catalysts.
5. Overall, the process of photosynthesis changes _____ energy into _____ energy.
6. Why must the light-dependent phase of photosynthesis happen in the thylakoid membrane?
7. What cycle is at work in the light-dependent phase of photosynthesis? in the light-independent phase?
8. What environmental factors affect photosynthesis?
9. How do some plants adjust for environmental conditions that are not favorable to photosynthesis during the day?
10. Give the three steps of aerobic cellular respiration.
11. Which steps of cellular respiration are aerobic?
12. Create a flow chart for aerobic cellular respiration, showing the three steps and the number of ATP molecules produced in each step. Find a way to show where each of the three steps happens.
13. Which steps of cellular respiration and fermentation are anaerobic?
14. How does cellular respiration affect an organism's environment?

TRUE OR FALSE

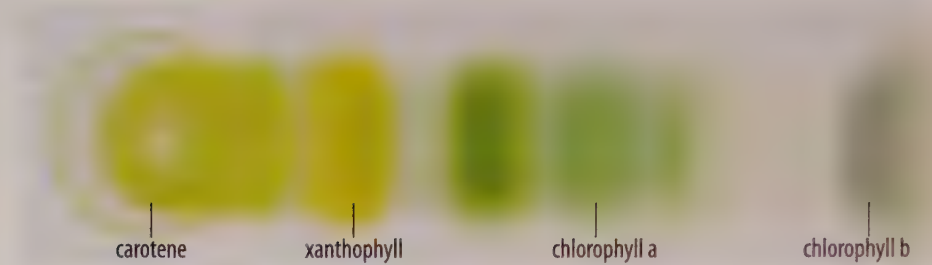
15. Photosynthesis happens only in the leaves of plants.
16. Chlorophyll absorbs every color but green.
17. All producers perform both photosynthetic and cellular respiration processes.
18. All consumers perform both photosynthetic and cellular respiration processes.
19. The main energy-carrying molecule produced by cellular respiration is ATP.
20. All living things get their energy from glucose.

Key Terms

photosynthesis	118
light-dependent phase	118
light-independent phase	118
stroma	119
thylakoid	119
chlorophyll	119
electron transport chain	119
Calvin cycle	120
cellular respiration	122
glycolysis	123
aerobic	123
citric acid cycle	123
anaerobic	126
fermentation	126

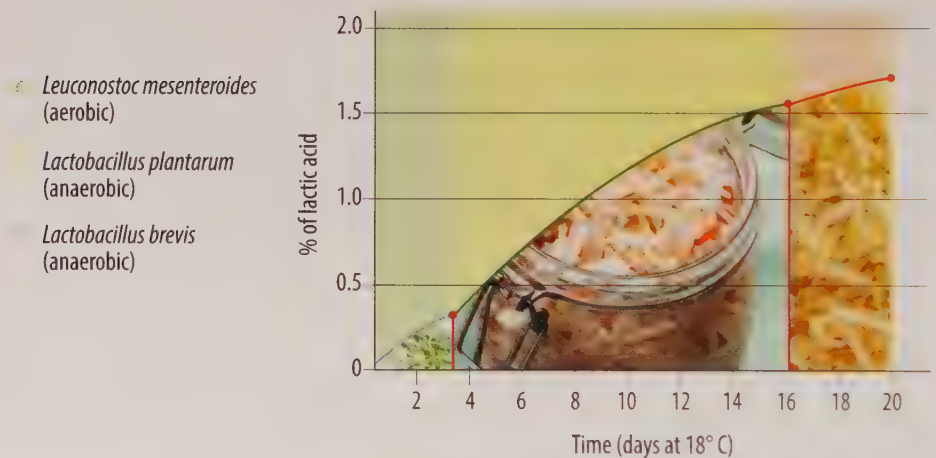
CRITICAL THINKING

- 21.** Why do you think that cellular processes would be so difficult for biological evolution to explain?
- 22.** Chemists can take a leaf extract and rub it onto a special kind of paper called *chromatography paper*. Some of the color rubs off on the paper, leaving a green smudge. If they put the edge of the paper in a solvent like acetone, it will travel up the paper and separate into different colors. What do you think this indicates about the pigments in leaves?

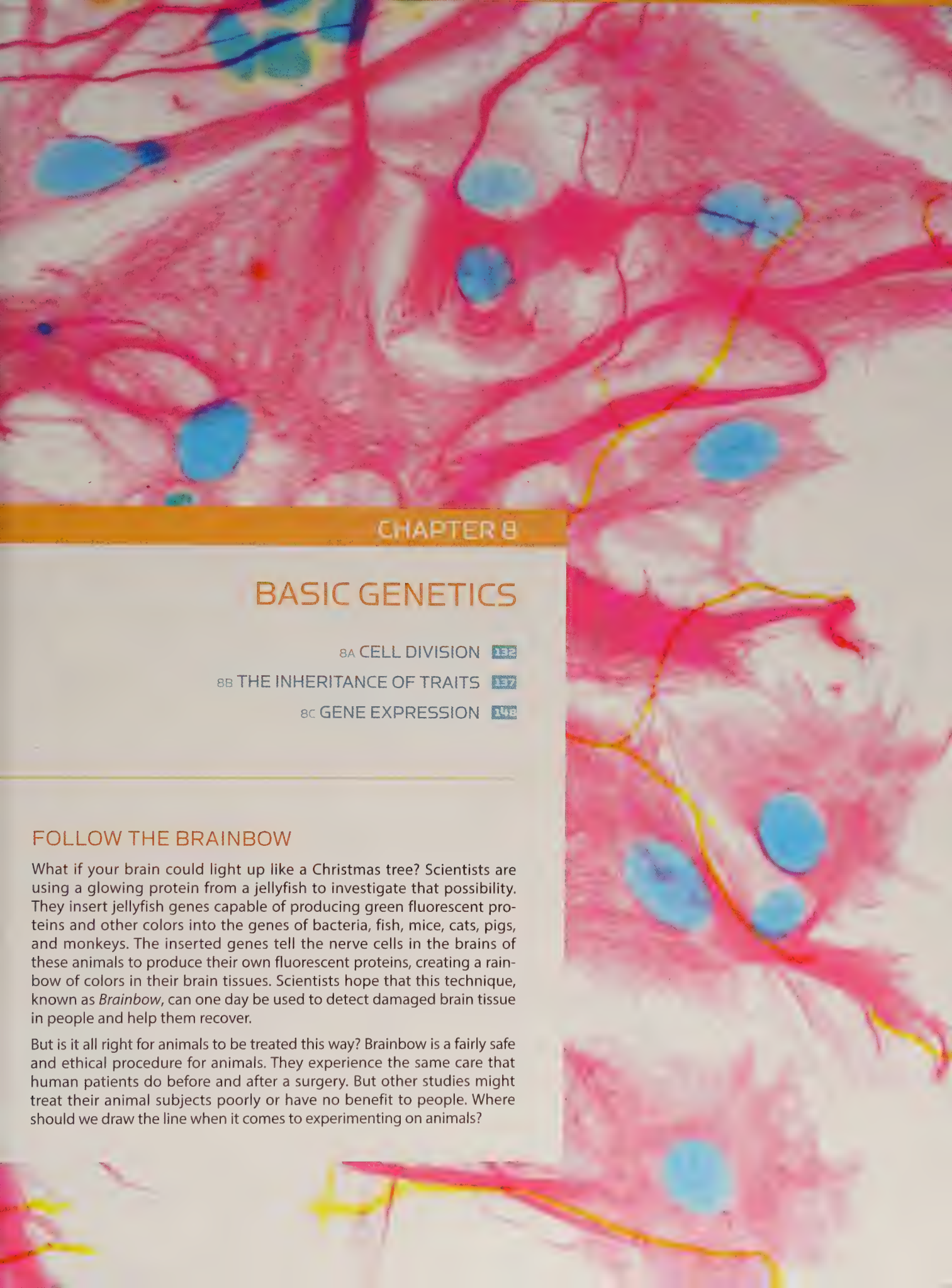


Use the graph below to answer Questions 23–26.

Cabbage goes through a fermentation process to produce sauerkraut with its characteristic taste. This process happens naturally if the cabbage is kept at a temperature of about 65 °F (18 °C). The graph below shows how long this process takes.



- 23.** The y-axis shows how much lactic acid is in the sauerkraut. How can producers tell when sauerkraut is ready?
- 24.** What do you think *Leuconostoc mesenteroides*, *Lactobacillus plantarum*, and *Lactobacillus brevis* are?
- 25.** Why does sauerkraut undergo lactic acid fermentation and not alcohol fermentation?
- 26.** Identify other foods that go through a similar process as sauerkraut.

A microscopic image of brain tissue, likely stained with hematoxylin and eosin (H&E). The image shows various cell types, including neurons with prominent blue nuclei and pink cytoplasm/extracellular matrix. There are also some yellowish structures, possibly myelinated axons or specific cell types. The overall texture is complex and fibrous.

CHAPTER 8

BASIC GENETICS

8A CELL DIVISION 132

8B THE INHERITANCE OF TRAITS 137

8C GENE EXPRESSION 148

FOLLOW THE BRAINBOW

What if your brain could light up like a Christmas tree? Scientists are using a glowing protein from a jellyfish to investigate that possibility. They insert jellyfish genes capable of producing green fluorescent proteins and other colors into the genes of bacteria, fish, mice, cats, pigs, and monkeys. The inserted genes tell the nerve cells in the brains of these animals to produce their own fluorescent proteins, creating a rainbow of colors in their brain tissues. Scientists hope that this technique, known as *Brainbow*, can one day be used to detect damaged brain tissue in people and help them recover.

But is it all right for animals to be treated this way? Brainbow is a fairly safe and ethical procedure for animals. They experience the same care that human patients do before and after a surgery. But other studies might treat their animal subjects poorly or have no benefit to people. Where should we draw the line when it comes to experimenting on animals?

8A Questions

- » How does information get from one cell to another?
- » How do cells contribute to an organism's growth and reproduction?

CELL DIVISION

How do cells help living things grow and reproduce?

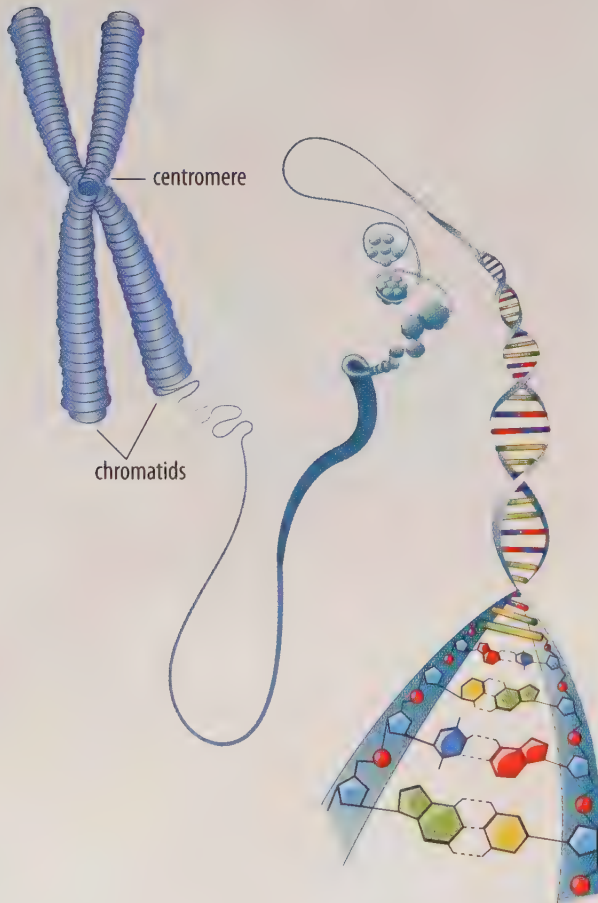
8.1 CHROMOSOMES AND GENES

The jellyfish genes that researchers are using for Brainbow (see Chapter opener) are made of DNA. This is the cell's genetic material and is found in the nucleus as part of the nucleus's *chromatin*. Strands of DNA in the chromatin are tightly coiled around proteins called *histones*. Just before a cell divides, the chromatin condenses to form structures called **chromosomes**. Think of a chromosome as a spool of thread: DNA is the thread, and the histones are the spool that the DNA wraps around. One chromosome can contain between 500 and 2000 of these spools of DNA.

Many of the sections of DNA within a chromosome are **genes**, which code for a specific protein to create a certain characteristic in an organism. Genes are the basic units of heredity. Everything about you is a result of your genes. Your eye color, height, blood type, natural muscle size, and so on are all coded in your genes and spooled together in your chromosomes. Your genes might also code for proteins that suppress tumors, direct the growth of nerves in the brain, or help cells with RNA transcription.

8-1

In chromatin, DNA and histones become organized into chromosomes.



STRUCTURE OF CHROMOSOMES AND GENES

Just before a cell divides, its chromosomes duplicate to form an X shape. The duplicated chromosome is made of two identical halves, and each half is called a **chromatid**, which are joined together at the **centromere** (Figure 8-1). Centromeres play a crucial role during cell division because they not only keep chromatids together but also help break them apart at the right time so that the information in chromosomes can be divided between two new cells.

KINDS OF CHROMOSOMES

There are two kinds of chromosomes. **Sex chromosomes** determine whether an organism will be male or female. They also carry a few genes that determine other traits. In humans, the two sex chromosomes are X and Y. The X chromosome is significantly larger than the Y, and so it carries a lot more genetic information. Children inherit one sex chromosome from each of their parents, giving them a combination of either XX, which codes for a female, or XY, which codes for a male.

Autosomes are chromosomes that *don't* determine an organism's sex. They contain most of an organism's genes. Humans have 44 autosomes that pair up to form 22 sets. Unlike sex chromosomes, the two autosomes in a pair are about the same size.

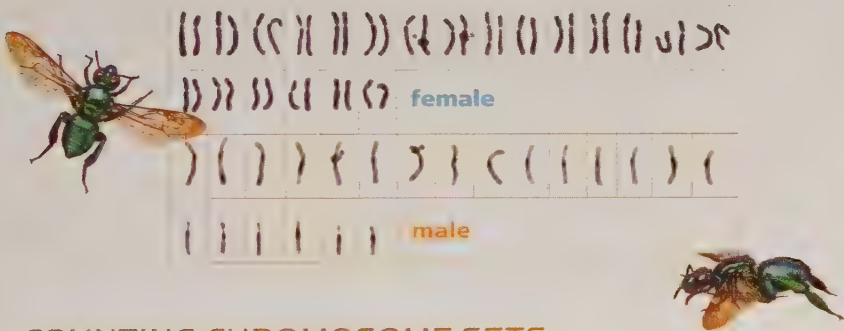
Chromosomes aren't aligned in the nucleus in a way that they can be counted easily, so scientists sort out the chromosome pairs, arrange them in size order, and take a picture of them under a microscope. The resulting image of the ordered chromosomes is called a *karyotype*.

CHROMOSOME PAIRS

The pairs of autosomes in the karyotype in Figure 8-2 are **homologous** pairs. For example, two copies of a chromosome in the karyotype are homologous. Your mother gave you one copy, and your father gave you the other. This set of chromosomes forms a homologous pair. Sex chromosomes aren't considered homologous, though they're still a pair of chromosomes.

Organisms that have homologous pairs of chromosomes are **diploid**. You are diploid, your dog is diploid, and so is the oak tree in your front yard. But not all organisms have chromosomes from each of their parents. They may have just one set of chromosomes and so are **haploid**.

Diploid organisms often have a few haploid cells in their bodies. Eggs and sperm are haploid cells that, whenever they join together, form a new organism that is diploid.



COUNTING CHROMOSOME SETS

The number of different chromosome sets that an organism has in its cells is given the abbreviation *n*. So a diploid cell is $2n$, and a haploid cell is simply *n*. In people, $n = 23$, so $2n = 46$. Keeping track of *n* is important for organisms that have lots of chromosome sets, such as wheat. Wheat can be $2n$, $4n$, or $6n$, depending on the species.

Table 8-1

Diploid Number of Chromosomes in Some Common Organisms

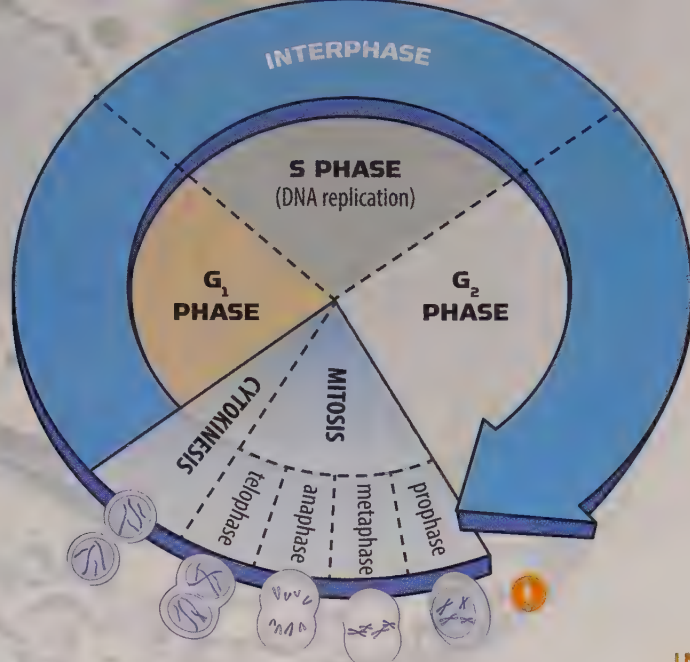
Organism	Number	Organism	Number
adder's tongue fern	1260	kangaroo	16
chicken	78	mosquito	6
chimpanzee	48	shrimp	92
dog	78	watermelon	22
human	46	wolf	78



8-2

A human karyotype showing the 22 pairs of autosomes and 1 pair of sex chromosomes for a total of 23 pairs. Notice the size difference between the sex chromosomes.

- homologous** (huh MAHL uh gus): homo- (Gk.—same) + -logous (Gk.—having proportion)
- diploid**: diplo- (Gk.—double) + -(o)id (Gk.—form or shape)
- haploid**: haplo- (Gk.—single) + -(o)id



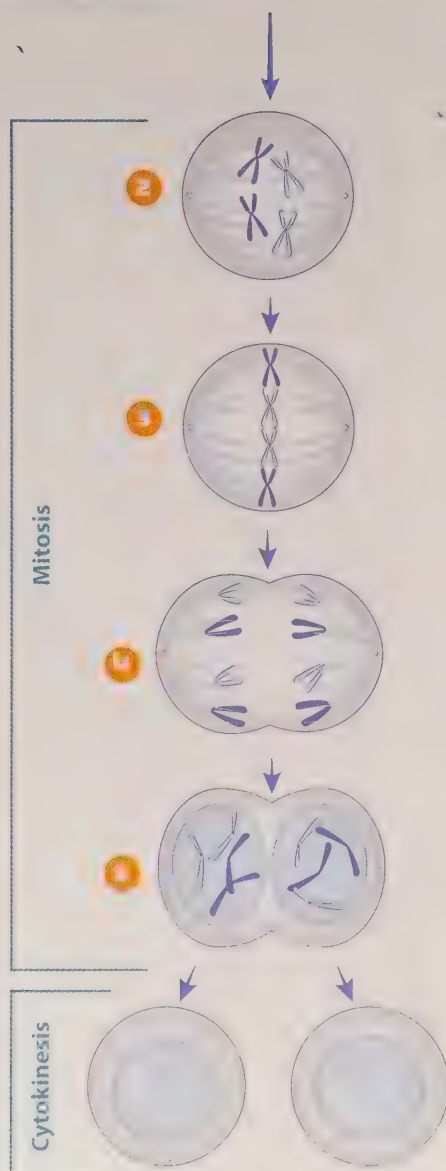
82 THE CELL CYCLE AND MEIOSIS

Believe it or not, a month ago you were living in a different skin. How is that possible? Skin cells die and are replaced every three to four weeks through the **cell cycle**, which is the process of cell growth that leads to cell division for many cells. The cell cycle is responsible for an organism's growth and repair, and it faithfully transfers the genetic information from one cell to every other cell in your body, keeping all your cells genetically identical.

The cell cycle is broken into three stages: **interphase**, **mitosis**, and **cytokinesis**.

INTERPHASE

Interphase is the phase where the cell spends most of its time. At the end of interphase, the tetraploid ($4n$) cell **1** with its extra organelles, proteins, and chromosomes is ready for the four phases of mitosis and cytokinesis.



MITOSIS

2 Prophase

In the cytoplasm, centrosomes are carried to opposite ends of the cell by protein motors. The centrosomes then assemble fibers from the cytoskeleton into a structure called the **mitotic spindle**, which will align and separate chromosomes in later phases.

In the nucleus, the chromatin begins to coil into visible chromosomes, the nucleolus is disassembled, and the membrane around the nucleus breaks down to release the chromosomes.

3 Metaphase begins as the fibers of the mitotic spindle attach to proteins on the centromere of each chromosome. These fibers pull the chromosomes to align them along an imaginary line called the *equatorial plane*.

4 Anaphase

The centromeres, which hold the two chromatids of each chromosome together, send out a signal that splits the centromeres in half. The mitotic spindle then pulls the chromatids toward the centrosomes.

5 Telophase

The chromatids are now their own chromosomes, and the nucleus begins to re-form around them. In the nucleus, the nucleolus reassembles and the chromosomes uncoil to become chromatin again. In the cytoplasm, the mitotic spindle disassembles. Cytokinesis also begins.

CYTOKINESIS

While mitosis is finishing, the cell divides the contents of its cytoplasm. The cell also forms a *contractile ring* between the two nuclei, which pinches the cell in two. There are now two genetically identical cells, each with its own organelles, proteins, and diploid set of chromosomes. There are no visible chromosomes during cytokinesis and interphase.

MEIOSIS

During sexual reproduction, **meiosis** happens instead of mitosis to form haploid gametes. Just as in mitosis, a tetraploid ($4n$) cell **1** about to enter meiosis has doubled its number of chromosomes and its cytoplasmic proteins and organelles.

2 Prophase I

Once the membrane around the nucleus has dissolved, each chromosome joins with its homologous chromosome to form a **tetrad**. Chromosomes in a tetrad exchange genes in a process called **crossing over**. The centrosomes migrate and the spindle forms.

3 Metaphase I

The spindle fibers align tetrads on the equatorial plane.

4 Anaphase I

The spindle separates each tetrad and pulls whole chromosomes toward the centrosomes instead of individual chromatids.

5 Telophase I and cytokinesis

Each side of the cell now has a haploid set (n) of chromosomes. A nucleus re-forms around each set, but the chromosomes don't uncoil. The cytoplasm is divided, and the cell is pinched in two.

6 Prophase II

Right after the cells divide, a spindle re-forms in each cell to begin meiosis II. The chromosomes do not duplicate.

7 Metaphase II

The spindle fibers align chromosomes on the equatorial plane.

8 Anaphase II

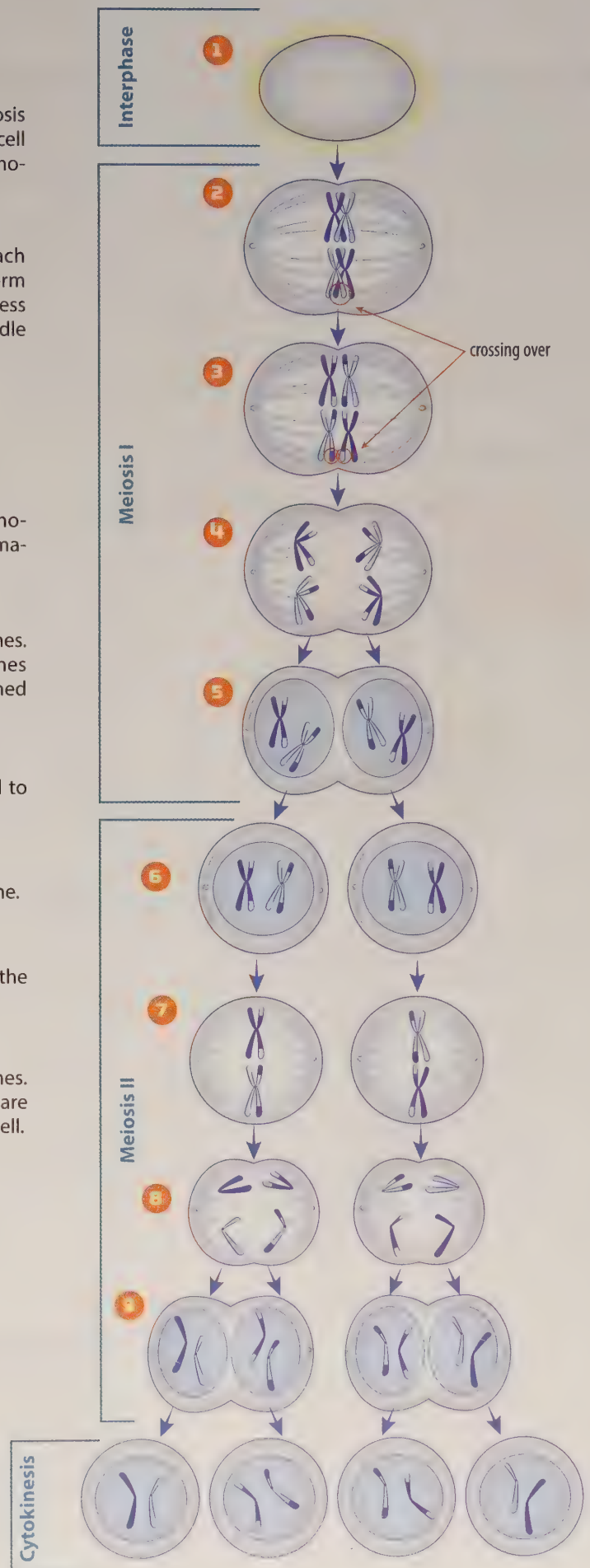
The chromosomes' centromeres split, and the spindle pulls the chromatids toward the centrosomes.

9 Telophase II and cytokinesis

A nucleus re-forms around each haploid set of chromosomes. Because of the chromosomes' crossing over, the four cells are genetically different from each other and from the original cell.

Healing and the Cell Cycle

On average, it takes human and mammal cells about 24 hours to go through the cell cycle. That may not sound fast, but think about how quickly a cut on your hand heals. Every day, it heals a little more and finally disappears. That's because your skin cells grow and divide to produce new cells every 24 hours, replacing the damaged cells.



Grand Design on a Tiny Scale

Crossing over, the process in which chromosomes in a cell exchange genes, involves amazing precision. While the 100 million DNA base pairs on a human chromosome are mixing during prophase I, the chromosome can't lose a single base pair, or the genes they code for will be defective.

Because our bodies are part of fallen creation, mistakes can happen during crossing over. But the odds are low because, in God's wisdom and grace, the unmatched engineering that He has designed into each of our cells is still at work.

Mitosis creates the trillions of identical diploid cells that are in your body. But your body also contains some haploid cells known as **gametes**, which are cells that can unite to form a zygote. A **zygote** is a diploid cell that is genetically different from either parent. The zygote divides by mitosis as it grows and develops before being born. In humans, the two kinds of gametes are egg cells and sperm cells. In a diploid organism, haploid gametes are produced through meiosis, the reduction of a cell's chromosome number from diploid to haploid. Just as in mitosis, a tetraploid ($4n$) cell about to enter meiosis has doubled its number of chromosomes, proteins, and organelles. Unlike mitosis, the cells go through two divisions, which are called *meiosis I* and *meiosis II*.

COMPARING MITOSIS AND MEIOSIS

MITOSIS

MEIOSIS

Similarities

- Both are a form of cell reproduction.
- Both begin with a tetraploid cell.
- Meiosis II is almost the same process as mitosis.

Daylilies reproduced asexually through mitosis are genetically identical.

- Leads to genetically identical cells
- Generates two diploid cells after one cell division
- Has homologous pairs of chromosomes that are separate
- Is a form of **asexual reproduction**, a process that produces offspring that are genetically identical to their parents. Many plants can reproduce this way, such as daylilies.



Daylilies sexually reproduced by seeds show genetic variety.

- Leads to genetically different cells
- Generates four haploid cells after two cell divisions
- Has homologous pairs of chromosomes that are connected to form tetrads
- Is a form of **sexual reproduction**, which occurs when two haploid cells join to form a genetically different diploid zygote. For example, when a haploid pollen grain joins with a haploid egg cell in a daylily flower, a seed is produced that will grow into a genetically different daylily.

8A REVIEW QUESTIONS

1. How many *homologous* pairs of chromosomes do you have?
2. In which stage of the cell cycle is the cell preparing itself to divide?
3. A single muscle cell can contain dozens of nuclei. Which stage of the cell cycle is the cell *not* completing? How do you know?
4. During which phase of mitosis do the centromeres split?

5. During which phase of mitosis does the mitotic spindle assemble? In which phase does it disassemble?
6. Why is meiosis split into meiosis I and II?
7. In which phase of meiosis is genetic information exchanged between chromosomes?
8. Give two differences between anaphase I and anaphase II in meiosis.
9. Which type of cell division turns a diploid cell into a haploid cell?
10. What's the difference between asexual and sexual reproduction?

8B

THE INHERITANCE OF TRAITS

How do traits pass from one generation to the next?

8.3 MENDEL'S GENETICS

In a small eastern European abbey during the 1850s, a monk named Gregor Mendel (1822–84) was making scientific history. Gardeners had known for centuries how to breed pea plants to get the kind of peas or flower colors that they wanted, but no one knew the mechanism that caused a trait to be handed down to the next generation until Mendel discovered it. Though he would never realize it during his lifetime, Mendel's pea plant experiments in his garden behind the abbey revolutionized the way scientists thought about **heredity**, the passing of traits from one generation to another.

Mendel published his ideas and experiments on pea plants (*Pisum sativum*) in a scientific journal, but his ideas were so advanced for that time that scientists couldn't make heads or tails of it. So his work lay forgotten until about 16 years after his death when a few botanists unknowingly repeated Mendel's experiments. As they researched the groundbreaking results of their experiments, they discovered that Mendel had gotten the same results decades earlier. His work was finally getting the attention it deserved, and he is now considered the Father of Modern Genetics.

So what were the results of Mendel's experiments that changed the way people thought about heredity? They can be boiled down to three principles: heredity, segregation, and independent assortment.

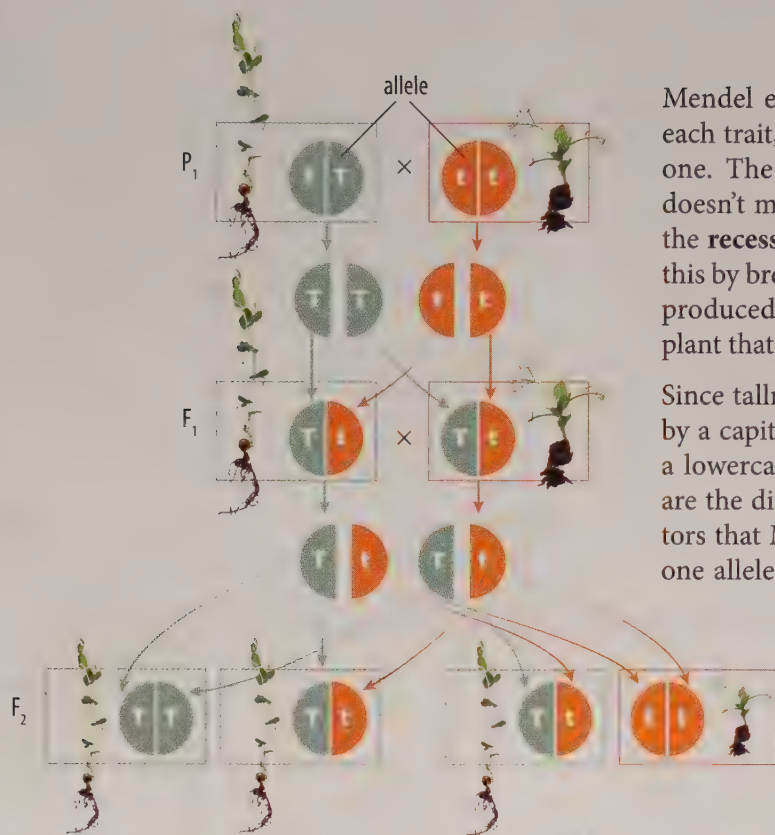
PRINCIPLE OF HEREDITY

Mendel bred thousands of pea plants together and traced their traits through each generation. He learned that each parent plant contributed what he called a *factor* for each trait, giving the offspring two factors for that trait. For example, two tall parent plants would each give their offspring a tall factor, resulting in tall offspring. But sometimes, two tall parents would produce short offspring. So what happened to the tall factors?

8B Questions

- » How is information from a cell expressed?
- » How do Mendel's principles apply to the different ways that traits are passed down?





Naming Traits

It makes sense that the dominant trait of tall pea plants is represented by a capital T , but why is the recessive trait of short plants represented with a lowercase t instead of a lowercase s ? The alleles for a trait need to have the same symbol, and a trait is always represented by its dominant expression. Since tall is the dominant height for pea plants, the letters t and T are used no matter what the recessive height is.

Mendel explained that since an organism has two factors for each trait, then one of those factors must win out over the other one. The trait that is expressed is the **dominant trait**. This doesn't mean that the losing factor disappears. It still codes for the **recessive trait**, the trait that isn't expressed. Mendel showed this by breeding a tall plant that was *purebred* (a plant that always produced tall plants) with a short plant that was purebred (a plant that always produced short plants).

Since tallness in pea plants is a dominant trait, it is represented by a capital T . Since shortness is considered recessive, it's given a lowercase t . These individual letters represent **alleles**, which are the different forms that a gene can have. Alleles are the factors that Mendel observed. For example, the tall trait (T) is just one allele for the gene that controls height. A purebred organism, also known as a **homozygous** organism, has the same alleles for a trait. A tall plant has two tall alleles, TT , and a purebred short plant has two short alleles, tt . These letters can help you visualize an organism's **genotype**, or genetic makeup.

Notice in the diagram to the left that the purebred tall and short pea plants first produce only tall plants. Though the parent plants (P_1) and offspring (F_1) both have the same **phenotype**, or physical expression of a trait, they have different genotypes—in other words, they're all tall, but their alleles are different. TT tall plants are purebred, and Tt tall plants are *hybrid*; that is, they contain two different alleles. Organisms with two different alleles for a gene are **heterozygous**.

When two F_1 offspring breed, they produce another generation of plants called F_2 . When the Tt alleles of F_1 combine, they can produce purebred tall (TT), hybrid tall (Tt), and purebred short (tt) plants as the F_2 offspring.

Table 8-2

Genotypes and Phenotypes

Genotypes	Phenotypes
TT —homozygous (purebred)	tall—dominant trait
Tt —heterozygous (hybrid)	
tt —homozygous (purebred)	short—recessive trait

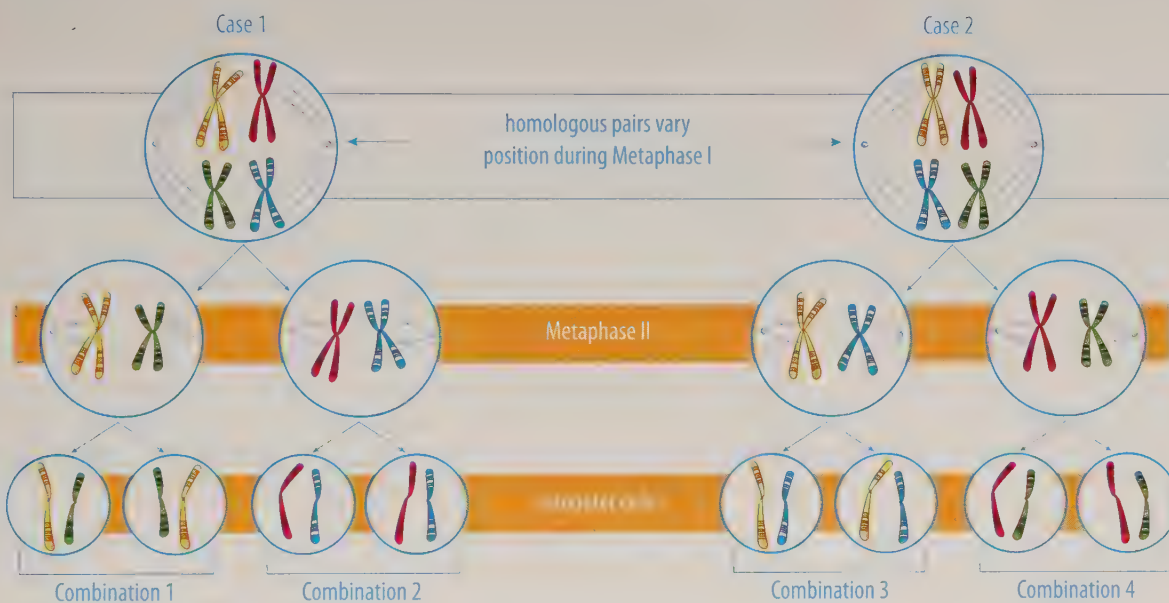
PRINCIPLE OF SEGREGATION

After studying his pea plants, Mendel decided that the factors that determine a trait must separate, or segregate, into the reproductive cells of the plants. Though he didn't know it, he was describing the process of meiosis, which forms haploid gametes that contain combinations of alleles that are different from the parents' combinations of alleles.



PRINCIPLE OF INDEPENDENT ASSORTMENT

Mendel didn't study just the height of his pea plants; he also studied the color and shape of peas. He noticed that each of these traits segregated independently during reproduction. In other words, the trait for yellow peas (*Y*) or round peas (*R*) didn't always accompany the trait for tallness (*T*); some tall plants had green (*y*), wrinkly (*r*) peas, and other tall plants had green, round peas. The traits mixed and matched freely.



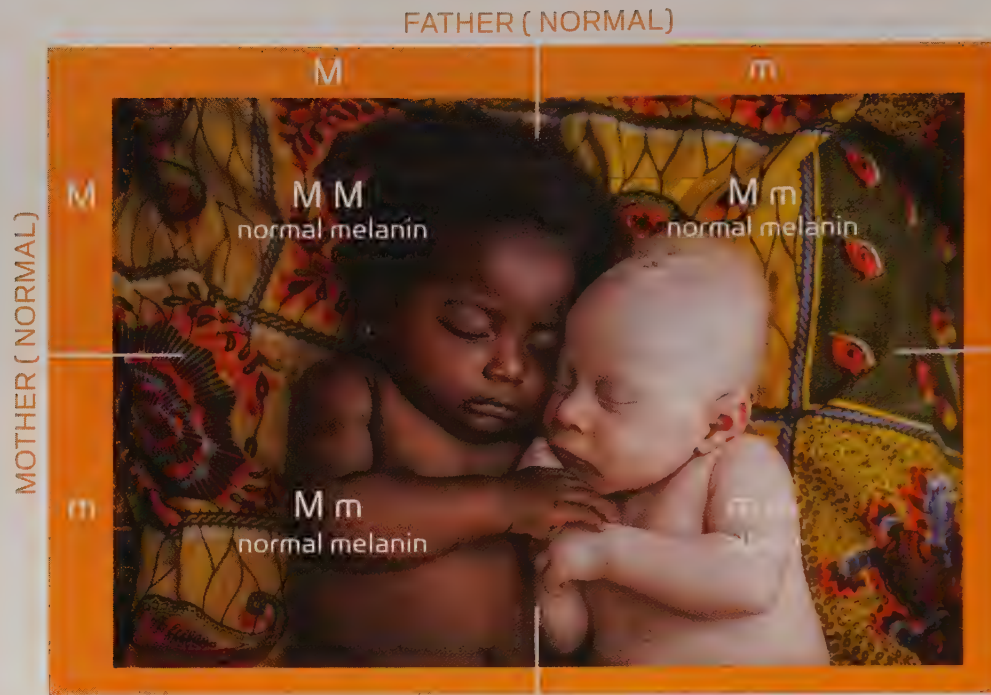
The independent assortment of traits is what creates variation from organism to organism. It's the reason why you may have your mom's eye shape, your dad's eyelashes, and an eye color that doesn't match anyone else's in your family.

8-3

Each chromatid of a chromosome carries an allele for each trait. There's no particular way the chromosomes align on the equatorial plane during meiosis, so the chromatids, and therefore the alleles, are recombined in the gametes in new ways.

8.4 PUNNETT SQUARES

Sorting out which alleles end up in which offspring can quickly become confusing. So Reginald Punnett (1875–1967), an avid student of Mendel's ideas of genetics, came up with a simple solution. He drew little squares to show the different ways that alleles can segregate. Known as **Punnett squares**, these diagrams are still helpful today for understanding how parents' alleles could be mixed in their offspring.



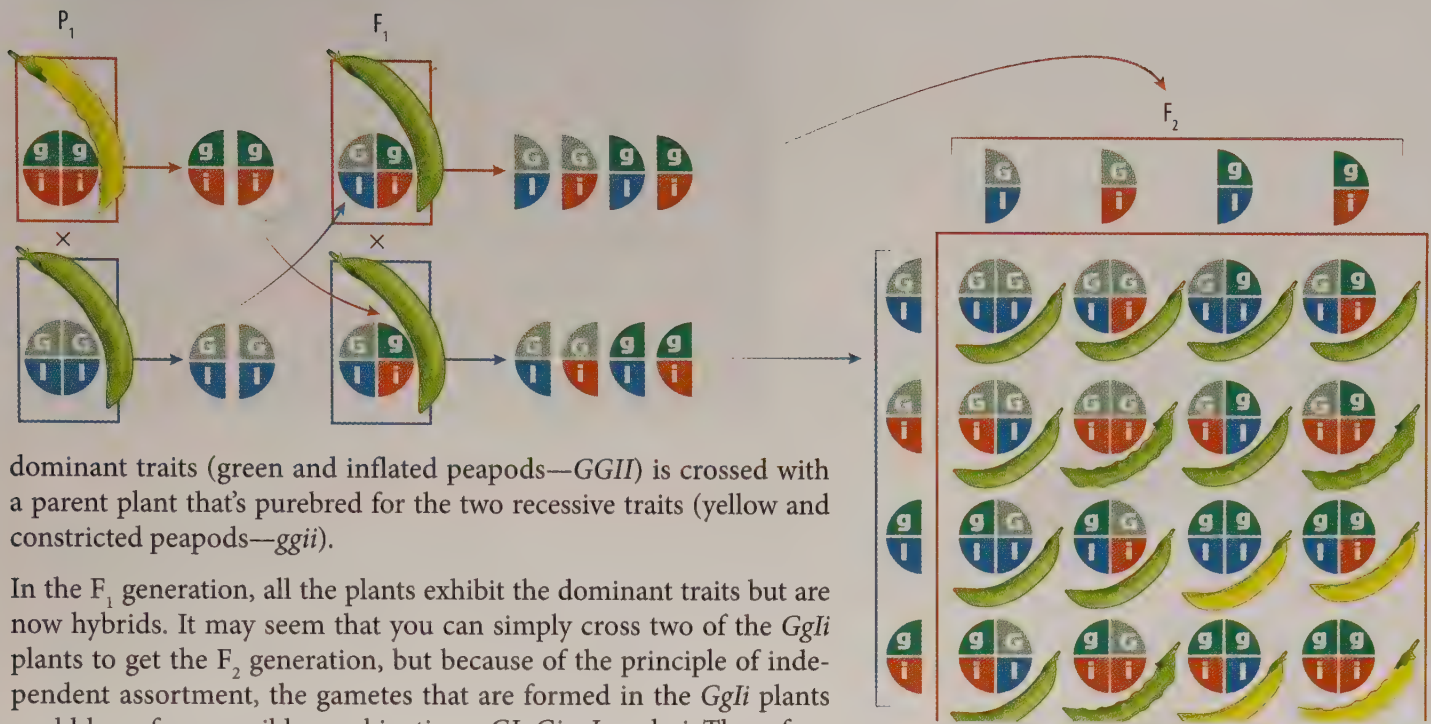
The image above is a Punnett square that shows how albinism can be passed from a mother and father to their children. Albinism is a recessive trait, and when it is expressed, a person's body doesn't produce melanin, the pigment that gives your skin, hair, and eyes their color.

In the Punnett square, the trait is represented with an *M* for normal melanin and an *m* for no melanin. A homozygous genotype of *mm* codes for albinism, showing that it's a recessive trait. The horizontal row of alleles are the father's, and the vertical row are the alleles of the mother. This Punnett square shows that the parents are heterozygous for albinism (*Mm*). When the parents' alleles are hypothetically crossed (*Mm* × *Mm*), known as a *cross*, you can see the possible combinations of alleles that might appear in their children.

These are just possibilities, however. These heterozygous parents might have 10 children and never have a child with albinism. What a Punnett square can show you, along with the possible combinations of alleles, is the probability of a particular combination. Notice how three of the four combinations of alleles in the Punnett square above include the dominant trait for normal melanin. So each of these parents' offspring has a 75% chance of inheriting the dominant trait. There's only a one-in-four chance (25%) that they'll have a child with albinism. About 1 in every 20,000 children inherits the recessive trait of albinism (*mm*).

8.5 TRACKING TRAITS

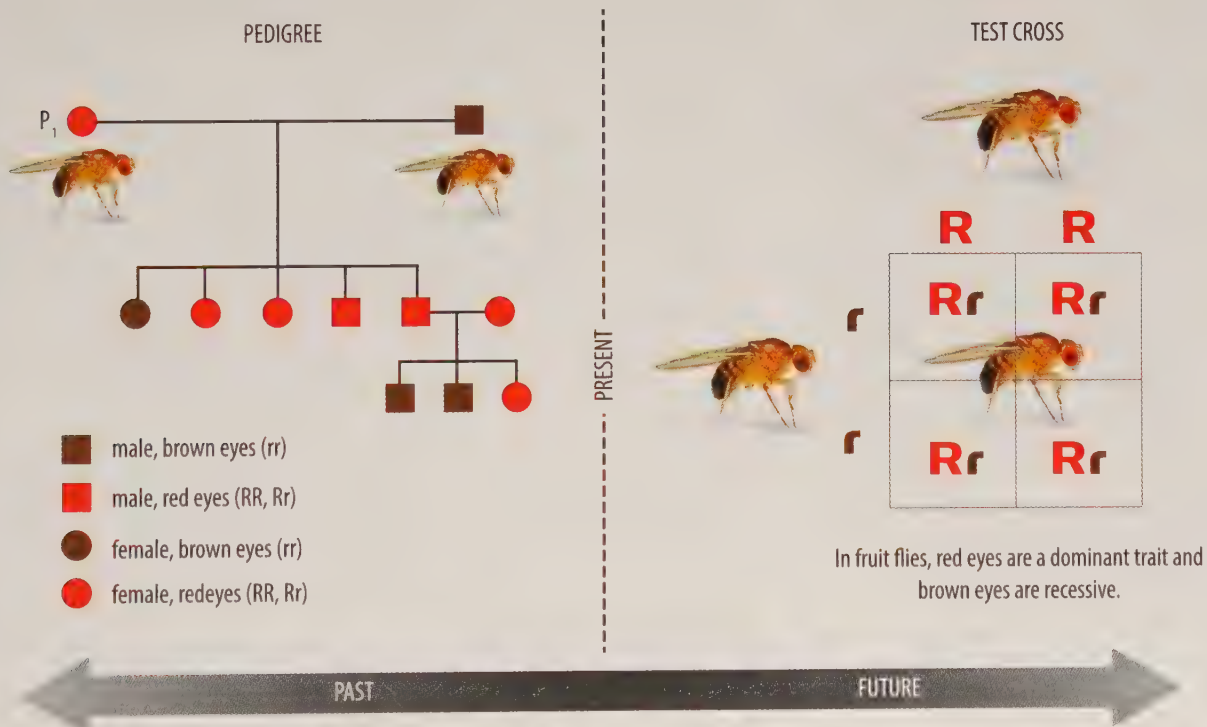
What if you want to track more than just one trait at a time, such as the color and shape of peapods? The Punnett square at the top of this page deals with a **monohybrid cross**, a cross that tests only one set of alleles. Crossing two sets of alleles results in a **dihybrid cross**. The Punnett square at the top of the facing page shows a dihybrid cross for peapod color and shape. A parent plant that is purebred for the two



dominant traits (green and inflated peapods— $GGII$) is crossed with a parent plant that's purebred for the two recessive traits (yellow and constricted peapods— $ggii$).

In the F₁ generation, all the plants exhibit the dominant traits but are now hybrids. It may seem that you can simply cross two of the $GgIi$ plants to get the F₂ generation, but because of the principle of independent assortment, the gametes that are formed in the $GgIi$ plants could have four possible combinations: GI , Gi , gI , and gi . These four possible gametes are crossed to produce the F₂ generation.

It's fairly simple to use a cross to track traits in pea plants because they can have hundreds of offspring in a short amount of time. But what about organisms that produce only a few offspring? Or what if you have a question about a trait from your family's history? For these situations, you can use a **pedigree**, a family history that charts a hereditary trait through past generations. Pedigrees show the phenotypes of traits as they are passed down from one generation to the next. Tracing phenotypes can help scientists figure out the genotypes of a family's ancestors and predict the genotypes of current family members. Notice the pedigree of fruit flies below.





8.6 REMODELING GENETICS

Poppies (*Papaver somniferum*) were the go-to flower in Britain during the early 1900s. Everyone had to have those vibrant red blooms. Red poppies became so admired that they inspired one of the most famous poems written about World War I, “In Flanders Fields,” and now they serve as a remembrance for Britain for that war.

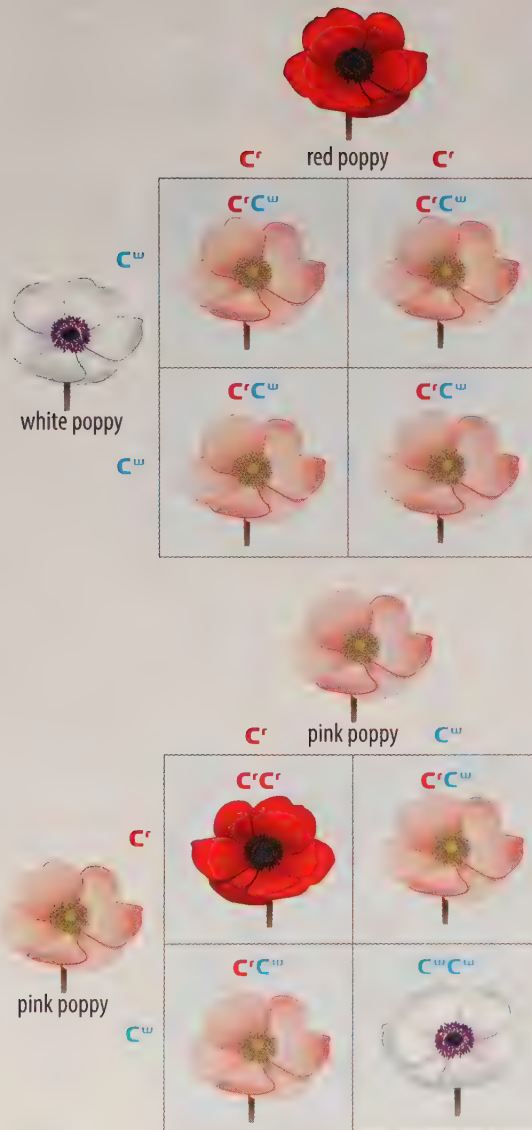
But the highly praised red poppy didn’t stay red for long. Amos Perry, the owner of a popular plant nursery in England, stumbled across a pink poppy in the middle of a bed of red poppies. Intrigued, he collected the pink poppy and began selling its pink offspring. But not everyone was happy with his pink poppies—a customer told Perry that one of the pink poppies he had bought was flowering white. Perry quickly apologized and replaced the poppy for the customer, and then he scooped up the rascally white poppy and created yet another breed of poppies.

Gregor Mendel’s ideas couldn’t fully explain the red-to-pink-to-white change, so is there something else going on with genes? The following five types of gene inheritance are models that deviate from Mendel’s model and help explain many traits, including color in poppies.

INCOMPLETE DOMINANCE

The traits that Mendel studied in pea plants were either dominant or recessive. But in some organisms, both alleles for a trait are expressed at the same time, creating a third phenotype. This blending of alleles is known as **incomplete dominance**. In poppies, a red flower has the genotype RR . A white flower is rr . Using Mendel’s principle of heredity, you might think that the genotype Rr would give you a red-flower phenotype, but it doesn’t. Rr creates a blend of red and white—a pink flower.

Since neither color is truly dominant, a capital C (for color) is used to represent flower color, and lowercase superscripts are used for the different colors. So a red poppy is $C^R C^R$, a white poppy is $C^W C^W$, and a pink poppy is $C^R C^W$. Crossing two pink poppies can result in pink, red, or white poppies.



8-4

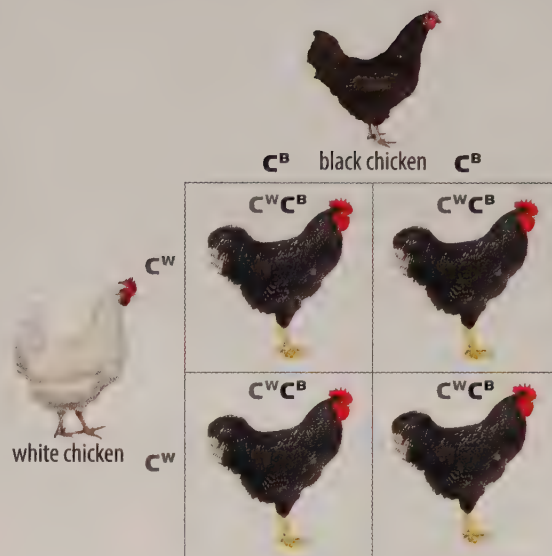
In incomplete dominance (top) the two alleles for a trait (red and white flowers) combine to produce a heterozygous genotype that is neither dominant nor recessive (pink flowers). When two pink poppies are crossed (bottom), they produce more pink poppies, but there’s a 25% chance each that they’ll produce red or white poppies.

Incomplete dominance also occurs in some human traits. For example, someone with a normal cholesterol level may have a genotype of C^nC^n (C is for cholesterol and n is for normal). Someone with really high cholesterol may have a genotype of C^hC^h , and someone with a hybrid genotype of C^nC^h may have a cholesterol level that's higher than normal but not as high as that of a C^hC^h person.

CODOMINANCE

Sometimes both alleles that are inherited are expressed, which is known as **codominance**. Think of a king and queen co-ruling, both expressing their commands at the same time—this is codominance.

Some breeds of chickens (*Gallus gallus domesticus*) exhibit codominance in their feathers. Since both alleles for feather color are dominant, they are both represented with a capital letter. When a white chicken (C^WC^W) mates with a black chicken (C^BC^B), an alternating pattern, or variegation, of black and white (C^WC^B) is produced.



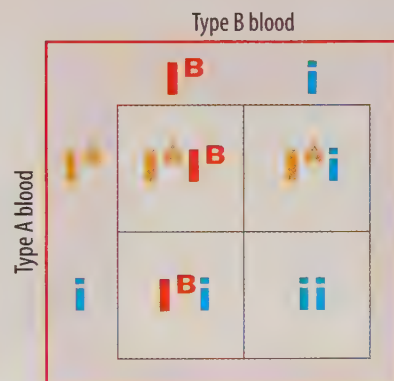
MULTIPLE ALLELES

So far, we've discussed traits that have two alleles, but there are traits that can have **multiple alleles**. One of the most familiar traits with multiple alleles is human blood type. Your blood type can contain the alleles A, B, or O. People can express only the two blood type alleles that they got from their parents, so no one can have all three. Traditionally, the two dominant alleles, A and B, are represented with a capital I , and the recessive allele, O, with a lowercase i .

Table 8-3

Allele Combinations for Blood Types

Genotype	Phenotype
$I^A I^A$, $I^A i$	Type A
$I^B I^B$, $I^B i$	Type B
$I^A I^B$	Type AB
ii	Type O



8-5

If one parent is heterozygous for blood type A, and the other is heterozygous for blood type B, then their children have the potential for any blood type. The "i" that is used as the symbol for blood type comes from the word "immunoglobulin," which is another name for an antibody in blood that latches onto disease-causing substances in the blood.

POLYGENIC INHERITANCE

Not only can a trait have more than one allele, it may even have more than one gene that controls it. Two or more genes working together to express a trait is called **polygenic inheritance**. Many human traits are the result of several genes working together, creating a greater variety of expressions than a single gene could.

The wide spectrum of skin color is an example. You have several genes, possibly dozens, that code for the amount of melanin that your

cells produce. Environmental factors such as UV rays also play a part. But let's consider just three genes for skin color. Very light skin is a recessive trait (*aabbcc*), and very dark skin is dominant (*AABBCC*). A completely heterozygous genotype, *AaBbCc*, creates a medium-color phenotype. The more dominant alleles you have in your skin color genotype, the darker your skin will be.

8-6

There are eight possible gametes that can be produced in two people with a heterozygous genotype (*AaBbCc*) for skin color. Crossing the gametes in a Punnett square shows that their children are much more likely to have medium skin than either dark or light skin.

SKIN COLOR								
	ABC	ABc	AbC	aBC	Abc	aBc	abC	abc
ABC	AABBCC	AABBCC	AABbCC	AaBBCC	AABbCc	AaBBCC	AaBbCC	AaBbCc
ABc	AABBCC	AABbCc	AABbCc	AaBBCC	AABbCc	AaBBCC	AaBbCc	Aabbcc
AbC	AABbCC	AABbCc	AABbCC	AaBbCC	AABbCc	AaBbCc	AabbCC	AabbCc
aBC	AaBBCC	AaBBCC	AaBbCC	aaBBCC	AaBbCc	aaBBCC	aaBbCC	aaBbCc
Abc	AABbCc	AABbCc	AABbCc	AaBbCc	AABbcc	AaBbcc	AabbCc	Aabbcc
aBc	AaBBCC	AaBbCc	AaBbCc	AaBBCC	AaBbcc	aaBBcc	aaBbCc	aaBbcc
abC	AaBbCC	AaBbCc	AabbCC	aaBbCc	AabbCc	aaBbCc	aabbCC	aabbCc
abc	AaBbCc	AaBbcc	AabbCc	AabbCc	Aabbcc	aaBbcc	aabbCc	aabbcc

8-7

An orange female cat ($X^O X^O$) crossed with a black male cat ($X^B Y$) can produce only calico females and orange males.



black cat (male)



orange cat (female)

	X^B	Y
X^O	$X^B X^O$ 	$X^O Y$ 
X^O	$X^O X^B$ 	$X^O Y$ 

SEX-LINKED TRAITS

Most of your traits are determined by your autosomes. But a few are controlled by the sex chromosomes, X and Y, and are called **sex-linked traits**. Most sex-linked traits are determined by the X chromosome. Why? The X chromosome is much larger than the Y (look back at Figure 8-2 to see how much larger), and so it carries a lot more information.

The color of calico cats (*Felis silvestris catus*) is a great example of a sex-linked trait. Almost all calico cats are female. The calico color contains a mix of orange and black fur. Both colors are carried only on the X chromosome and are expressed codominantly. A female cat can be $X^B X^B$ (black), $X^O X^O$ (orange), or $X^B X^O$ (calico). A male cat can be $X^B Y$ (black) or $X^O Y$ (orange).

A common sex-linked trait in humans is red-green colorblindness. The allele for this trait is found on the X chromosome. Normal vision is dominant (X^N), and red-green colorblindness is recessive (X^n). Men are much more likely than women to inherit colorblindness because all they need is one recessive allele on their X chromosome ($X^n Y$) to express the trait.

Women must have the recessive allele on both of their X chromosomes (X^nX^n) to be colorblind.

Notice in Figure 8-8 that any of the daughters of the colorblind man and his homozygous, normal wife will be heterozygous, carrying one allele for normal vision and one for colorblindness. People who carry an allele but don't express it are called **carriers**. The wife can't have colorblindness because it's a recessive trait, but she could potentially pass it along to her sons, making them colorblind, or pass it along to her daughters, making them carriers.

	X^n	Y
X^N	X^NX^n	X^NY
X^n	X^nX^n	X^nY

8-8

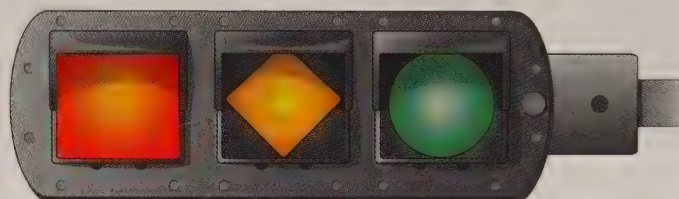
A colorblind man (X^nY) won't have any colorblind children if his wife is homozygous for normal vision (X^NX^N), but his grandchildren might be colorblind.

Is a Colorblind Woman Possible?

Colorblindness in women isn't common, but it's genetically possible. Draw a Punnett square that shows how the trait can be expressed in a woman.

8-9

Since people with red-green colorblindness can't tell the difference between the colors in a traffic light, some cities have altered the colors or changed the shape of the stoplight itself.



BIOETHICS AND STEM CELLS



Stem cell research has been in the news ever since the 1940s, when Dr. Leon Jacobson pioneered a way to use adult stem cells from bone marrow to treat leukemia. Stem cells can do amazing things for organisms. For example, a chunk taken out of a flatworm will regrow in just a few days thanks to its somatic stem cells. Scientists are working to apply the flatworm's power of regeneration to human somatic stem cells. But some scientists are focusing their research on embryonic stem cells. To produce a line of human embryonic stem cells for experimentation, researchers create an embryo and then kill it to harvest its pluripotent cells. Life begins when a sperm and egg unite to form a zygote and then an embryo, so killing human

embryos creates a moral dilemma: is embryonic stem cell research appropriate for finding treatments for diseases, or is it wrong to kill innocent lives no matter what stage of life they're in?

Nature itself seems to fight against the use of embryonic stem cells. Over the decades, adult stem cells have been successfully used to treat cancer, diabetes, heart disease, and autoimmune diseases, and they're becoming promising as treatments for Alzheimer disease and amyotrophic lateral sclerosis (ALS). But embryonic stem cells haven't proven useful, and there are currently no approved treatments using them.

Bioethics committees view embryos as alive, but they often believe that embryos aren't humans until they can survive outside the womb. Scripture affirms that God considers babies still in the womb to be people that He has formed (Ps. 139:13–16). It is far better to follow God's Word and preserve human life, even when that life is still fragile and completely dependent on another person to survive.



8-10

This pot contains two different types of coleus plants (*Plectranthus scutellarioides*) that are dominant (solid green) and recessive (variegated red and green).

8B REVIEW QUESTIONS

1. In gerbils, solid-colored fur is a dominant trait (C), and multicolored fur is recessive (c). If a gerbil has the genotype Cc , what is its phenotype?
2. Can you identify the genotype of a person with normal melanin? Why or why not?
3. In many plants, variegated leaves (leaves with splotches, stripes, and other color variations) are a recessive trait, and solid-colored leaves are dominant.
 - a. Choose a letter and list the two alleles using that letter.
 - b. Using a Punnett square, show the possible genotypes that result from a cross between a plant with variegated leaves and a plant with heterozygous solid leaves.
 - c. List their possible phenotypes.
4. Jake has albinism (mm), but no one else in his family does. How did his parents pass the trait down to him? Draw a Punnett square to help explain your answer.
5. If Jake wanted to trace the trait of albinism to see where it appears earlier in his family's history, what could he do?
6. If a black-feathered chicken were bred with a white-feathered chicken, and their offspring's colors were a result of incomplete dominance, what color would their offspring's feathers be? Why would they be that color?
7. Is type AB blood an example of incomplete dominance or codominance? Explain your answer.
8. Your eye color is a result of polygenic inheritance—two alleles on one gene and two alleles on another. One gene codes for either brown (B) or blue (b). The other codes for dark green (G) or light green (g). Brown is dominant over green. Someone with the homozygous genotype $bbgg$ has very blue eyes; someone with the homozygous genotype $BBGG$ has very brown eyes. Can a couple who both have brown eyes have a child with blue eyes? Support your answer with a Punnett square.
9. Using the information and the Punnett square that you created in Question 8, determine whether brown-eyed parents can have a green-eyed child? If so, what are the genotypes for green eyes? Is it more likely that these parents would have a blue-eyed child or a green-eyed child?
10. Fabry disease is a recessive genetic disorder that leads to the buildup of lipids throughout the body. Men most often have the disease and usually show severe symptoms. Occasionally women have it, and they may have either mild or severe symptoms. Using this information about Fabry disease, what two types of gene inheritance do you think are involved? Explain why you chose these two types.

EXPERIMENTING WITH ANIMALS

Research companies often try to avoid testing their products on animals, but for potentially dangerous products, it's not always avoidable. Before treatments like stem cell transplants or new medications are ever used on a person, they're tested extensively on animals. Every research lab must follow a set of rules for taking care of the animals, making sure that they're treated as humanely as possible. But many of them still die as a result of the treatments and diseases that they're given. Could there be a better way to create treatments that are safe for people without sacrificing so many animals?

For thousands of people who suffer from diabetes, animal research has been a lifesaver. Before the 1920s, diabetes was a death sentence. But two physicians began experimenting on dogs and discovered that diabetes is caused by the faulty production of insulin. They were able to isolate insulin and offer it to people with diabetes as a treatment. Today, we don't have to rely on animals to produce insulin because medical researchers have found ways to produce insulin artificially.

A more recent move away from using animals is in asthma and allergy research. The chemicals in asthma inhalers and allergy pills are usually tested on animals, but a new procedure is gaining in popularity—taking a few cells from a person's respiratory system and testing the medications on those cells. This procedure might be the first step toward eliminating animal studies for many kinds of medications.



8-11

The controversial Enviropig was genetically altered to produce less phosphorus in its manure. Why? Manure from farms can end up in nearby lakes and create algal blooms. Many felt that creating Enviropig was a poor solution to the problem of manure in lakes. Since 2012, Enviropigs have not been produced.

What makes a product natural and good?



No animal testing or animal ingredients.

We share every ingredient, its purpose, and its source



A darker side of animal research is manipulating animals' genes in such a way that it permanently disfigures them. In the late eighteenth century, a sheep with a crippling form of dwarfism was prized because it was unable to jump over low fences. This trait was bred into an entire line of sheep that became known as Ancon sheep (*Ovis aries*). These sheep went extinct in the nineteenth century because breeding for the genetic disease of dwarfism made them incredibly weak. On a different note, many research animals today have their genes manipulated on the molecular level so that they can be cloned, produce human diseases, grow human organs, and create bizarre combinations of species that don't survive. The purpose of this animal research is to benefit people or the animals themselves.

The Bible gives us a balanced view of how to use animals. They were used daily as sacrifices to show the Israelites their need for the permanent Sacrifice that would one day come, but the sacrificed animals weren't wasted. Meat that was left over after certain sacrifices fed the priests (Lev. 2:3, 10). In Exodus 20:10, God includes animals in the Sabbath day rest, and in Deuteronomy 25:4, God reminds His people to take care of the animals that they have. This command is repeated in 1 Corinthians 9:9 and 1 Timothy 5:18, applying not only to animals, but to anyone who serves another. We should also care for animals that we may not value as highly as others (Matt. 10:29). Your pets aren't the only animals that deserve to be treated well!

We live in a world marred by sin and suffering, and because of that, our stewardship is less than ideal. But that doesn't mean that we should treat animals with little or no respect. Human lives have more value than animal lives (Matt. 10:31), but we should continue to improve our technology and research techniques so that we can minimize the harm that we bring to the animals in our care.

8C Questions

- » How are genes and cell development related?
- » How does the environment affect gene expression?
- » When can a cell express certain genes?
- » How should we use animal genes to benefit people?

GENE EXPRESSION

How does genetic information show up in an organism?

8.7 ACTIVATING GENES

Every gene you have can be found in every cell of your body. That means that the genes that code for your eye color are found not just in your eyes; they're also in your stomach, kidneys, ears, feet—they're everywhere! So how does your body know to express your eye color genes only in your eyes?

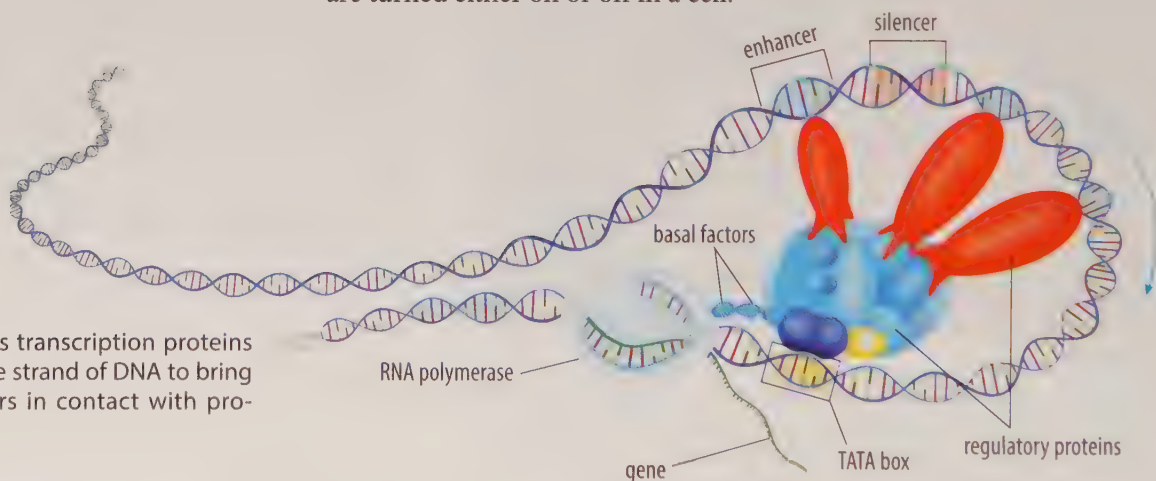
Gene expression is the process in which genetic information is activated to make a genetic product. The journey from DNA to proteins that you studied in Chapter 6 is part of the process of gene expression. A genetic product could be an obvious trait, like the proteins that produce eye color, or a trait that you'll never see, like the enzymes that help digest materials in the small intestine. Two main factors—DNA molecules and the environment—control gene expression.

THE ROLE OF DNA

During the transcription of DNA, little sequences of DNA called **promoters** come before each gene and tell the *RNA polymerase* molecule where to bind to begin copying the gene into a strand of mRNA. Promoters are found in all eukaryotic cells and accompany every gene in a cell. One common promoter, called the **TATA box**, binds to a group of *transcription proteins* that are attached to RNA polymerase. Through the different combinations of promoters and proteins, genes are turned either on or off in a cell.

8-12

RNA polymerase and its transcription proteins form a loop in the single strand of DNA to bring enhancers and silencers in contact with promoters.



DNA also contains sequences called *enhancers* and *silencers*. These can bind to the promoters in front of genes and act as switches, telling the RNA polymerase whether the gene needs to be turned on (enhanced) or turned off (silenced). A promoter is told what to do by

enhancers and silencers. Think of a promoter as a car that's on but not moving yet. It requires an enhancer (the gas pedal) to go or a silencer (the brake) to stop.

But the enhancers and silencers don't act alone. Just as the RNA polymerase molecule and transcription proteins bind to promoters, proteins called *regulatory proteins* bind to enhancers and silencers. Regulatory proteins are the actual link between the enhancers and silencers and the promoters. Going back to the car analogy, regulatory proteins are like your foot stepping on the gas or brake pedal. When your eye cells are expressing eye genes, they are stepping on the gas whenever eye genes appear in the DNA strand and hitting the brakes whenever other genes appear.

Once the right genes are turned on and transcribed to mRNA, the *introns* (noncoding sections of DNA) are removed, and the *exons* (coding sections of DNA) are stitched together and are ready to leave the nucleus to be translated into a protein.

THE ROLE OF THE ENVIRONMENT

Transcription can be affected by things other than promoters and proteins.

Hormone-activated traits. Whether you're male or female can affect your gene expression. For example, whenever a child reaches puberty, the body sends out a wave of hormones (chemical messengers) to tell the body how to begin preparing for adolescence. These hormones bind to the DNA strand during transcription and activate genes that have never been active before. Because males have different levels of hormones than females do, different genes are activated, resulting in two very different developments between the sexes.

Light and temperature. The fur color of Himalayan rabbits (*Oryctolagus cuniculus*) changes depending on the climate of the region it lives in. When the rabbits are warm, their genes produce a uniform coat color. When they're cold, their extremities—ears, nose, feet, and tail—turn a much darker color than the rest of their coat. Sometimes a Himalayan rabbit that lies against the side of a cold wire cage will develop dark lines of fur where the cage was touching, creating “grill marks” on the rabbit.

One of the reasons you get sleepy when it's dark outside is due to gene expression. As light levels drop, your genes send out a signal to produce melatonin, the hormone that regulates sleep patterns. Being in a brightly lit area all day and night will throw off your body's production of melatonin and therefore your sleep cycle.

Chemicals. Chemicals such as drugs and pollutants can radically alter gene expression in babies that are still developing. If a mother takes certain medications, breathes in or eats pesticides, or touches certain parasites during her pregnancy, the chemicals can disrupt transcription and create defective genes throughout her baby's cells. On the other hand, researchers are looking for ways to use chemicals to

Keeping Chemicals off the Table

Methemoglobinemia, sometimes known as blue baby syndrome, is a life-threatening genetic disease that is either inherited or acquired from ingesting certain chemicals. The disease prevents oxygen from leaving the blood to enter the cells. The result is that each cell begins to suffocate.

Farm animals are at risk for methemoglobinemia when fertilizer chemicals such as nitrates collect in their water supply or food. Even certain bacteria can trigger the disease in farm animals.

One way that people avoid the disease is to rinse their fruits and vegetables in case there are chemicals on them. But animals can't tell you whether their dinner is making them sick. So a farmer must learn about his animals, the environment they live in, and the food they eat to keep them healthy.



8-13

A Himalayan rabbit that was raised below room temperature (below 73 °F, or 20 °C) will have darker ears, nose, and paw coloration than one raised above room temperature. The rabbit raised at the higher temperature will appear lighter.

turn off genes that code for disorders. The hope is that these chemicals might one day lead to a better treatment for cancer, cystic fibrosis, sickle cell anemia, and the scores of other genetic disorders that we have to deal with in our fallen world.

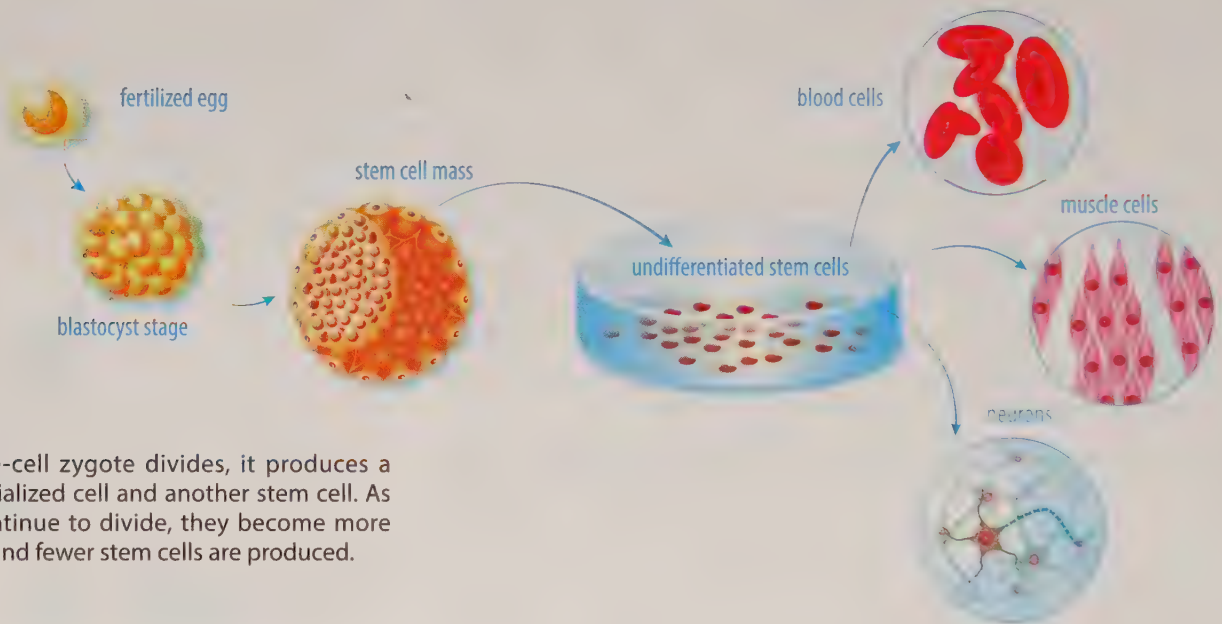
8.8 GENES AND DEVELOPMENT

So how does a tiny, one-cell zygote turn into an organism with trillions of cells that each do something different? Zygotes go through the process of **cell differentiation**, which changes cells so that they can perform more specialized tasks.

While a baby is still a single-cell zygote or a several-cell embryo, the baby's cells are **totipotent**, meaning that they have the potential to turn into any kind of cell. A cell from a baby during the totipotent stage can become a liver cell, eye cell, bone cell, or any other kind of cell. After a few cell divisions, the cells become **pluripotent**, still able to produce many kinds of cells, but not all kinds.

totipotent (toh TIP uh tunt): toti- (L.—whole, total) + -potent (L.—power)

pluripotent (pluh RIP uh tunt): pluri- (L.—more) + -potent



8-14

When a one-cell zygote divides, it produces a slightly specialized cell and another stem cell. As the cells continue to divide, they become more specialized, and fewer stem cells are produced.

A special set of genes in a developing baby's cells, known as **homeotic genes**, are working to produce each kind of cell that he will need. Homeotic genes act as a map for the baby's body structure. They make sure that you look human, that a cow looks like a cow, and so on. Once that's done, the baby's cells are no longer totipotent, and the genes that were responsible for cell differentiation are switched off.

These amazingly changeable cells are called **stem cells**—cells that have not yet differentiated into specialized cells. The cells described in the previous paragraph are called **embryonic stem cells** because they appear during the zygote and embryo stages of development. An **embryo** is the early stage of an unborn young of a multicellular organism. But there are a few cells that don't differentiate in a fully developed organism. These are called **somatic stem cells**, or adult stem cells.

somatic: somat- (Gk.—body) + -ic (Gk.—pertaining to)

Physicians have been using somatic stem cells for years to help people with bone cancer or other diseases that damage bones. These people receive a bone marrow transplant from another person because bone marrow contains somatic stem cells. Once the donor cells have been transplanted and are established, they begin differentiating, producing healthy cells to replace the damaged ones. And stem cells are not found just in bones; researchers are finding more and more places in the human body that contain them. They hope to harness the versatility of these cells to create treatments and cures for even more diseases.

8C REVIEW QUESTIONS

1. How does a cell in your spleen know how to express spleen genes? Use the terms *enhancer*, *promoter*, *regulatory protein*, *RNA polymerase*, *silencer*, and *transcription protein* in your answer.
2. Gestational diabetes occurs when a pregnant woman has high levels of blood sugar. Cells in the pancreas usually keep blood sugar levels normal, but hormones produced during pregnancy deactivate the cells. After pregnancy, hormone levels return to normal, and so do the pancreas cells. Is this an example of DNA or the environment controlling gene expression? Explain your answer.
3. What would happen if there were only enhancers and no silencers in a strand of DNA?
4. If you breathed in a lot of chlorine at the pool, which of your cells would be affected? If an embryo were exposed to chlorine, which of his cells would be affected?
5. Which has the greater potential to turn into any kind of cell—a totipotent or a pluripotent cell?
6. What is the difference between an embryonic stem cell and a somatic stem cell?
7. What is the balance between caring for animals and using them for medical research? Justify your answer with a Bible reference.
8. Give two problems associated with research using human embryonic stem cells and two ways that somatic stem cells provide solutions to those problems.

REVIEW QUESTIONS

T Key Terms	
chromosome	132
gene	132
chromatid	132
centromere	132
sex chromosome	132
autosome	132
homologous	133
diploid	133
haploid	133
cell cycle	134
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mitosis	134
cytokinesis	134
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telophase	134
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heredity	137
dominant trait	138
recessive trait	138
allele	138
homozygous	138
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heterozygous	138
Punnett square	139

(continued)

CONCEPT REVIEW

1. Organize the following terms from least complex to most complex: chromosome, DNA, gene.
2. The haploid number of chromosomes (n) for wheat is 7. How many sets of chromosomes does wheat have if it has 42 chromosomes total?
3. Describe two differences between sex chromosomes and autosomes.
4. The green-spotted pufferfish (*Tetraodon fluviatilis*) has 42 chromosomes. Its eggs and sperm each have 21 chromosomes. Which is the haploid number of chromosomes? Which is the diploid number?
5. Using the numbers from Question 4, how many chromosomes would you suggest the offspring of green-spotted pufferfish have? How many homologous pairs of chromosomes do they have?
6. During which part of interphase does a cell make a copy of its chromosomes?
7. How is cytokinesis after mitosis different from cytokinesis after meiosis I?
8. Gametes divide by _____ (mitosis/meiosis), and zygotes divide by _____ (mitosis/meiosis).
9. How do cells become genetically different from each other during meiosis?
10. Sketch out the four phases of mitosis and cytokinesis. Include in your sketch the location of the nucleus (whether it's in the cell during a phase or not), the identity of the genetic material (chromatin, chromosome, or chromatid), and labels for each phase.
11. Sketch out the eight phases of meiosis and cytokinesis. Include in your sketch the location of the nucleus (whether it's in the cell during a phase or not), the identity of genetic material (chromatin, chromosome, or chromatid), and labels for each phase. Also label the phase at which the diploid cell becomes haploid.
12. A peanut farmer discovers a special trait in one of his peanut plants—it's resistant to rootworms, a pest that eats peanuts before they're harvested. Which method of reproduction would be better to use to make sure that this trait stays in future peanut plants—asexual or sexual reproduction? Explain your answer.
13. Of Mendel's three principles of genetics, which deals with the movement of a trait into the reproductive cells of an organism? Which deals with the dominance of a trait? Which deals with each trait moving separately, regardless of how other traits move?
14. Heterozygous is to hybrid as homozygous is to _____.

Use the Case Study on the facing page to answer Questions 15–17.

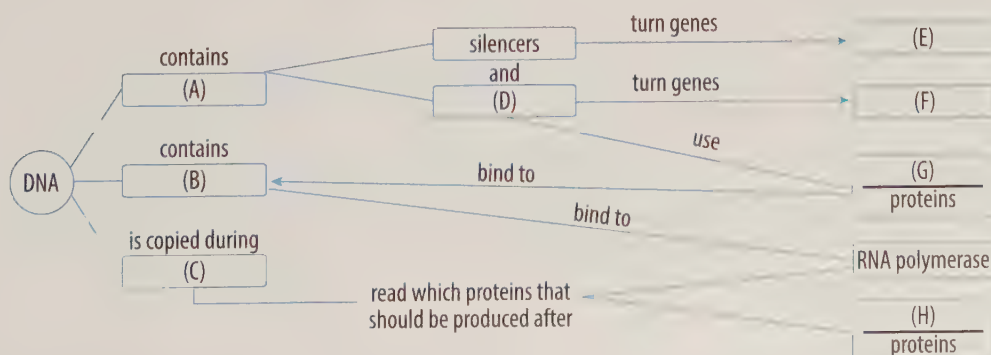
15. What are the possible genotypes of Kate's dad? of Kate's mom?
16. What are Kate's possible genotypes?
17. Is anyone in Kate's family homozygous for the trait? Why is it not possible for Kate to be homozygous?

CASE STUDY: THE INHERITED HANDCLASP



When Kate clasps her hands together, she notices that her left thumb sits on top of her right thumb, which is a dominant trait (E). Kate then asks her parents to clasp their hands, and she discovers that her dad's left thumb is also on top of the right thumb. However, her mom's right thumb is on top, which is the recessive trait (e).

18. Green cucumbers (*Cucumis sativus*) are dominant over orange cucumbers. Show a cross between two green cucumbers that could produce orange cucumbers. First, list the genotypes of the two parent cucumbers, and then draw a Punnett square to show the cross. Second, identify the genotype(s) of the offspring that would be orange.
19. In a dihybrid cross, why must you figure out all the possible combinations of gametes before crossing them?
20. A(n) _____ tries to predict future generations; a(n) _____ traces past generations.
21. Why is Mendel's model of genetics not the *only* model of inheritance?
22. What is the difference between incomplete dominance and codominance?
23. Wavy hair is the result of one allele for curly hair and one allele for straight hair. Is wavy hair an example of incomplete dominance or codominance? Draw a Punnett square to show the cross between someone with curly hair and someone with straight hair to show the likelihood of producing wavy-haired children.
24. In Texas Longhorn cattle (*Bos taurus*), a red cow bred with a white bull produces offspring with a roan coat—cattle with both red and white fur. Are roan cattle an example of incomplete dominance or codominance? Draw a Punnett square to show the cross between a red cow and white bull to show the likelihood of producing roan cattle.
25. Multiple allele inheritance involves more than two _____ coding for the same trait. Polygenic inheritance involves more than two _____ coding for the same trait.
26. Is the polygenic inheritance of skin color a type of incomplete dominance or codominance? Explain your answer.
27. Using a Punnett square, show a cross between a colorblind woman and a normal man. List the possible phenotypes of their children.
28. Fill in the following flow chart, which shows how genes are expressed by associating the correct term with the lettered blanks.



Key Terms (continued)

monohybrid cross	140
dihybrid cross	140
pedigree	141
incomplete dominance	142
codominance	143
multiple alleles	143
polygenic inheritance	143
sex-linked trait	144
carrier	145
gene expression	148
promoter	148
TATA box	148
cell differentiation	150
homeotic gene	150
stem cell	150
embryo	150

T

29. If it's cool outside, a turtle will lay eggs that contain mostly male turtles. If it's warm, the turtle will lay eggs with mostly females in them. What two environmental factors of gene expression are at work here?
30. Researchers can reprogram certain genes in fruit flies (*Drosophila melanogaster*), creating legs in the place of wings on the flies. Which genes are the researchers reprogramming?
31. Which type of stem cells can be harvested and used without killing the donor of the cells?
32. Why should a lab mouse in an experiment be treated well, even if the experiment leads to its death? Explain your answer from a biblical point of view.

TRUE OR FALSE

33. Your DNA forms chromosomes whether or not the cells are ready to divide.
34. The X chromosome carries a lot more information than the Y chromosome does.
35. Mitosis begins with a diploid cell, and meiosis begins with a haploid cell.
36. Hybridization adds new genes to an organism's gene pool, which weakens the organism.
37. If a person has type O blood even though neither of his parents do, then his parents must both have heterozygous blood types.
38. Women are more likely than men to be carriers of sex-linked traits.
39. Genes are turned on or off during the translation of DNA.
40. Both adults and unborn embryos have stem cells.

CRITICAL THINKING

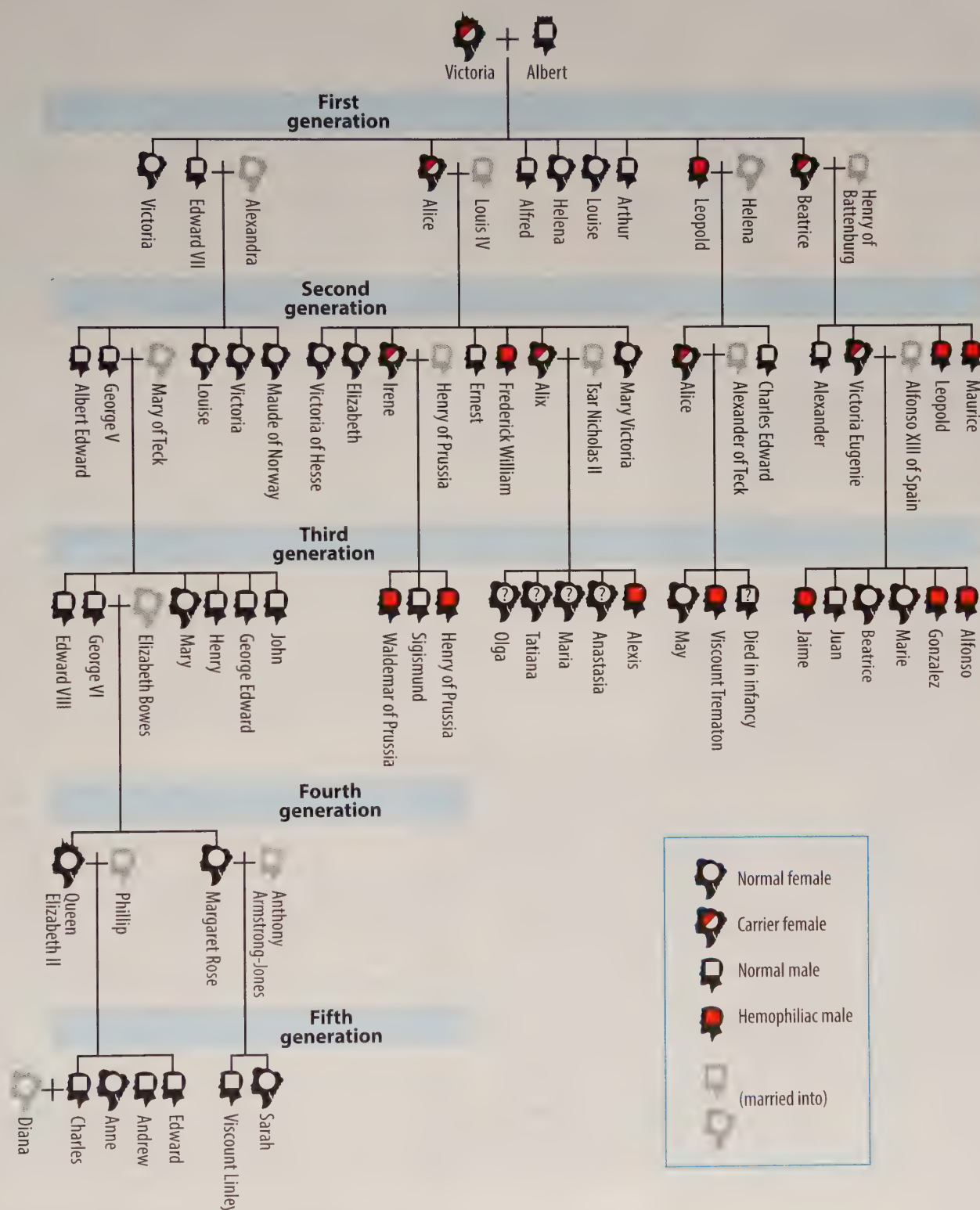
Use the Case Study below to answer Questions 41–44.

CASE STUDY: HEMOPHILIA

Hemophilia is a sex-linked disease that is caused by a missing enzyme in the blood. The enzyme is responsible for clotting blood; without it, a person with hemophilia can bleed to death from a paper cut or a bruise. This disease has been prominent in the British royal family, whose pedigree for hemophilia is shown on the facing page.

41. Using the pedigree, determine whether hemophilia is a dominant or recessive trait.
42. Use a Punnett square to predict the genotypes of Victoria and Albert's children. What percentage of them should have a completely normal genotype? How does this percentage compare to the actual number of normal genotypes among the couple's children?

43. Victoria and Albert had a son with hemophilia, Leopold. In the 1800s, most people with hemophilia didn't live long enough to marry and have children, but Leopold did. How did he and his wife Helena have a child with a completely normal genotype? Use a Punnett square to support your answer.
44. Today, there are medications for people with hemophilia that allow them to lead normal lives. How does this affect the probability of the hemophilia allele being passed down from generation to generation?





CHAPTER 9

ADVANCED GENETICS

- POPULATION GENETICS 117
- MUTATIONS 145
- GENETIC ENGINEERING 155

FOOD FOR THE FUTURE

It was 1960, and it seemed that agriculture was struggling to keep up with a growing world population. The International Rice Research Institute developed an almost miraculous strain of rice called *IR8*. Rice production soared, with the Philippines having a self-sufficient rice harvest in 1966 for the first time in many years. The Vietnamese called it *Honda rice*, because bumper crops allowed them to buy new motorcycles. Indian parents named their children after the rice. This crop and many others produced in labs led to the Green Revolution, the period between the 1930s and the 1960s during which food production around the world grew dramatically because of advances in science and technology. The Green Revolution may have saved a billion people from starvation around the world.

By 2050, there may be nine billion mouths to feed, and we need a new Green Revolution. Biotechnology—the use of technology to enhance living organisms and their processes—may be the power tool that helps us fight against world hunger. Geneticists are working to produce crops that resist drought, pests, and herbicides to produce greater harvests with less land. But how can we pursue this science in a way that helps the most people?

POPULATION GENETICS

How does genetics drive the way a population changes over time?

9.1 GENETIC VARIABILITY

When researchers developed IR8 (see Chapter opener), they were using selective breeding to tease out desirable traits from a rice population. IR8 was so successful because it had a short stalk and produced abundantly without falling over. Researchers have developed more *cultivars*, or varieties, of rice and other crops using selective breeding and hybridization. These cultivars are bred to taste and produce better than the original.

The sum of all the alleles that all individuals of a population of organisms can conceivably possess is called its **gene pool**. If a farmer plants a whole field of IR8 rice, he is taking advantage of the combination of alleles that are unique to IR8. This can be dangerous, however, as pests, viruses, and changing environmental conditions can wipe out an entire field of plants. But if farmers plant their fields with a variety of cultivars and strains of the same organism, the same field can represent a greater genetic diversity. There is a lower risk of losing the crops due to pests and poor environmental conditions that can result in plant disease.

God created the world full of living things that have the potential for amazing variety. Just think about all the different kinds of people that came from Adam and Eve! When you look around at all the people at the mall, you see a perfect example of variation. **Variation** in a population is the range of genotype differences between individuals from the same gene pool.

As people are born and die or move to or away from your area, there is a constant incoming and outgoing of genetic information in the population. This ebb and flow of genetic material in a population is called **gene flow**. Some alleles are more common than others. For example, if you were to count the number of people with blue, brown, and green eyes that passed you in ten minutes at the mall, you would be considering **allele frequency**—how often an allele shows up in a gene pool. For example, in Scotland about 57% of the population has blue eyes.

9A Questions

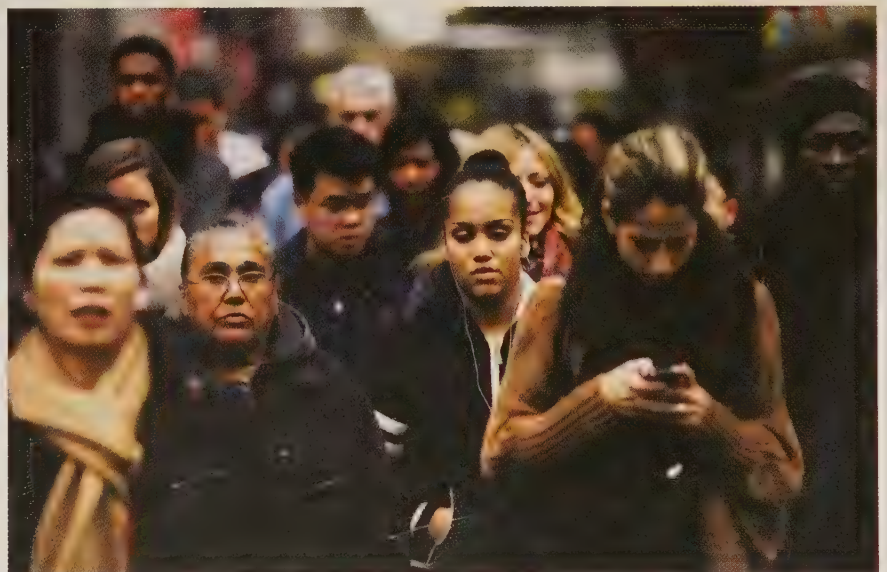
- » Why do organisms in a population change?
- » What limits genetic change in a population?

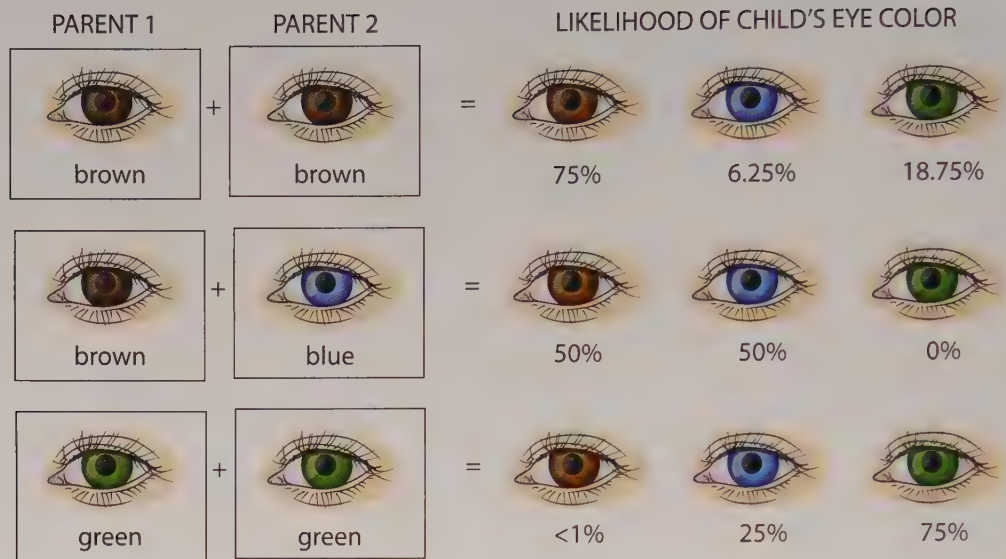
Race and a Christian Worldview

People link many physical traits, such as skin color and hair color, with race. A *race* is a group of people that have distinct physical and genetic traits. There has even been an effort to examine the genes of different people groups. From a biblical perspective, is there more than one race? Why or why not?

9-1

Observe the genetic variability of the population in your area.





Where does all this variety come from? One source of genetic variation is the different types of alleles that combine when two parents reproduce. Another source of genetic variation happens during meiosis, when chromatids can switch information to form new combinations of alleles, called *crossing over*. Also, single-celled organisms such as bacteria can exchange genes through **plasmids**—small, circular DNA molecules that function like chromosomes—without the process of reproduction. This is called *lateral gene transfer*.

In Chapter 6, we saw that a cell can make errors when copying or decoding DNA. These mistakes—called *mutations*—in a population can be passed down to introduce variation and new traits into a population, though most mutations aren't passed on. The number of mutations sustained by an organism or a gene pool is called its *mutation load*. A population's mutation load is directly related to its *genetic load*, a measure of the health and fitness of a population. A heavier mutation load means a heavier genetic load and a less healthy population since mutations are usually harmful to a population. We'll look more closely at mutations in the next section of this chapter.

9.2 GENETIC LIMITS

Bi

Genetic Drift and Evolution

So how does change in allele frequency in a population relate to evolution? "Change in allele frequency" is one of the most basic definitions for evolution. Genetic drift (see facing page) is the fluctuation of allele frequency based on random events, whereas natural selection is the nonrandom change of gene frequency. You'll learn more about evolution and natural selection in Chapter 10.

In large populations with thousands of individuals, the allele frequency is stable. Geneticists call this condition **genetic equilibrium**. For example, we wouldn't expect the blue-eyed trend in Scotland to change unless there was a mass exodus of a large segment of the population, or an influx of a new group. However, we can't assume, just because blue-eyed people are the majority in Scotland, that blue eyes are a dominant allele.

At the start of the 1900s, when the study of genetics was just beginning and Mendel's work had been rediscovered, scientists began wondering how gene pools and populations might be affected over time. One of the questions scientists wanted to investigate was, "Will the dominant forms of an allele eventually replace the recessive ones?"

Two researchers working independently of each other were able to demonstrate that dominant alleles will not automatically replace the recessive alleles for a population in genetic equilibrium. The *Hardy-Weinberg principle* was named in honor of the two men who investigated this idea.

Genetic equilibrium is the theoretical result of the Hardy-Weinberg principle. No population is ever truly at equilibrium because it is constantly changing. Its size, individuals, and mutation load are constantly in flux. But what happens when an allele randomly becomes more common in a gene pool? This doesn't usually happen in large populations, but it could happen in small ones like those living on islands. Geneticists call a change in the allele frequency based on random events **genetic drift**.

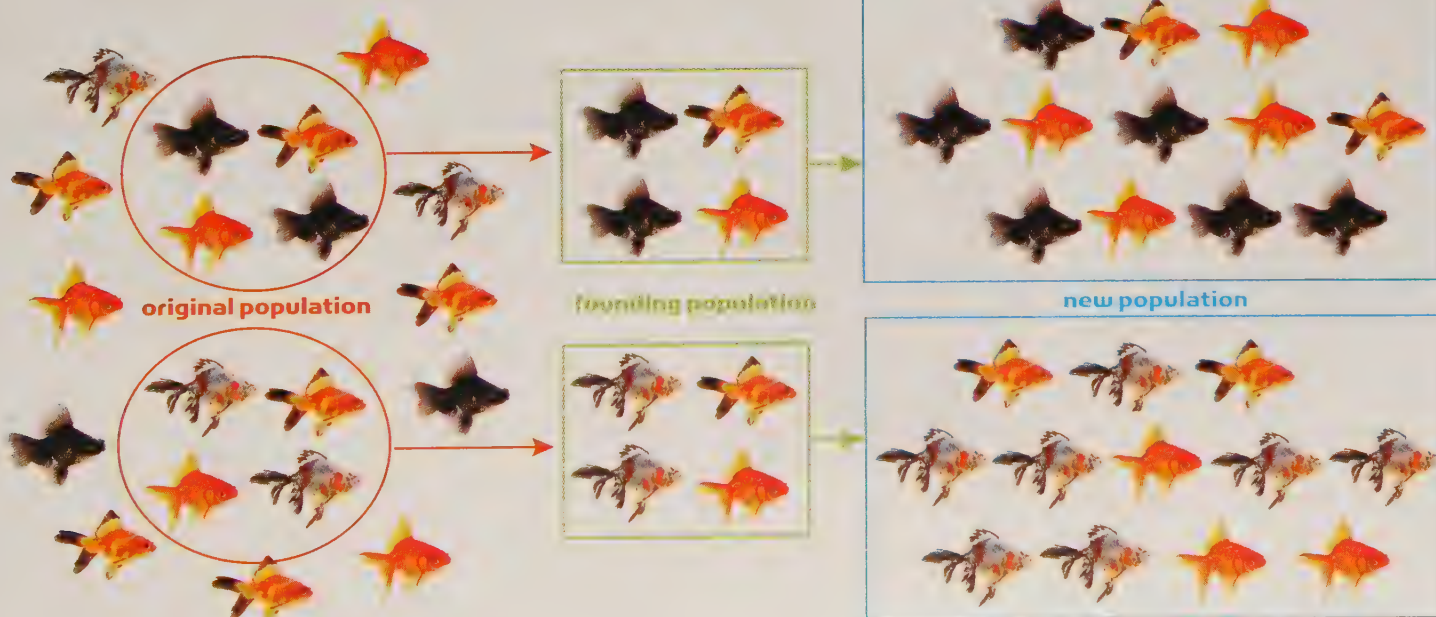
What kinds of random events can cause genetic drift? When a large portion of a population dies, for example, observation of the survivors may reveal that the gene pool and allele frequency have changed dramatically. This is called the **bottleneck effect**. In another phenomenon known as the **founder effect**, a small population moves to a new area and the allele frequency changes as this smaller group starts a new population.

Evolutionists see genetic drift as being a major player in natural selection. The fact that genetic drift happens, however, doesn't prove evolution. Genetic drift usually represents a loss of variation and information in a population. This becomes evident when you compare the original population with the new populations after the founder effect, shown in the image below, or the bottleneck effect. No one has ever observed genetic drift creating a new kind of animal. People who believe God's Word can see the variety within a kind of animal, such as butterflies, as an example of genetic drift without the need for large-scale change. Variety in nature is a fingerprint of God's creativity and order.



9-2

The spirit bear (*Ursus americanus kermodei*), also called the Kermode bear, is not an albino or a polar bear. It's actually a black bear that is born white due to two mutations in the gene for fur color that have been passed down. About 40% of the black bears in British Columbia have white fur, though most appear on islands in the Great Bear Rainforest. Scientists hypothesize that this could be a form of genetic drift or a result of competition with grizzly bears for food in local fish-laden streams.



CASE STUDY: CITRUS GREENING

There is great genetic variety in oranges—bitter oranges used in making marmalade, bergamot oranges grown for their perfumed peel, and mandarin oranges used for juice and eating. The oranges used to make your orange juice typically come from Florida. But many orange trees in Florida are dying because of a disease called *citrus greening*. This disease, which makes unripe fruit fall off the tree, is spread by a bacteria that hitchhikes a ride on an insect called the Asian citrus psyllid (*Diaphorina citri*). The disease started in Asia and was first spotted in Florida in 1998 and in California in 2012. No orange trees are naturally immune to citrus greening.



9-3

Citrus greening first attacks the root of citrus trees like tangerine trees, and then travels up the trunk to affect the fruit. The results are devastating to farmers who often can't spot the disease until it is too late.

9A REVIEW QUESTIONS

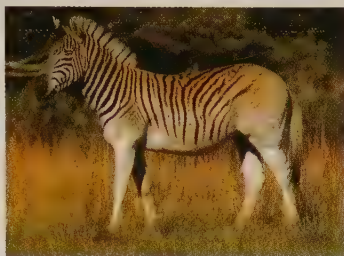
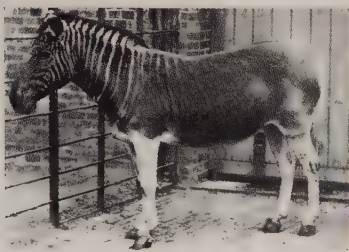
1. Suggest three factors that affect a gene pool.
2. What are three sources of genetic variation in a population?
3. How does mutation load affect the variability of a population?
4. What is the difference between genetic flow and genetic drift?
5. Evolutionists look to genetic drift as a main agent of evolution to produce different species. From a biblical standpoint, what is the correct view on this?

Use the case study above to answer Questions 6–9.

6. Describe some of the variations in the orange population.
7. Is it possible for the allele frequency to hold constant despite citrus greening? Explain.
8. Is the orange population in Florida in equilibrium? Explain your answer.
9. What kind of genetic drift is the orange population experiencing?

BREEDING THEM BACK

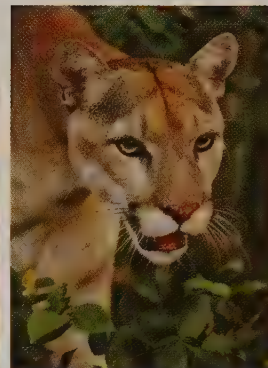
The quagga (*Equus quagga quagga*) looks like something from a myth. With its half zebra, half horse appearance, hunters flocked to the quagga's habitat in Africa to claim one of these strange animals for themselves. Before the end of the nineteenth century, there were no more quaggas. But in 1987, a museum historian decided to bring back the quagga. DNA testing of a museum specimen had revealed that the quagga was a subspecies of the Plains zebra (*Equus quagga*), so he realized that it might be possible to breed a new line of quaggas from the Plains zebra. Through five generations of *selective breeding*, which is the process of breeding for a particular trait, the quagga is becoming less of a myth as it makes its appearance again on the plains of Africa.



This quagga (left) was the last of her kind before her death in 1883. Today, genetically similar quaggas (right) roam a preserve in Africa.

Not all species have genes as flexible as the quagga's. The Florida panther (*Puma concolor coryi*), a subspecies of the cougar, has been in decline ever since settlers came to Florida in the 1600s. The big cat was almost eradicated in the twentieth century due to hunting and inbreeding. *Inbreeding* is the breeding of closely related individuals over several generations. The tiny population of Florida panthers had developed a host of health problems as their alleles were becoming more and more concentrated with each generation. So in 1995, several cougars from another subspecies in Texas were shipped to Florida and bred with the panthers. This *hybridization*, or the crossbreeding of individuals to form different traits, gave the Florida panthers a much-needed infusion of new alleles into their gene pool. Hunting by man is still a problem for the panthers, but their population has grown thanks to the scientists who hybridized them with their Texas cousins.

This cloned banteng lived at the San Diego Zoo from 2003 to 2010.



The dwindling Florida panther (left) population was given a boost when Texas cougars (right) were added, giving genetic diversity to a limited population.

Not all attempts to bring back species have been successful. Because there are so many DNA samples of extinct animals in museums and endangered animals in zoos, scientists are attracted to the idea of *cloning*—the duplicating of genetic information to create an identical copy of an organism. So far, many animals that scientists have tried to resurrect through cloning, like the Pyrenean ibex (*Capra pyrenaica pyrenaica*), haven't survived very long. But some are showing promise. One example is the banteng (*Bos javanicus*), a type of cattle in Southeast Asia used as a food source and as a work animal. But they have become a threatened species. So in 2003, a lab took the DNA from a banteng that had died twenty-five years ago and inserted it into a cow's egg cell that had its nucleus removed (an *enucleated egg*). Why use old DNA instead of DNA from a living specimen? The goal was to reintroduce the alleles that modern banteng had lost due to inbreeding. The result was an offspring with the exact DNA as the long-dead banteng. The cloned banteng lived for only seven years, about half the normal lifespan of a banteng. Though scientists



haven't completely figured out the genetics or the ethics behind cloning, they hope that one day they can breed cloned bantengs with wild ones to increase their genetic diversity and save them from extinction. The banteng and Dolly the sheep, the first successfully cloned mammal, are examples of *artificial clones*. Artificially cloned plants, discussed in Chapter 14, are much more common. *Natural clones* also exist, such as identical twins and plants that reproduce asexually.

9B Questions

- » How do changes in DNA affect chromosomes and genes?
- » How can one mutated cell affect other cells?
- » How does a mutation show itself in an organism?

A Growing Population = a Growing Problem?

What do you think—is a growing world population a good or bad thing? What does the Bible have to say about this?

MUTATIONS

How do changes in the genetic code happen?

9.3 DNA, CHROMOSOMES, AND MUTATIONS

So how do geneticists breed plants like the miracle rice IR8? The key to unleashing the traits that we need in plants is locked up in their DNA. DNA is information, and information comes only from a designer. The wording of the Creation Mandate in Genesis 1:28 is closely linked with investigating how we can use plants and the DNA they contain to provide a growing world population with food.

GENE MUTATIONS

In Chapter 6, we studied the process by which a cell replicates DNA and uses it to produce proteins. This copy of DNA provides information for the cell to carry on life-sustaining processes such as photosynthesis, cellular respiration, and protein synthesis. It is also used to prepare for cell growth and reproduction through mitosis or meiosis. By now, you should think of a *gene* as a section of DNA that can be decoded to create a certain protein. As you explored in Chapter 7, these genes produce certain recognizable characteristics in an organism. Your genes, and thus your DNA, make you special, different from everyone else.

But, as we saw in Chapter 6, mistakes in the process of decoding, copying, and using DNA sometimes occur. We used the term *mutation* to represent a genetic error that is produced when a nucleotide base in a section of DNA is added, deleted, or skipped in either replication or decoding. A mutation is like a misspelling in the words and sentences of DNA nucleotide bases. Some mutations happen randomly, and some are caused by a **mutagen**, a physical or chemical substance that changes genetic structure. A mutagen could be any toxin in the form of a virus, radiation, or a chemical (cigarette smoke, pollutants, dyes, etc.).

The results of a mutation depend on whether a nucleotide base was added, deleted or skipped and where on the DNA chain the mistake happened. When just one nucleotide base changes in the DNA chain, we call it a **point mutation**, whether it is substituted, added, or deleted. Point mutations can have a domino effect depending on what they involve. Mutations in gametes or in cells that produce gametes are called *germ mutations*. Germ mutations get passed down to the next generation. Mutations in cells that don't make gametes are called *somatic mutations*; these are not passed down. Germ mutations affect every cell in the offspring produced; somatic mutations affect only a few cells of the original organism. When a nucleotide base is swapped out for another one, a point mutation may not be harmful to the organism. But things

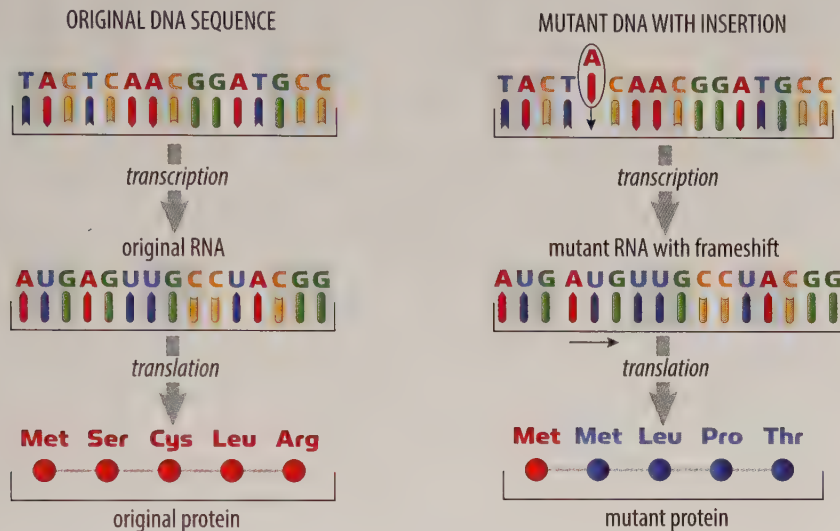
9-4 |

So what causes a four-leaf clover? Geneticists wonder whether it is a rare recessive allele or a mutation. It is possible that both could produce your next unexpected four-leaf clover find!



can get thornier when one is added or deleted, especially if it is a germ mutation.

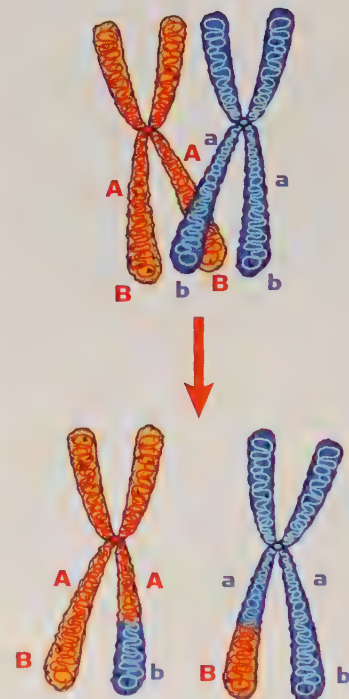
Consider the diagram showing protein synthesis on page 114. If a nucleotide base is added or deleted from the chain, what happens to the codon? The base shifts the whole codon, producing a **frameshift mutation**. This means that when RNA is coded from the DNA, it will probably make a very different protein than it would have before the mutation since the codons and the amino acids they code for will be much different. The protein will have a different shape than the one it was intended to have, and this will probably cause problems for an organism.



CHROMOSOMAL MUTATIONS

Sometimes mutations affect more than just genes. A mutation may involve rearranging a chromosome in a way that also affects a large portion of the DNA sequence. Crossing over is a normal way for chromosomes to exchange information. But **telomeres**, which are the tips of chromosomes, don't usually participate in crossing over. They mark the end of a chromosome. An enzyme called *telomerase* ensures that the telomeres remain fairly stable during meiosis. If a mutation that stops the production of telomerase occurs, then the telomeres get shorter and shorter, leading to cell death. If a mutation causes telomerase to be produced continually, then the telomeres mutate, which can lead to uncontrolled cell division.

Sections of chromosomes can experience changes. Occasionally, a segment of a chromosome is left out after it separates during cell division. This complete loss of a segment of the chromosome is called a **deletion**. The chromosome piece usually winds up outside the nucleus, where it disintegrates. This mutation can create serious problems for the next generation if valuable genetic material is missing. Also, a segment of a chromosome may break off and reattach in the same position, but upside down. This is called an **inversion**. Inversions are less likely to cause serious conditions because the genetic material is still present, though in a different order, on the chromosome. See Figure 9-6 on the next page.

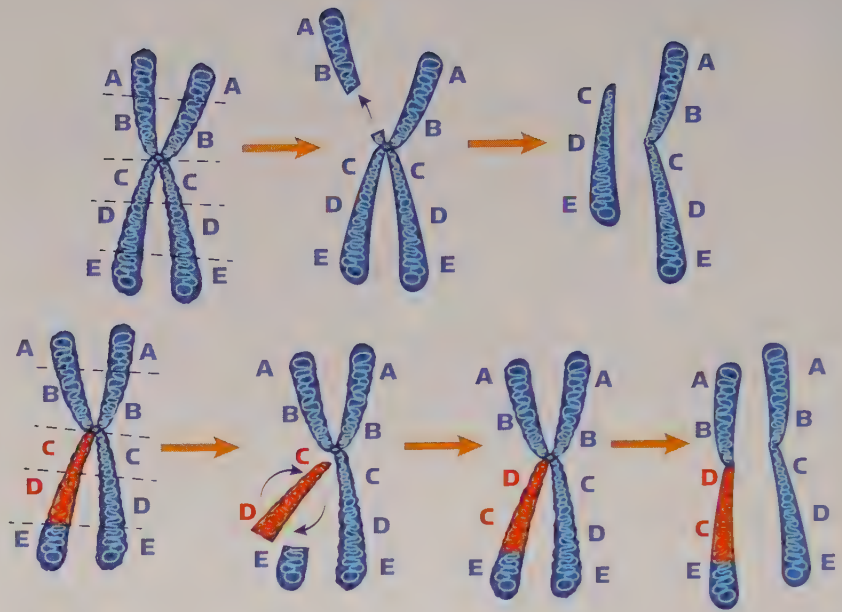


9-5

Crossing over occurs when pairs of chromosomes exchange genetic information.

9-6

Both deletions (top) and inversions (bottom) are chromosomal mutations. In the first, the chromosome fragment fails to attach. In the second, the chromosome fragment reattaches in an inverted position.



Sometimes homologous chromosomes or sister chromatids in a cell don't fully separate during anaphase I or II in meiosis. The gamete mutation is then propagated through mitosis. This failure of the chromosome to separate is called a **nondisjunction**. A nondisjunction leads to gametes that either have extra chromosomes or not enough. This means that haploid gametes produce something other than a normal diploid zygote ($2n$). Depending on which anaphase of which process the disjunction occurs in, they could produce a *monosomy* (MON o so my) ($n - 1$) with one less chromosome or a *trisomy* (tri SO my) ($n + 1$) with one extra chromosome. A nondisjunction doesn't change the entire set of chromosomes of an organism. It simply adds or subtracts a chromosome from an otherwise normal set.

However, when gamete cells do not divide properly, especially during metaphase I in meiosis, a diploid gamete can unite with a normal haploid gamete to produce a *triploid* ($3n$) zygote with three whole sets of chromosomes. Two diploid gametes could unite to produce a *tetraploid* ($4n$) zygote with four sets of chromosomes. If a diploid gamete doesn't divide after making copies of its chromosomes, it can form a tetraploid ($2n + 2n$). Cells such as these with three or more full sets of chromosomes exhibit **polyploidy**. A person can't live with triploid cells. Trisomy cells are also usually lethal, but there are a few exceptions. Most people born with three sex chromosomes can live a fairly normal life without any major health issues, though they usually are infertile.

Babies that develop trisomy in autosomes usually die, but people with three of Chromosome 21 often live a fairly normal life. This condition, known as Down Syndrome, causes mental retardation. The effects of the condition vary from person to person. Medical advances and therapy have helped people with Down Syndrome enter the workforce and live very fulfilled lives. They are known for being affectionate and personable.

9-7

Bananas that you buy in the grocery store don't have seeds like this one because they are triploids. This makes triploid bananas much easier to eat!

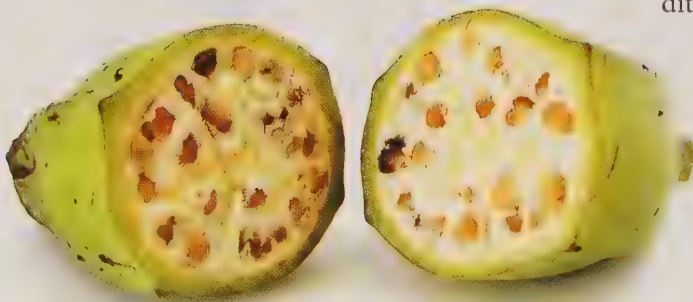
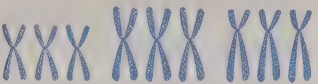
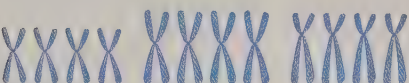
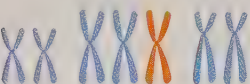


Table 9-1

Various Chromosome Number Changes

Euploidy (complete chromosome sets)	haploid (n)		gametes, mosses, algae, fungi, bee drones
	diploid ($2n$)		man, animals, most plants
	triploid ($3n$)		seedless plants (watermelons, bananas)
	tetraploid ($4n$)		Irish potatoes, alfalfa, some rare plants
Aneuploidy (missing or extra chromosomes)	tetraploid ($2n + 2n$)		corn, wheat
	monosomy ($2n - 1$)		various types of plants, Turner syndrome in humans
	trisomy ($2n + 1$)		various types of plants, Down and Klinefelter syndromes in humans

Polyploidy can be used in agriculture to produce triploid grapes, oranges, and other fruits. Because they lack seeds, triploids must be reproduced asexually. Many valuable crops are polyploids—corn, wheat, cotton, grapes, alfalfa, bananas, and potatoes. Though man didn't breed these polyploids, their survival is due completely to man's cultivation. We have used the larger sizes and genetic flexibility of polyploids to grow them in different areas to feed a growing world population. Without good and wise dominion over polyploids, people may have starved.

9.4 MUTATIONS AND CELL GROWTH

We've seen the different types of mutations that can happen both in genes and chromosomes. But what about their effect on cell growth? A single mutated cell can significantly affect an organism when it multiplies. Just as genes code for different phenotypes in an organism, there are specific genes that govern the cycles of cell growth and reproduction and the proteins that the cells use to make this happen. When a mutation affects these genes, mutated cells can begin to divide uncontrollably. When a mutated cell begins to divide uncontrollably, it produces an abnormal mass of cells called a **tumor**. Anything that



9-8

A large bump on a tree called a *burl* is a plant's version of a tumor. These tumors are rarely harmful to the tree because cell walls keep abnormal cells from spreading. Woodworkers prize burls for making bowls with decorative grains.

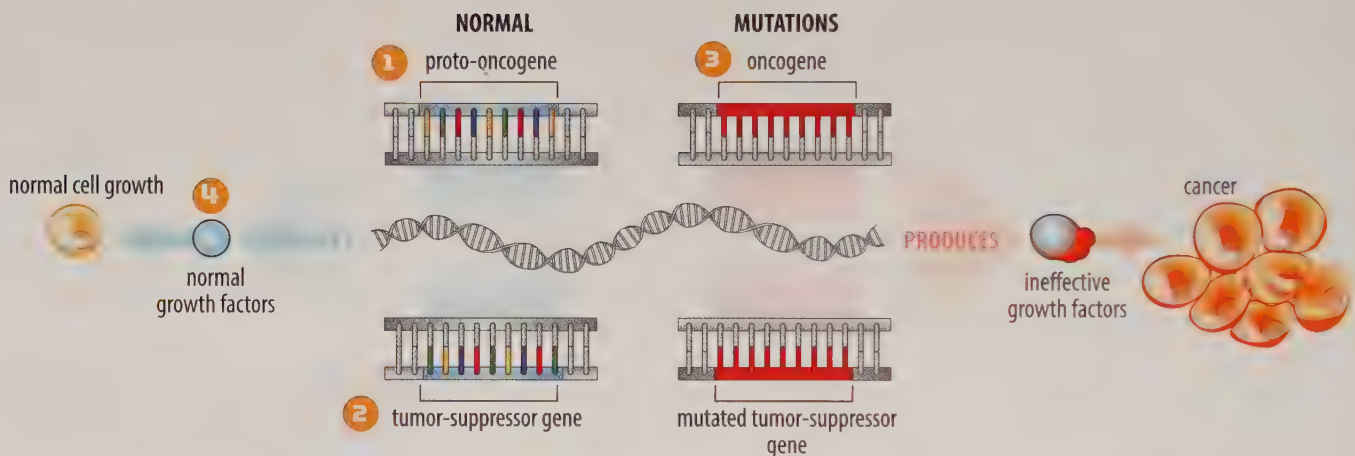
has cells can develop a tumor, even plants and animals. *Benign* tumors don't spread to other parts of the body. An example of a common benign tumor is a polyp in the large intestine. But tumors can also be *malignant*, which means that they may *metastasize*, or spread to other parts of the body. Malignant tumors can cause major parts of an organism to shut down as these cells fail to fulfill their purpose in life-sustaining processes for an organism.

9.5 CANCER

Preventing Cancer

1. Use sunscreen.
2. Eat fresh fruits and vegetables.
3. Exercise and stay fit and lean.
4. Get regular screenings.
5. Don't smoke.

Cancer causes one out of every four deaths in the United States, and anyone can develop it. Malignant tumors are one form of **cancer**, which is an unrestrained growth of abnormal cells in the body. Not all cancers form tumors, however. *Leukemia* is a form of cancer that involves spreading abnormal blood cells in the circulatory system. This kind of cancer is harder to treat because the abnormal cells can be more widely distributed in an organism.



- 1 **proto-oncogene** (pro toh ON kuh geen): one of two types of genes that regulate cell cycles. These genes stimulate cells to grow and divide.
- 2 **tumor suppressor gene**: another gene that regulates cell cycles. This gene prevents uncontrolled cell growth.
- 3 **oncogene**: a mutated proto-oncogene. This gene stimulates cells to grow out of control, preventing cells from dying.
- 4 **growth factor**: a protein that stimulates normal cell growth and division. This is produced by proto-oncogenes.

9-9

A breast cancer cell.



Because cancer is such a widespread disease, the search for effective treatments is a priority for science. The main goal of treating cancer is to destroy abnormal cells in ways that do the least amount of damage to healthy cells. The best ways to kill abnormal cells are to poison, burn, or cut them out. *Chemotherapy* uses chemicals to poison and disrupt cell processes in abnormal cells so that they can't divide, killing the cells and shutting down their reproduction. *Radiation therapy* uses high doses of energetic radiation to burn cancer cells in ways that slow down or stop their growth completely. Doctors can use *surgery* to

cut out clumps of abnormal cells that have formed a tumor. For many cancer patients, a combination of these therapies is used to kill cancer cells while hurting as few normal cells as possible.

Most people know that, to lower their risk of certain kinds of cancer, they shouldn't smoke or stay in the sun too long. Substances like radiation, tobacco smoke, and certain chemicals that increase one's cancer risk are called **carcinogens**. Many carcinogens are also mutagens, though some work by disturbing cellular metabolism. What can people do when their own genetics is fighting against them?

In 1989, a biochemist working late one night had the idea that cancer might have a genetic component. To test his idea, he removed a suspected cancer gene from a tumor sample and replaced it with a normal gene. The cancer cells in the tumor immediately stopped growing. This discovery was an amazing breakthrough, but it created lots of unanswered questions about how to best treat cancer. Researchers are working to develop an ethical gene therapy treatment that targets cancer cells. They've also come up with a solution using a virus and the body's own immune system. Because cancer is so common in our world, doctors and researchers are on a quest to produce treatments that don't require poisoning, burning, or cutting to improve quality of life for patients who suffer from this disease. To do this, they use the tools of genetic engineering, our topic in the next section.



9-10

This patient is undergoing treatment for cancer. Finding more effective treatments that kill cancer cells while doing minimal damage to healthy cells is a priority for science.

9B REVIEW QUESTIONS

1. What is the difference between a gene mutation and a chromosomal mutation?
2. Use the DNA base sequence ATT CGA TAG GCT to demonstrate the three types of point mutations.
3. What determines whether a nondisjunction will create monosomy or trisomy?
4. From what you have learned, indicate what specific kinds of mutations would be most harmful to a population of organisms?
5. Give examples of the ways that a mutation can be expressed in an organism.
6. Why do tumors form in organisms?
7. A doctor has just done a scan on a patient and found a mole that has become cancerous on his arm. What treatment(s) would he recommend? Justify your answer.

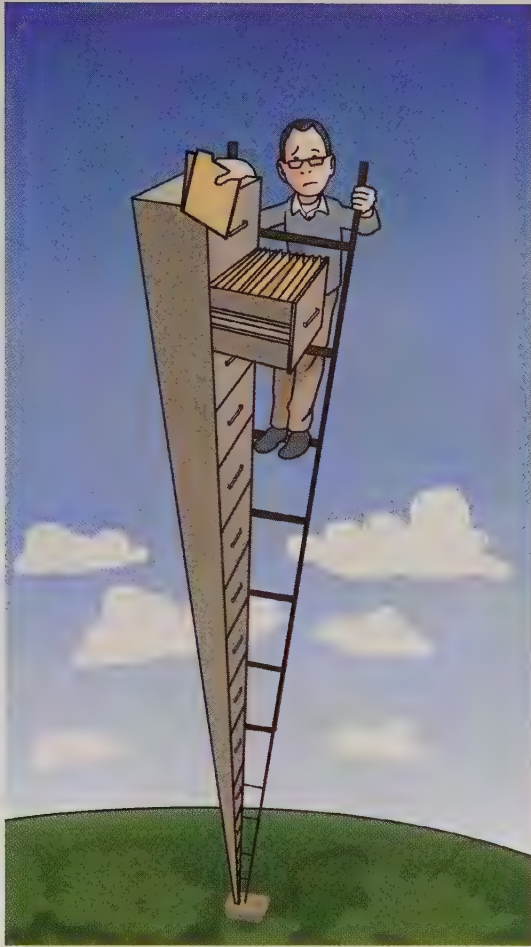


9-11

How would you recommend treating skin cancer?

9C Questions

- » How are genes separated, cataloged, and rearranged?
- » How do scientists change DNA?
- » How can we use genetic engineering to better exercise dominion over God's world?



9-12

The information in your DNA could fill a million pages!

GENETIC ENGINEERING

How can people control changes in the genetic code?

9.5 STUDYING DNA

In 1984, Francis Collins began writing an encyclopedia. This encyclopedia wasn't about famous people in history or countries of the world; it was all about the human genetic code. Collins was head of the *Human Genome Project*, a scientific study to identify and list all human genes, the phenotypes they express, and the variations in these phenotypes. This adds up to over 3 billion base pairs! This project, completed in 2003, was the largest team effort in biology in history.

Genomics is the study of **genomes**, or an organism's full set of genetic information coded in its DNA. Scientists have studied the genomes of a variety of organisms, ranging from the 3 billion base pairs in human DNA to the almost 5 million base pairs in *E. coli* bacteria.

Researchers have found that the genomes of two different people share 99.9% of the exact same information. That makes sense since most life processes in people are exactly the same. About 1.5% of the human genome contains codes for making proteins, about 24% contains codes that control genes, and about 59% is code that is duplicated in other places in human DNA. This duplicated DNA doesn't appear to code for any proteins. One of the main benefits of this project was to trace certain diseases such as diabetes, Alzheimer's, and cancers back to their genetic roots.

Table 9-2

Comparing the Genomes of Some Common Organisms

Organism	Number of base pairs	Number of genes
human	3,200,000,000	21,000
chimpanzee	3,100,000,000	22,000
mouse	2,600,000,000	22,000
rice	430,000,000	42,000
yeast	12,000,000	6,300
bacterium	4,600,000	4,400

9.7 READING AND MANIPULATING DNA

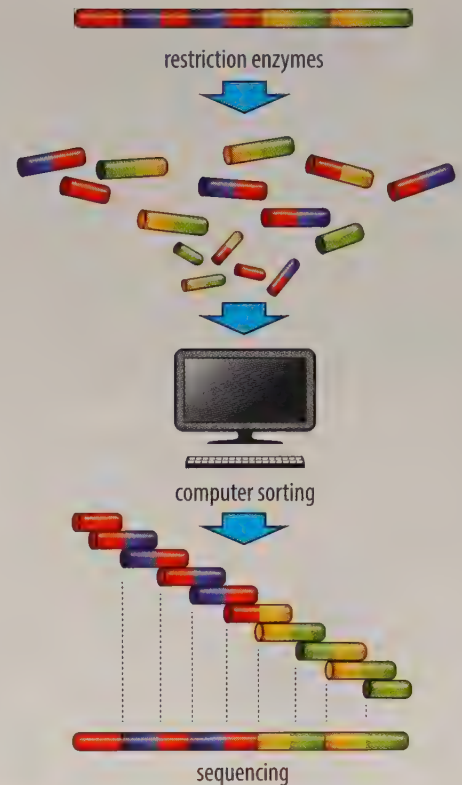
We can determine which genes cause certain characteristics in organisms, but is there a way to change those genes to bring out a new characteristic? **Genetic engineering** is the process of deliberately manipulating the genes within an organism in ways other than natural processes

like reproduction. It involves changing an organism's DNA by inserting new genetic material. Genetic engineering is a blossoming field of biology with real potential to solve significant real-world problems.

READING DNA

To begin studying an organism's genome, researchers must isolate DNA from gametes of that organism. DNA molecules are too long to work with easily, so they must be divided into pieces. Geneticists use a **restriction enzyme**—an enzyme used to cut DNA in specific places into pieces for study. An uncombined base pair at the end of a snipped piece of DNA is called a *sticky end* since it is available for pairing.

Then comes the work of **sequencing** the DNA, or determining the order of nucleotides in an organism's DNA. Geneticists use an automated sequencing machine to help them sequence billions of base pairs. In addition, computers aid geneticists by comparing sections of the genome to find areas that overlap. They can use this information to figure out the original sequence of the DNA. The team on the Human Genome Project used this process to map the human genome.



MANIPULATING DNA

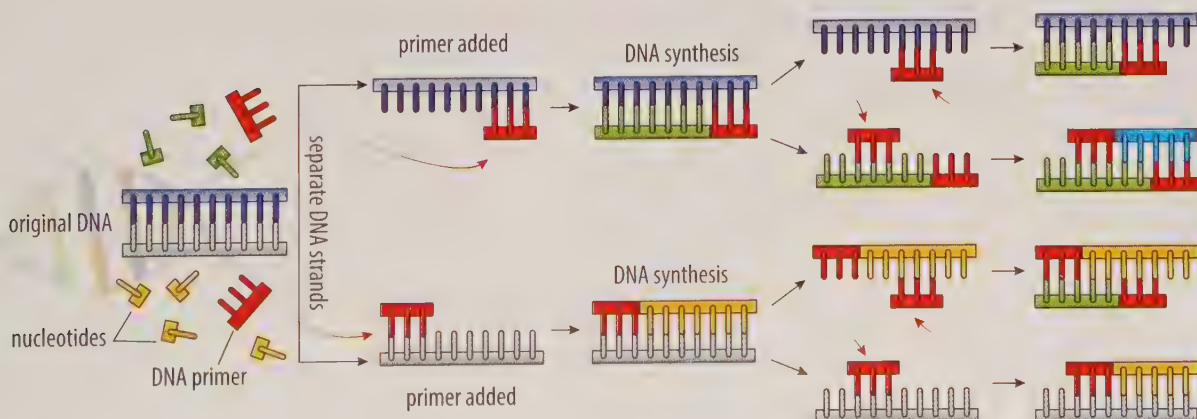
Genetic engineers often need to make multiple copies of a section of DNA before working on them. They use the cell's own natural process of DNA replication to generate millions of copies of DNA in just a few hours. The process of making multiple copies of a gene under study is called the **polymerase chain reaction**. This process involves several steps, beginning with separating the DNA strand to be copied by heating it up. After the DNA cools, complementary primers (short chains of base pairs) are added and bond to the sticky ends to jumpstart replication. DNA polymerase takes over the normal replication process, beginning at primers to produce two copies. This cycle of heating and cooling is repeated until enough copies of the gene are produced.

9-13

The process of chopping up DNA, sorting and looking for overlap, and determining the original sequence is called *shotgun sequencing*.

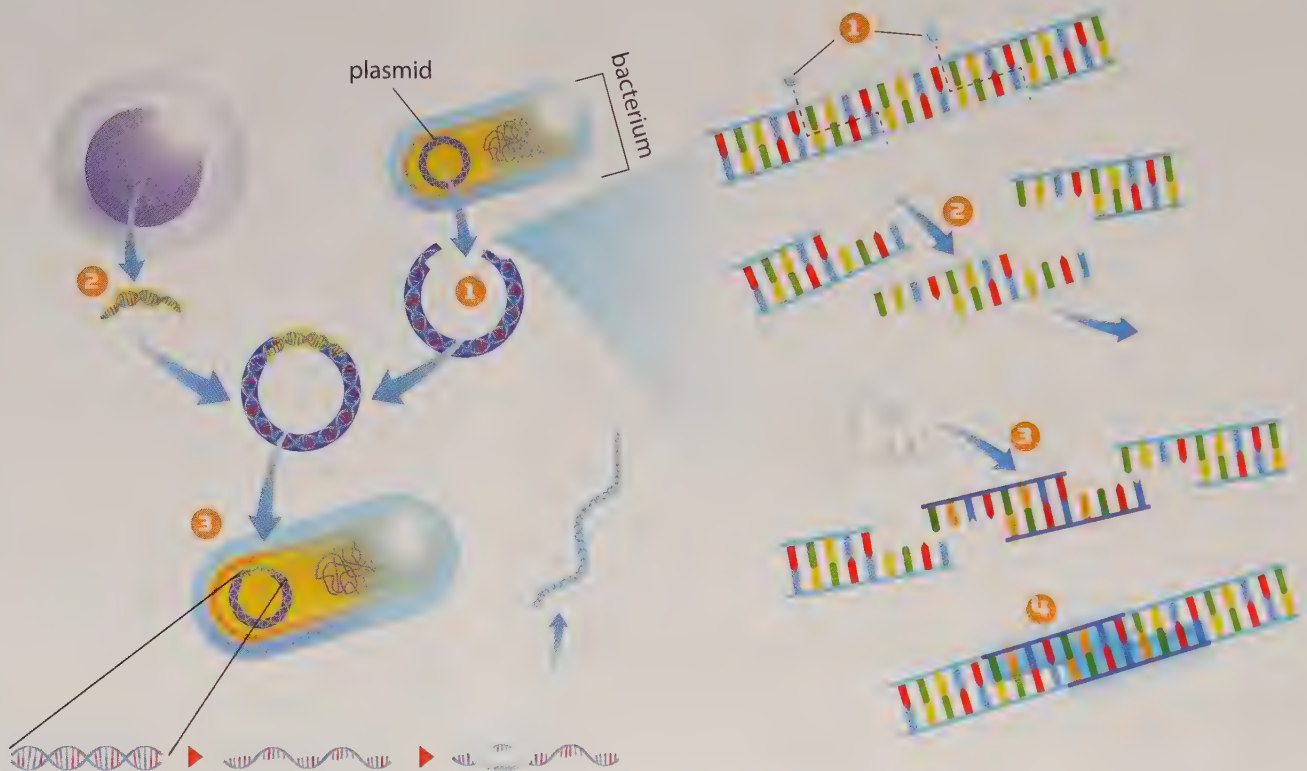
9-14

The polymerase chain reaction is an artificial and speedy beginning to normal DNA replication. The process begins by chopping up DNA into fragments which can be primed and then replicated over and over again.



Geneticists can introduce genes into strands of DNA to produce customized DNA. Sometimes they can connect smaller pieces of DNA containing genes that code for certain phenotypes that they want an organism to express. These smaller pieces of DNA are combined with original DNA from an organism to form a customized DNA called **recombinant DNA**. Restriction enzymes ❶ are used to open the DNA and put the pieces together to form a new DNA fragment ❷. Sometimes a segment of DNA that contains genes that code for desired phenotypes can be pasted into bacterial plasmids ❸. Restriction enzymes can snip open plasmids and insert the DNA to make recombinant DNA ❹ that will serve a desired purpose in a cell, such as getting bacteria to produce human insulin for diabetics whose bodies reject insulin from animals.

- ❶ plasmid snipped open by restrictive enzymes
- ❷ DNA fragment from another source
- ❸ phenotypes pasted into bacterial plasmids
- ❹ recombinant DNA with new DNA fragment



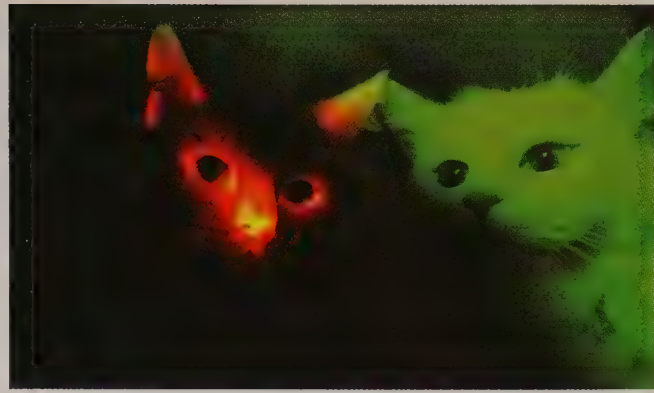
9.8 | USING ENGINEERED DNA

GENETICALLY MODIFIED ORGANISMS

We've already seen some of the applications of biotechnology, such as detecting disease and producing more useful crops that feed more people and use land efficiently. Genetically engineered plants are just one kind of **genetically modified organism (GMO)**, which is an organism that has undergone genetic engineering. Geneticists can use recombinant DNA to introduce genes from other living things of the same species or of different species. Organisms that contain genes that have been introduced from other kinds of organisms are called **transgenic organisms**.

Monsanto, a leading biotechnology company, develops 90% of the world's genetically modified crops. Scientists from this company found plants near an herbicide factory that had developed the ability to resist the herbicide. They were able to isolate the herbicide-resistance gene and introduce it into crops using bacteria. Now farmers can apply herbicides that kill weeds without harming the crops planted in their fields.

Most of our corn, sugar, and soybeans are genetically modified crops. Genetically engineering a plant can have the same effect that breeding has had for centuries, but in quicker and more efficient ways and with a more reliable outcome. At this time, we are unsure of the long-term effects that using and eating genetically modified organisms will have on our environment, culture, and health. But geneticists and botanists are working to produce genetically modified crops that won't rely as heavily on chemicals such as fertilizers, herbicides, and pesticides.



9-15

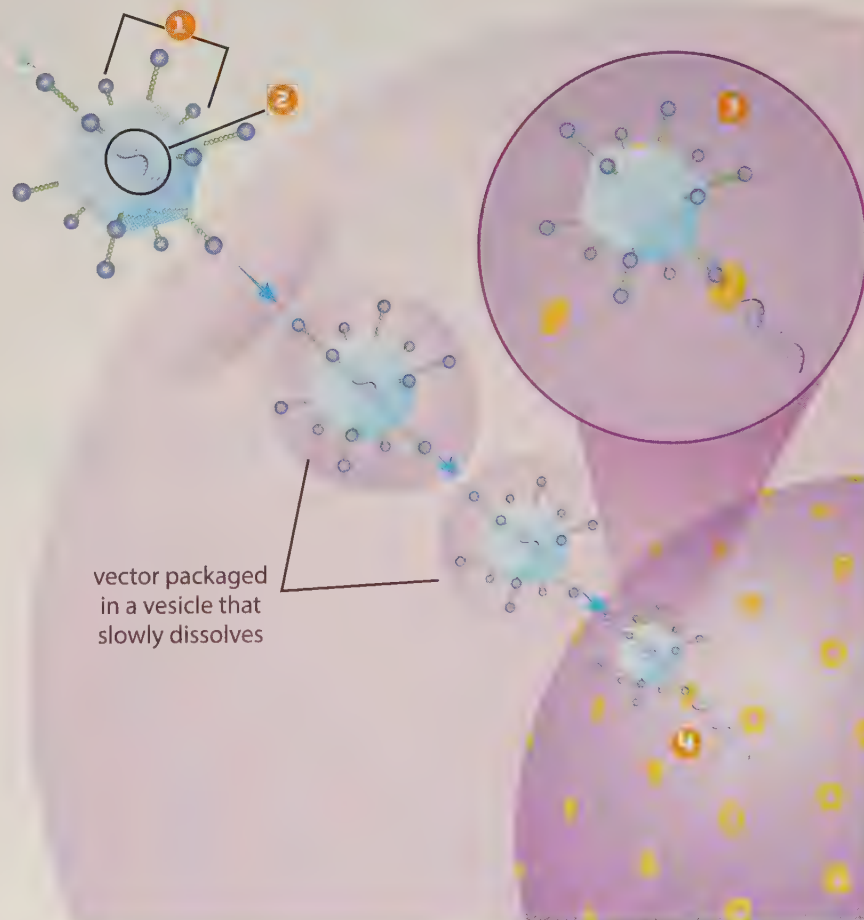
Not all transgenic organisms are plants. The transgenic cat on the left has been genetically modified to express the gene from a jellyfish to produce a protein that makes the cat glow under a green light.

GENE THERAPY

Another way that scientists can use genetic engineering is to change a gene in an organism to relieve a genetic disorder or disease. This kind of genetic engineering is called **gene therapy**, a technique that relies on a microscopic vehicle (known as a *vector* ①) to deliver recombinant DNA ②. Vectors can be bacteria or viruses called *bacteriophages* that attach to certain bacteria or cells. Scientists use vectors to transfer new genetic material to an organism in order to change its DNA. After this new genetic information has been inserted ③, the therapeutic DNA produces the desired effect. Sometimes therapeutic DNA produces proteins ④ needed to reverse a disease or counteract a problem.

Though this process sounds foolproof, sometimes the treatment doesn't last for long periods of time or even work at all. Gene therapy is never a permanent solution. Often this requires treatment that patients need to continue for the rest of their lives. An organism can reject the vector completely, sometimes causing serious side effects in the organism. It's also possible that the gene therapy fails to be effective because geneticists don't completely understand the disease and all the genes that are related to it, so the therapeutic DNA is insufficient to reverse the disease even if it is successfully introduced. Scientists are still experimenting with gene therapy in clinical trials.

- ① viral vector
- ② recombinant DNA
- ③ new DNA inserted into cell nucleus
- ④ therapeutic DNA produced



DNA FINGERPRINTING

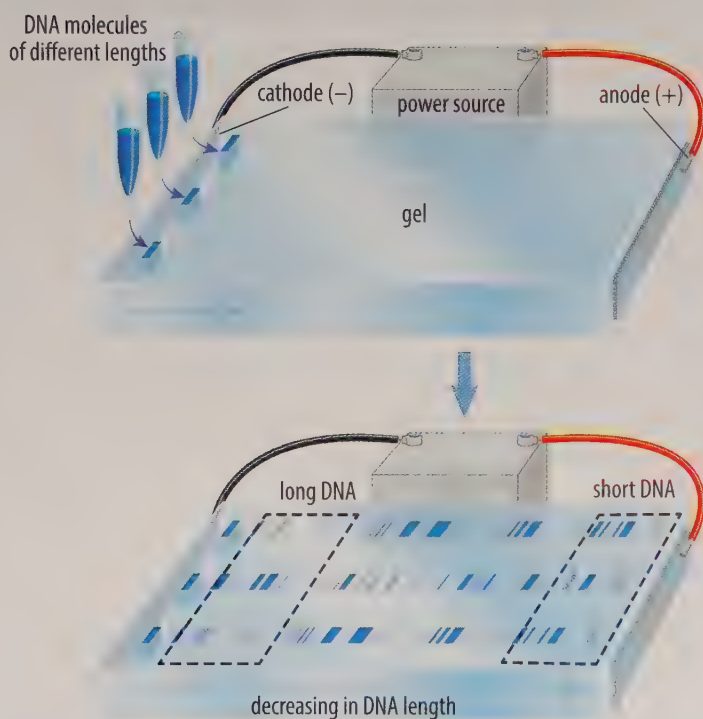
Another application of genetic engineering that is especially helpful in forensics and archaeology is to use samples of DNA to identify individuals, since no two people have the exact same DNA (identical twins are an exception). The process of using fragments of DNA to identify individuals is called **DNA fingerprinting**. Since 1987, when DNA fingerprinting was first used in forensics, hundreds of court cases have been decided with the help of DNA fingerprinting, clearing the innocent and incriminating the guilty. Another important use is identifying lost

family members or the remains of people killed in natural disasters or accidents. DNA fingerprinting can also be used to diagnose inherited disorders in newborns, such as cystic fibrosis, hemophilia, sickle cell disease, Huntington's disease, and some types of Alzheimer's.

The earliest forms of DNA fingerprinting developed in the 1980s involved a process called *gel electrophoresis*. Fragments of DNA created by restriction enzymes are applied to a gel-covered plate attached to a power source. When an electrical current is applied, the DNA fragments are sorted as they travel down the plate, with the longest strands traveling slower and staying closer to the power supply while the shortest fragments migrate farthest away. Bands of different lengths of DNA are revealed by staining the finished gel. Today, DNA fingerprinting looks for unique patterns in an individual's DNA to identify them using this process.

Stepping back, we can see that God has given us an amazing resource coded in the DNA of all living things. We can exercise good and wise dominion over the field of genetics to heal diseases, serve out justice, and provide food for people with a mind for the future citizens of the world.

Our Creator is the only source of the remarkable arrangement of information in DNA. Origen, an early church father who died in AD 254, said, "I cannot understand how so many distinguished men have supposed [the world] to be uncreated, that is, not made by God himself the Creator of all things, but in its nature and power the result of chance." (*On First Principles*, 2.1.4.)



9-16

The process of gel electrophoresis allows fragments of DNA to be read and sequenced. This creates patterns that can help identify individuals.

9C REVIEW QUESTIONS

1. Do you think that the Human Genome Project was a worthy endeavor? Why or why not?
2. Table 9-2 on page 168 shows the number of nucleotide base pairs in an organism and compares them with the number of genes. Describe an overall pattern that you observe.
3. Are there any organisms in Table 9-2 that are exceptions to the general pattern that you observed in Question 2? If so, name them and explain why they are exceptions.
4. How would you respond to an evolutionist who supports his belief in evolution with the fact that 98% of the DNA in chimpanzees and humans is the same? (The genomes of both have been sequenced.) Consider doing

a keyword search with the words “human chimpanzee DNA comparison” to help you form your response.

5. List and explain four ways that DNA can be manipulated.
6. Draw a diagram that shows how a gene can be transferred from one plant to another.
7. Give an example of a genetically modified organism.
8. What are three practical ways to use the tools of genetic engineering?
9. Researchers hope to use genetically modified orange trees that use two genes from spinach to give oranges immunity to citrus greening. The goal is to rescue the orange population in the United States without the heavy use of pesticides. What things should scientists, farmers, and orange juice producers consider if they decide to grow genetically modified oranges?

WORLDVIEW SLEUTHING: FIGHTING DROUGHT WITH GENETICS



One of the major problems with genetically engineered seed is that the crops they produce are designed for modern farms. This translates into crops that rely on automated watering, regular fertilizing, and applications of pesticides and herbicides. Also, the desirable traits of genetically modified plants are not passed on to the next generation of seeds, so farmers need to purchase seeds year after year. This makes it difficult for farmers in underdeveloped countries who rely on rainfall and harvest their own seed for the next year's planting. Recently, Monsanto has been making an attempt to produce strains of crops specifically for underdeveloped countries, since they are the people who could benefit the most from biotechnology. The crops of small local farmers feed a larger percentage of the world's population than industrial farms, so it makes sense to develop seeds to help the neediest people in the world.

Introduction

You are an American farmer working for the Kenya-based African Agricultural Technology Foundation. You are working with Monsanto to produce water-efficient crops (specifically corn) to help small, drought-stricken Kenyan farms fight hunger.

Task

Your task is to develop a general plan to use biotechnology to produce and distribute drought-resistant corn that will allow farmers to reuse their seed and use a minimal amount of chemicals on their fields. You will communicate your plan in a 10-slide presentation.

Procedure

1. Do some research on selective breeding, perhaps using information in the box on page 161.
2. Research the process and the tools used to genetically modify plants.
3. Plan your presentation and collect any photos or videos you need, giving proper credit. Make sure that you think of how to distribute the new seed.
4. Create your presentation and show it to another person.
5. Deliver your presentation to your class or family.

Conclusion

Several foundations, such as the Bill and Melinda Gates Foundation, have funded the collaboration between Monsanto and the African Agricultural Technology Foundation to produce a strain of corn called drought-TEGO. Scientists have used biotechnology to develop this corn to provide the most food for the people who desperately need it. This is a good example of how we can wisely use biology to help God's image bearers, with a mind for the future.

REVIEW QUESTIONS

Key Terms

gene pool	157
variation	157
gene flow	157
allele frequency	157
plasmid	158
genetic equilibrium	158
genetic drift	159
bottleneck effect	159
founder effect	159
mutagen	162
point mutation	162
frameshift mutation	163
telomere	163
nondisjunction	164
polyploidy	164
tumor	165
cancer	166
carcinogen	167
genome	168
genetic engineering	168
restriction enzyme	169
sequencing	169
polymerase chain reaction	169
recombinant DNA	170
genetically modified organism (GMO)	170
transgenic organism	170
gene therapy	171
DNA fingerprinting	172

Is It Really Junk?

Want to find out what later studies on “junk DNA” revealed? Do an Internet search using keywords “*ENCODE project junk DNA*.”

CONCEPT REVIEW

1. What are some of the advantages of using biotechnology to improve crops?
2. What are three ways to add genetic information to increase variations in a population?
3. What can change the allele frequency in a gene pool?
4. What is the difference between germ mutations and somatic mutations?

For Questions 5–7, use the original sequence of DNA below.

AAG CTG ATG

5. Identify the following sequences of RNA that are transcribed from the DNA above as correct (no mutations), as a point mutation, or as a frameshift mutation. (*Hint: You may want to begin by writing the correct mRNA on your paper.*)
 - a. UUC GAC UUC
 - b. UUC CGA CUA C
 - c. UUC GAC UAC
 - d. UUG GAC UAC
6. What does each of the groups of three nucleotide bases in Question 5 represent?
7. What makes the frameshift mutated strand of mRNA different from the other strands of mRNA?
8. Draw a chromosome and label the telomeres.
9. How are chromosomal mutations different from gene mutations? How are they similar?
10. Draw a Venn diagram to illustrate the relationships between mutagens and carcinogens. Use one circle to represent each. Also use the words “mutation” and “cancer” in your diagram.
11. Why do tumors form in organisms?
12. Are tumors always cancerous? Explain.
13. How are biologists and doctors working to fight cancer to save the valuable lives of people?
14. How do the genomes of different organisms compare? Use Table 9-2 to help you answer this question.
15. During the human genome project, researchers initially found that 97% of the human genome did not appear to code for any specific genes and appeared to serve no function. Compare this to a typical prokaryotic genome, which has 20% noncoding DNA. People began to refer to this as “junk DNA” and to assert that this was proof of human evolution. How would you respond to this claim?
16. Name four ways scientists manipulate an organism’s genetic material.
17. Are all genetically modified organisms plants? Explain.

18. What are some of the drawbacks of genetically modified organisms, especially crops?
19. How do DNA, genomes, and genetic engineering point to a master creator?

TRUE OR FALSE

20. The white fur of the Spirit bear (see Figure 9-2) is an example of a mutation that would be a part of this population's genetic load.
21. A survey of students in your school reveals that about 36% of the students have detached ear lobes. It is correct to conclude that detached earlobes is a recessive trait.
22. Large populations are most susceptible to genetic drift.
23. All mutations create problems in organisms for generations.
24. Selective breeding is an example of genetic engineering.
25. Transgenic organisms are a type of GMO.
26. We can use DNA fingerprinting to tell the difference between identical twins.

CRITICAL THINKING

Use the case study below to answer Questions 27–28.

CASE STUDY: GENE THERAPY FOR SCID

Scientists are experimenting with gene therapy on bubble babies, children born with a disease called *severe combined immunodeficiency (SCID)*. Their immune systems are so weak that the only way they can survive is to live in a germ-free plastic bubble, limiting both their life expectancy and their quality of life. SCID is caused by two different mutations that produce different types of the disease. Early efforts in gene therapy to treat this disease resulted in four young children developing leukemia, with one of them dying, though the approach has cured 18 children born with the disease.



27. Scientists thought that the reason children in early studies developed leukemia was because of the viral vectors and oncogenes they contained. These oncogenes stimulated cells to reproduce therapeutic DNA. How did this cause leukemia?
28. Can you think of a way to solve this problem?

Research in Biotechnology

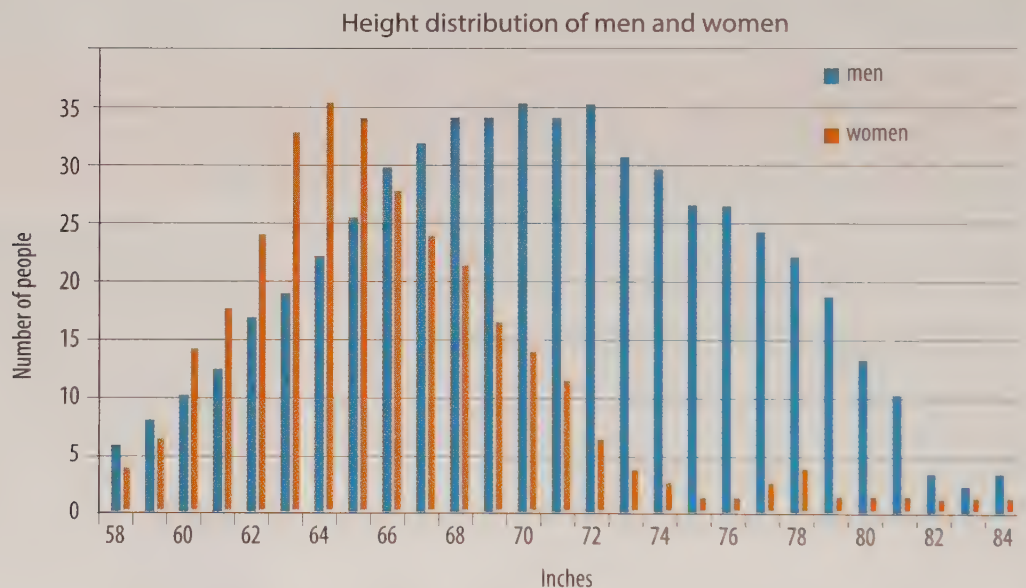
Interested in learning more about the cutting-edge tools of biology? Consider doing some research on stem cells, cloning, GMOs, gene therapy, and DNA profiling in forensics, medicine, and archaeology.

29. A civil court is trying to determine the father of a child, with two men both claiming to be the father. Both want custody of the child. The judge orders DNA fingerprinting to be done, using DNA from the mother, the child, and both men. On the basis of the gel-electrophoresis samples below, which do you think is the father? Explain your answer.

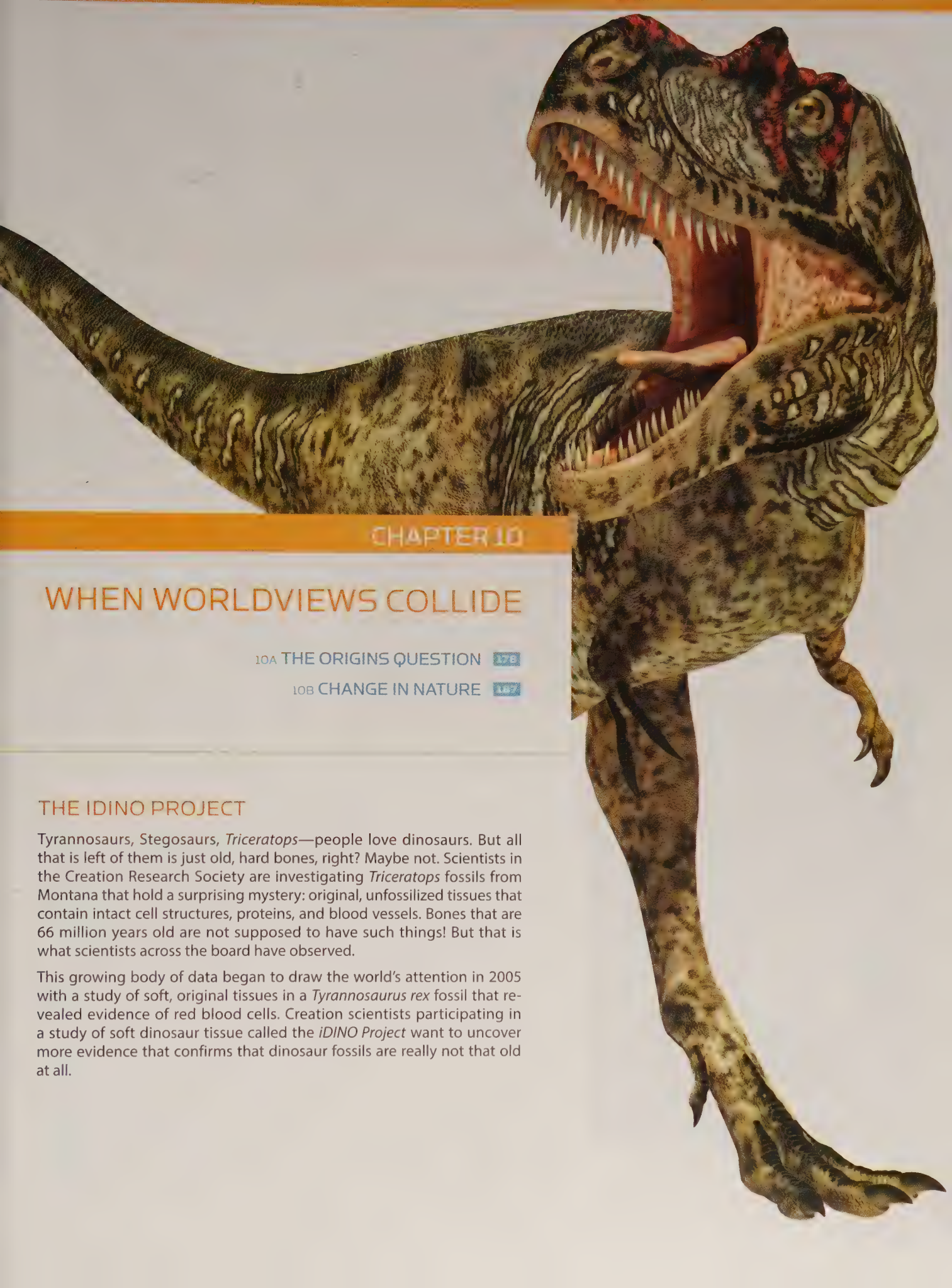


Use the graph below for Questions 30–33.

The average height of men and women in the United States has remained relatively constant over the past decade. It is also one of the highest in the world, along with that of Europeans. The graph shows a sampling of husband and wife height in the United States in 2009.



30. What is the average height of men in the United States?
31. The shortest people in the world are usually from underdeveloped countries like Tanzania and Guatemala. Create a sketch of what you think the graph would look like for Nepal, where average adult male height is 4 feet 11.5 inches.
32. Do you think human height is affected only by genetics? Explain your answer.
33. What would happen to average height if immigration from South America to the United States increased dramatically? What is this phenomenon called?



CHAPTER 10

WHEN WORLDVIEWS COLLIDE

10A THE ORIGINS QUESTION 176

10B CHANGE IN NATURE 187

THE IDINO PROJECT

Tyrannosaurs, Stegosaurus, *Triceratops*—people love dinosaurs. But all that is left of them is just old, hard bones, right? Maybe not. Scientists in the Creation Research Society are investigating *Triceratops* fossils from Montana that hold a surprising mystery: original, unfossilized tissues that contain intact cell structures, proteins, and blood vessels. Bones that are 66 million years old are not supposed to have such things! But that is what scientists across the board have observed.

This growing body of data began to draw the world's attention in 2005 with a study of soft, original tissues in a *Tyrannosaurus rex* fossil that revealed evidence of red blood cells. Creation scientists participating in a study of soft dinosaur tissue called the *iDINO Project* want to uncover more evidence that confirms that dinosaur fossils are really not that old at all.



10A Questions

- » Where did the idea of evolution come from?
- » What do people believe about evolution today?
- » How is evolution different from creation?

10A

THE ORIGINS QUESTION

How does worldview affect how people think about the history of life?

101 THE EVOLUTION OF EVOLUTION

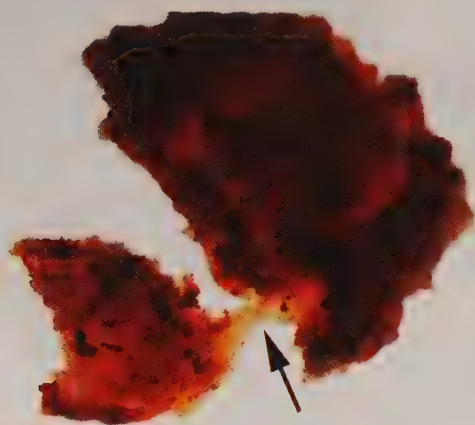
Mary Schweitzer, a paleontologist at North Carolina State University, has been investigating soft tissue in dinosaur bones for a decade. It was her team in 2005 that showed the world that dinosaur fossils may not be as fossilized as we once thought. She is a forthright Christian who is also an evolutionist. She is doing excellent scientific research investigating and imaging dinosaur tissues with electron microscopes. Her evolutionary worldview affects how she views and interprets the fossils she finds, and she and her team are unwilling to admit that the fossils are perhaps much younger than millions of years. In fact, some evolutionary scientists have accused creation scientists of misrepresenting her data to support their own cause.

Her team has worked to form realistic explanations for why cells and soft tissues could last so long. But others think that explanations of soft tissues in fossils are beginning to fail as soft tissues in fossils all over the world continue to be documented. When these fossils are tested with radiometric dating techniques, calculated ages are much younger than evolutionists think they should be.

Evolution simply refers to how things change over time. People have applied this term to everything from stars and molecules to living things. Usually when people refer to evolution they are viewing the world from a completely natural perspective. **Biological evolution** is the slow, gradual change in organisms from one kind to another.

Most people in Charles Darwin's time and culture believed that God created the world in six normal days, though scientists and eventually theologians were beginning to question this belief. The average person in Darwin's time also believed that the **species** in the world—groups of organisms that look the same and have the same structure—didn't change over time. This idea, called *fixity of species*, goes all the way back to ancient Greece. Darwin felt dissatisfied with both of these ideas. He observed growing evidence of change in nature. And he observed indications of suffering in the world and would later observe it in his own family when his daughter Anne died in 1851. He just couldn't understand a good Creator God who would allow suffering and pain to exist in the world.

Darwin was training at Cambridge (1825–31) to be an Anglican priest, and he hoped for a country parish where he would have the leisure to pursue his scientific interests, mostly geology and collecting beetles. During this time he struggled to reconcile his theological training with the evolutionary thinking of other scientists such as Jean-Baptiste Lamarck. Darwin's own grandfather, Erasmus Darwin, a naturalist and freethinker, had also questioned the fixity of species and developed his own evolutionary theories.



10-1

One of several photos that drew the world's attention to soft tissue in *T. rex* fossils



10-2

This wall of fossils has been enclosed and investigated by paleontologists at Dinosaur National Monument.

DARWIN'S JOURNEY

As Darwin struggled with these ideas, he was presented with the opportunity to travel as a companion to the captain of HMS *Beagle*, a ship bound for a voyage around the world. The captain gave him a recently written book that had changed his life, *Principles of Geology*, by geologist Charles Lyell. In the book, Lyell suggested that the earth is very old and has been changing very slowly over time, an idea called *uniformitarianism*. His ideas began to shape the way Darwin interpreted what he observed for the next five years.

In his travels from 1831 to 1836, Darwin observed fossils, geologic formations, plants, animals, and native peoples. On islands near South America, including the Galapagos, Darwin observed variation within species. He took Lyell's ideas of geology and began to view living organisms the same way. After returning to England, he began to formulate his theory of **descent with modification**, the idea that all living things came from common ancestors and change a little with each passing generation to be more different than their ancestors. Those organisms with modifications helped them survive to reproduce, an idea called **survival of the fittest**. Being “fit” means producing more offspring. Inheritable traits that make organisms fit and are passed down to the next generation are called **adaptations**.



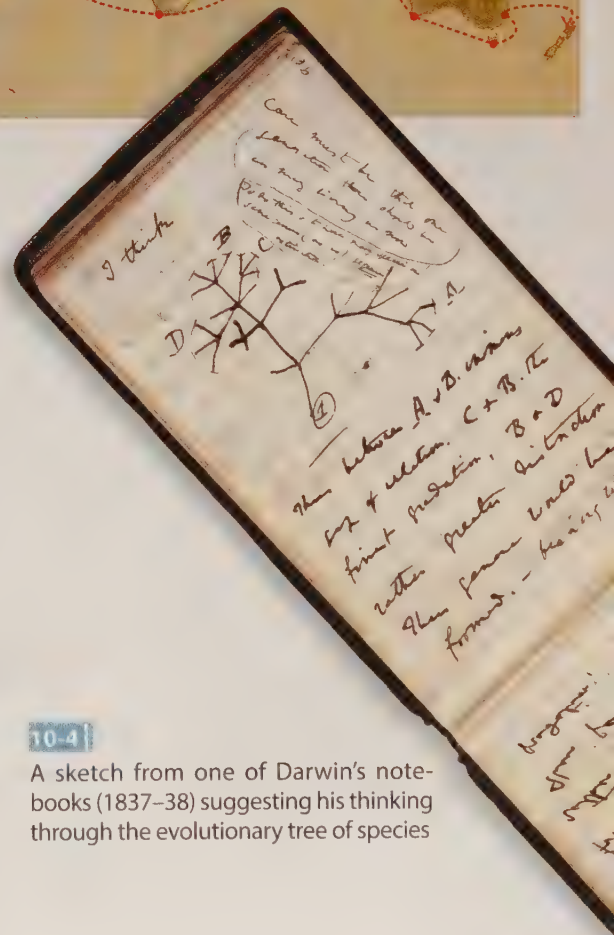
10-3

Darwin's voyage around the world on HMS *Beagle* changed his life and revolutionized how people thought about science and religion in ways that brought the Bible into question.

DARWIN'S WRITINGS

Sometime after returning to England, Darwin also read the works of other scientists who were studying how species change over time. Darwin thought that nature could “breed” organisms, similar to the way people bred organisms to have desirable traits and variations through **artificial selection**. Through the process of **natural selection**, organisms with variations that increase their fitness are more likely to pass on their traits to the next generation than organisms with other variations.

Darwin published *On the Origin of Species* in November 1859. It was an instant success, though it was very controversial because it questioned the basic beliefs of people in his time. His theory was one that required death, something that he observed up close as three of his children died. Darwin's theory of evolution revolutionized both science and theology because of its philosophical implications. By the late 1900s, most people accepted the theory of evolution as scientific fact.



10-4

A sketch from one of Darwin's notebooks (1837–38) suggesting his thinking through the evolutionary tree of species

Aristotle, along with many ancient Greeks, believes that living things do not change over time, an idea called the *fixity of species*. Aristotle classifies organisms on his "ladder of life."



C. 300 BC

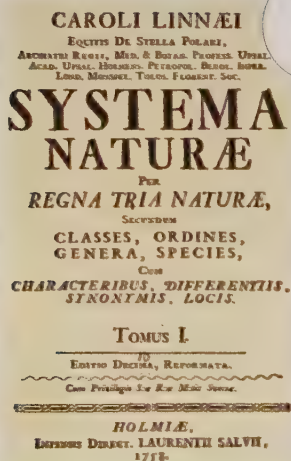


1798

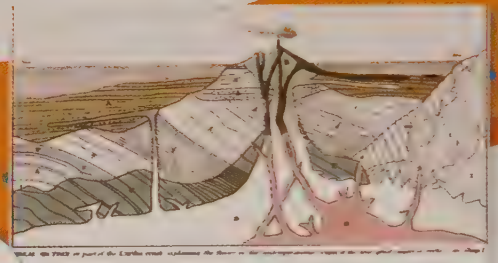
Thomas Malthus, an English pastor and scholar, writes an essay that predicts that if human population growth were not checked by disease or famine, eventually it would grow beyond what the food supply could support since population grows faster than food production. This would lead to a *Malthusian catastrophe*.

THE EVOLUTION OF EVOLUTION

Swedish botanist Carolus Linnaeus first publishes *Systema Naturae* in which he spells out his system for classifying life "for the greater glory of God." Linnaeus originally held to the fixity of species but changed his mind because of his scientific observations. He viewed similarities in organisms as the mark of the Creator.



1735



1830

British geologist Charles Lyell publishes his *Principles of Geology* in which he describes the laws of nature and the forces of geology operating slowly at the same rate over time. This idea, not original to Lyell, is called *uniformitarianism*. Lyell was influenced by fellow geologist James Hutton who intended to remove God from science. Hutton and Lyell both thought that the earth was much older than thousands of years.



1809

French biology professor Jean-Baptiste Lamarck publishes his idea that if an organism stops using a structure, it will disappear from the species (the *theory of use and disuse*). If an organism acquires a useful characteristic, it can pass this along to its offspring (the *theory of inheritance of acquired characteristics*). Experts call Lamarck's ideas the first systematic theory of evolution. An example is a giraffe that stretches its neck more and more to reach leaves. Over time, giraffe necks get longer and longer.



Darwin's voyage aboard HMS *Beagle* begins. After this voyage, Darwin is willing to view God as the source of morality but not the source of living things. He observed nature through Lyell's uniformitarianism, Lamarck's naturalism, and Malthus's ideas on population to formulate his theory.

1900



Dutch geneticist Hugo de Vries introduces his idea that mutations in a population could lead to favorable variations in a population that would lead to evolution through natural selection. This is called the **mutation theory of evolution**. De Vries formulated his idea after observing variations in a wild primrose population.

1831

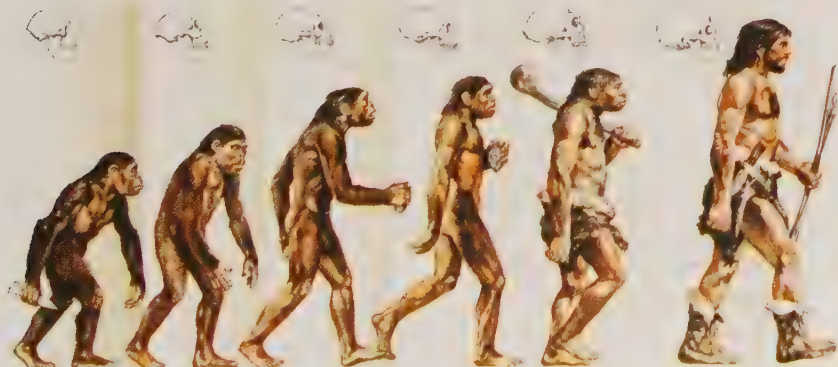
1858

British biologist Alfred Russel Wallace publishes papers on natural selection, which spurs Darwin to publish *On the Origin of Species* the next year. Wallace and Darwin collaborated on their publications with Wallace later dedicating a book to Darwin on his travels in Indonesia collecting specimens.



10.2 MODERN EVOLUTIONARY THEORY

Darwin spent the rest of his life after the publication of *On the Origin of Species* reviewing the responses of critics and friends and refining his theory of evolution despite recurring illness. He extended his theory to formulate a theory of human descent from animals. But the development of evolution didn't end with Darwin's death in 1882. Just as Darwin had synthesized many of the ideas of his time, people continued to incorporate Darwin's ideas with those of modern philosophy and science, referred to as *Darwinism*.

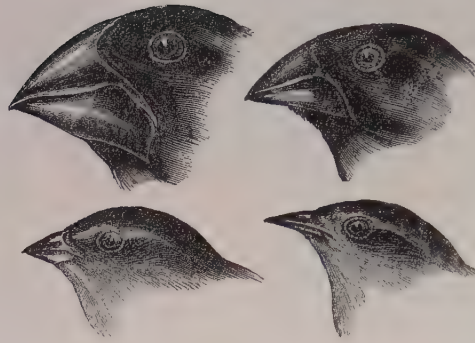


10-5

Darwin extended his theory of common descent with modification to human development.

10-6

Natural selection relies on the presence of great genetic diversity and an abundance of variations in a population. Darwin studied the beaks of finches on the Galapagos as he was considering his theory of common descent with modification.



The twentieth century saw a refinement of Darwin's ideas to form a modern evolutionary theory. One of the most fertile fields for development in the theory of evolution was genetics. Dutch geneticist Hugo de Vries rediscovered Mendelian genetics and formulated the ideas of genes, genotypes, and phenotypes. After noticing various sudden changes in a field of wild primroses, De Vries suggested that these sudden inheritable characteristics, which he called mutations, introduced variations into the population that could produce evolution. The concept that mutation supplies the variations and that natural selection determines which variations will survive and reproduce is called the *mutation selection theory*. Some refer to this theory that blends Mendelian genetics with Darwin's natural selection as *neo-Darwinism*.

Scientists have taken Darwin's ideas and applied the sciences of population genetics, molecular biology, and *paleontology* (the study of fossils) to form a modern evolutionary theory. Evolutionists begin with the framework of common descent and use populations, genes, and fossils to build evidence for their theory. Though many people have lots of different ideas about what evolution involves, most evolutionists agree with the following basic tenants.

Scientists have taken Darwin's ideas and applied the sciences of population genetics, molecular biology, and *paleontology* (the study of fossils) to form a modern evolutionary theory. Evolutionists begin with the framework of common descent and use populations, genes, and fossils to build evidence for their theory. Though many people have lots of different ideas about what evolution involves, most evolutionists agree with the following basic tenants.

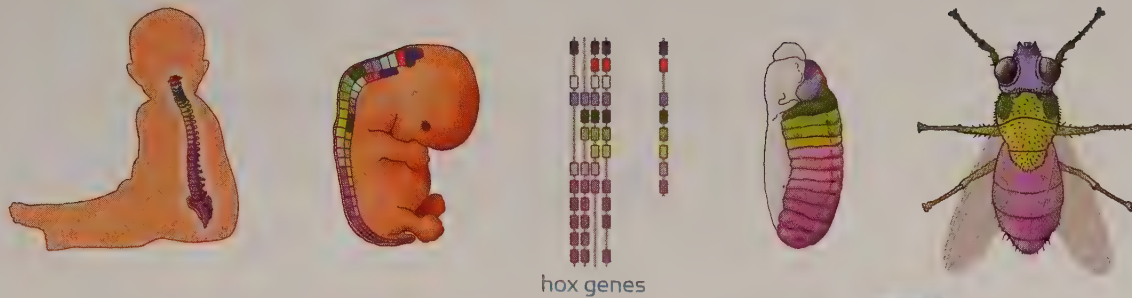
1. Genetics is the foundation for observed variation necessary for biological evolution.
2. Natural selection is one of the main drivers of biological evolution and depends on genetic diversity.
3. Biological evolution is the result of small, gradual changes over long periods of time.
4. Biological evolution relies on fossil evidence to reconstruct the tree of life from simple to complex organisms.

Evolutionists are continuing to hone their theory, especially as technology makes it possible for us to learn more and more about DNA, genetics, and the cell and its processes. Evolutionary biologists are exploring how and why different organisms that come from a common ancestor appear to have similar structures (called **homologous structures**) in the science of *homology*. Similar structures in organisms assumed to be homologous that are shown by further study not to be related by a common ancestor are called *analogous structures*, like the wings of insects, birds, and bats. Structures that seem to have no function in an organism are called **vestigial structures** and are assumed to be leftovers from the evolutionary process. Homologous and vestigial structures are ideas from early evolutionary theory, but they have been revitalized by modern evolution and the use of genetics to identify organisms related to common ancestors.



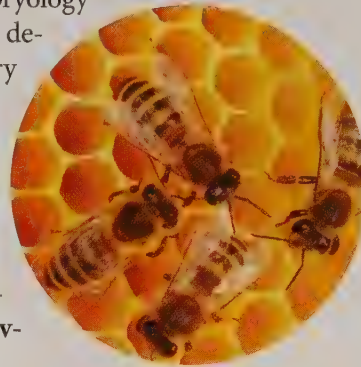
10-7

The science of comparing the body structures of different organisms is called *comparative anatomy*.



Evolutionists are also revamping the classification of organisms on the basis of genetic similarities. Evolutionists are probing into the genetics of embryos to look for homology and to investigate how homeotic genes, called *hox genes*, code for proteins that determine how an embryo will take shape. This field of study is called *embryology*. Both embryology and homology use the science of **comparative anatomy** to determine which organisms come from a common evolutionary ancestor.

Evolutionary geneticists study populations to see how natural selection affects population genetics and how it changes with geography, an effort known as *biogeography*. They are also investigating the evolutionary origins of animal behaviors, such as herding, flocking, schooling, hunting, migrating, and swarming, in a field of study called **behavioral ecology**.



EVALUATING MODERN EVOLUTIONARY THEORY

Christians who believe in a young earth can accept many of the ideas of evolution with a few stipulations, though their worldview is very different from a naturalistic one. It's true that genetics is the foundation for the observed limited variation in nature. Natural selection does produce changes in the allele frequency of a population, but not enough to change one kind of organism into another.

Evolutionists have used homology and comparative anatomy to try to figure out which modern organisms are related to each other through a common ancestor. However, structures that seem to be homologous often *don't come from genes that are homologous*. We'll see later in this textbook that homology has completely changed how organisms are classified, sometimes with some confusing results. Structures in organisms that were once thought to be vestigial have later been found to have some very useful purposes. Homologous structures are not proof of evolution; they could also be interpreted as the plan of life from the wise Designer.

Though evolutionists also use embryology to further their naturalistic ideas, this science has uses that Christians can value and appreciate. Embryology helps us understand how organisms develop and birth defects happen. Embryology links genetics with body plan and structure in ways that help us learn how information in the cells of living organisms signal growth and development.

Behavioral ecology, though it can be viewed through an evolutionary worldview, can also be viewed through the lens of the Bible. Studying how animals behave in their environment can help us understand them

10-8

Evolutionists look at the genes in different embryos and compare how similar genes result in similar body plans. This study of genetic homology is called *embryology*.

10-9

Bees have a very complex social structure that beekeepers must understand to maintain a healthy hive. This knowledge comes from the work of behavioral ecology.

Gradual, not Constant

Most evolutionists no longer think that, just because evolution happens slowly, it occurred at the same rate throughout history. Lyell and Hutton's views of uniformitarianism are generally accepted, but evolutionists don't have a problem with acknowledging the presence of catastrophes in Earth's history. Some evolutionists have suggested that there have been periods of time in which organisms have evolved much quicker than at other times in history when populations were stable. This idea is called *punctuated equilibrium*.

to manage them better. Using behavioral ecology, we can better conserve the living resources we have on Earth with a mind for the future, rather than imagining how the complex web of life evolved through random, natural processes.

10.3 THE BIBLE AND EVOLUTION

10-10

Many believers feel the pressure to make God's Word agree with what scientists claim about the natural world.



As we've looked at the history of the theory of biological evolution, we've seen that many of these people believed in God and valued the Bible. That's true today too. There are many Christians who believe that God's Word, including Genesis, is true and yet struggle to accept a literal six-day view of Creation.

Many believers feel pressure from the scientific community to reinterpret the opening chapters of Genesis. They don't do this to discredit the Bible. In fact, they offer these explanations to demonstrate that the Bible is compatible with evolutionary science. But their attempts to equate biblical truth with the claims of science are dangerous. If there's no Creation, then the Fall must be redefined. If you redefine the Fall, then you must alter the Bible's teaching about Redemption through Jesus Christ. Reinterpreting Genesis 1 shakes the very foundations of biblical Christianity. The following views attempt to reconcile extreme changes in living things and billions of years by reinterpreting Genesis 1 and the Creation narrative.

Bi ID, Please?

The Intelligent Design (ID) movement is the effort of a body of scientific professionals to argue against the evidence for evolution. The goal is to prompt changes in both science and education but outside the context of religion. ID recognizes that there's design in nature that had to come from an intelligent source. This movement sees irreducible complexity in living things, structures like eyes that can't operate unless all the parts are there and working at the same time. Most proponents of ID believe that biological evolution is incapable of explaining the great diversity we see in nature today, but they have different ideas about who the designer is and how old the earth is. What should a Christian think of the ID movement?

ANALOGICAL DAY AND FRAMEWORK VIEWS

The *analogical day view* begins by pointing out that Genesis 2:1–3 never says that the seventh day ended. People who hold this view say that God is still resting from His creation. Since the seventh day is an analogy that corresponds to the day on which God's people are to rest, then the other six days are simply analogies too. These are "God days," not Earth days.

The *framework view* goes further. It says that God did not even follow the order of the days presented in Genesis 1; the order is topical rather than historical. This view proposes that days 1–3 involved the creation of kingdoms, and days 4–5 provide creatures to fill and rule over those kingdoms. This view suggests that the days represent a literary structure that pairs days 1 and 4, days 2 and 5, and days 3 and 6.

Both views assert that Genesis 1 is not a historical account. This means that Genesis does not give any information about how long Creation took or how precisely God created. These interpretations view Genesis 1 as creative literature, not history, making the whole passage pliable enough to "fit" in evolution. This allows for long periods of time and drastic changes in living things.

PROGRESSIVE CREATIONISM

The view of *progressive creationism* claims that the days of Genesis 1 are long periods of time. The logical conclusion is that the earth is billions of years old, and that it began with a God-initiated big bang. Unlike the framework view, progressive creationists believe that Genesis 1 does provide the order in which God created the universe. Many progressive creationists also believe that God intervened many times in Earth's long history to directly create each species that exists today.

THEISTIC EVOLUTION (EVOLUTIONARY CREATIONISM)

Theistic evolutionists believe that evolutionary science is correct in its narrative of Earth's origins and the development of life. They believe that God initially created the world and is providentially at work in the world. But they do not believe that He specially intervened in the world to create different species. This allows for long periods of time and drastic changes in living things.

Theistic evolutionists offer differing views on how to harmonize Scripture and evolution. One popular theory is the *cosmic temple inauguration theory*. This theory teaches that Genesis 1 is not about the creation of the physical world at all. Instead, Genesis 1 is about the creation of the universe as a cosmic temple. Humans are given the function of serving as priests in that temple.

Is Adam Historical?

A debate related to alternate views of Creation is whether or not Adam was a historical person. Some theistic evolutionists claim that he was, but many say that Adam was mythological or figurative.

ARTIST'S RENDERING: *VELOCIRAPTOR*

The dinos below are all artists' renderings of the same dinosaur—*Velociraptor* (*V. mongoliensis*). Surprised? Take a minute to compare these artists' illustrations of dinosaurs, keeping in mind that we have only bones and fossil imprints to work with when creating these images.

Scientists aren't the only people that can promote biological evolution. Artists often perpetuate facts or myths that are based on their artwork. Notice that one of these images has feather-like structures. Evolutionists say that birds descended from dinosaurs. Fossil imprints of earlier dinosaurs of the same family had some kind of frills or fine structures. Paleontologists found one *Velociraptor* bone that had six bumps on it that they compared to bumps on the bones of birds where the quills

attach. Because of this one bone, evolutionists conclude that all *Velociraptors* had feathers and might even have been able to fly!

Remember that the evidence *and* your worldview affect how you interpret and make sense of the evidence. So next time you pick up a science magazine and see dinosaur art, remember, it's all about your worldview.



10.4 THE GREAT PROBLEM

Though many believers have a genuine desire to uphold the authority of God's Word, their attempts to harmonize the Bible with evolution just don't work. We should not be so quick to question a natural reading of the Bible. Because the Bible is inerrant and inspired by God, the best interpretation of Scripture must guide our scientific conclusions.

Views of creation that accommodate molecules-to-man evolution run into one major problem—death before sin. The theory of evolution is a theory that progresses through death. The presence of death and suffering in the world is what drove Darwin to question God's creation in the first place.

Death and suffering haven't always been a part of our world. The Bible teaches that death and suffering in our broken, fallen world trace back to one historic event: the Fall (Rom. 5:12; 8:20–23; Gen. 3:17–19). When Adam and Eve sinned, they died (Gen. 2:17). But God's curse not only affected them, it also affected reptiles (Gen. 3:14), the ground (3:17), the plants (3:18), and the animals (3:21; 4:4). Just as death came through the sin of one real man, Adam, life comes through the righteousness of one real man, Jesus (Rom. 5:18–19). Without the sin of Adam, there is no need for Jesus the Redeemer. The whole creation groans under the curse and looks for God's redemption (Rom. 8:20–23). In the Bible, death is an intruder into God's creation, an enemy. But in the evolutionary story, death is a main character, the vital component that propels us from obscurity to something great. These two perspectives on death are not compatible.

10A REVIEW QUESTIONS

1. Put the following events in chronological order.
 - 1 Darwin's voyage on HMS *Beagle*
 - 2 Linnaeus's paper on classification
 - 3 *Triceratops* soft tissue study
 - 4 Publication of *On the Origin of Species*
 - 5 Malthus's paper on population growth and Malthusian catastrophes
 - 6 Lyell's publication of *Principles of Geology*
 - 7 De Vries's mutation theory
2. Suppose that scientists succeed in developing a successful malaria vaccine. India, the second most populated country in the world, gets access to this vaccine, and population explodes, until local food supplies begin to dwindle and starvation plagues the largest cities in India. Which evolutionary scientist would predict this kind of change in population: Darwin, Lamarck, Lyell, or Malthus? Comment on the accuracy of his theory in this case.
3. Which evolutionary scientist would say that the seeds from a bonsai could be used to grow another bonsai: Darwin, Lamarck, Lyell, or Malthus? (See Figure 10-11.) Comment on the accuracy of his theory in this case.
4. A study at several Australian universities in 2010 showed that obese male rats have daughters who are also obese. Which evolutionary scientist would suggest this: Darwin, Lamarck, Lyell, or Malthus? Comment on the accuracy of his theory in this case.



10-11

Bonsai are normal trees whose branches and roots are pruned continually over many years to form a dwarf tree. Junipers are the traditional bonsai tree, although cedars, Japanese maples, and even azaleas are also used.

5. Some bacteria have mutations that give them immunity to penicillin, while those without the mutation die off. The surviving bacteria reproduce. This means that doctors have to more carefully prescribe antibiotics. What process allows this kind of change in the bacteria population?
6. Two bull hippopotamuses (*Hippopotamus amphibius*) fight to dominate a certain region of an African river and a pod of hippopotamuses (right). The one who wins mates with the females in the pod, producing more offspring than the loser. What evolutionary idea does this illustrate?
7. Many people in Darwin's day thought that organisms never changed, and they linked this idea with God's Creation of the world. Does God's Word teach that organisms can't change at all? Explain your answer.
8. What three sciences do evolutionists use to build evidence for their theory?
9. Many nonliteral interpretations of Genesis include death before sin. Why is this a problem?
10. Most alternative views of Genesis other than a straightforward view contain aspects of both creation and evolution. Why do you think this is a problem?
11. The two main parts of evolution that Christians often try to reconcile with Scripture are the extent of change in organisms and the timetable of change. Fill in the following table, describing the different views of origins. The first row has been completed for you as an example.



View	Timetable of change	Extent of change
biological evolution	long periods of time	drastic changes in organisms
analogical day framework		
progressive creationism		
theistic evolution (evolutionary creationism)		
intelligent design		
straightforward view of Genesis		

10B

CHANGE IN NATURE

How should we view changes in nature?

10.5 THE STORY OF EVOLUTION

The theory of evolution is not just one theory. Actually, it is made up of many smaller theories that come together to form one overarching story of how everything got here through purely natural processes. If any of these smaller theories breaks down, there is a gap in the big story which endangers a completely naturalistic view of origins.

Evolutionists have to deal with a few limitations. There was no human who directly observed life's beginning, and any records that we have about early Earth are incomplete. Let's look at the big story of evolution, including biological evolution.

10B Questions

- » How do changes affect organisms and populations?
- » What are some problems with the evolutionary story?
- » How does change fit into a biblical worldview?

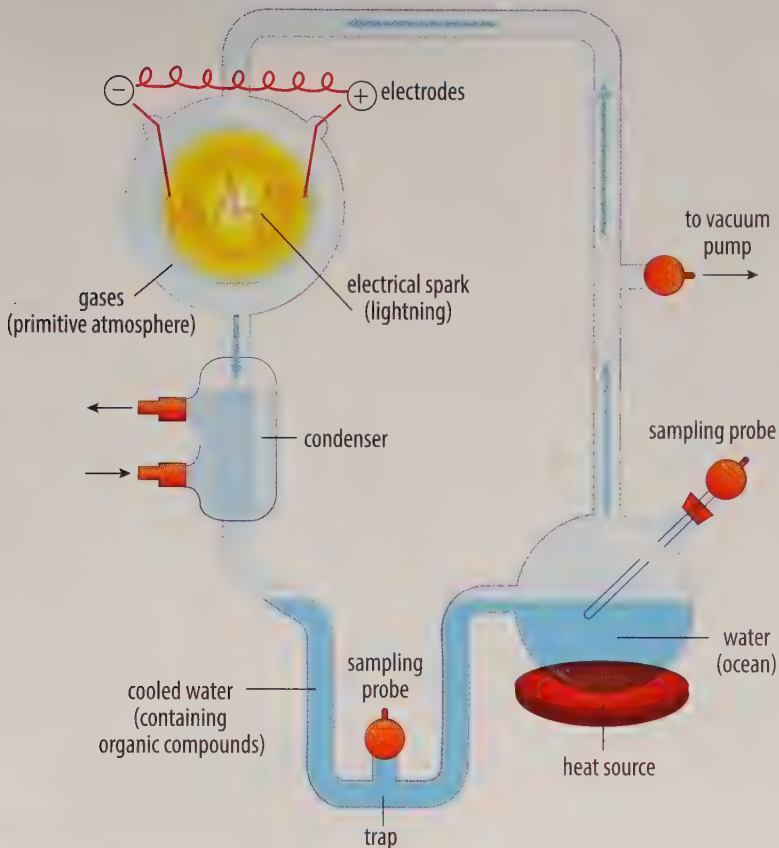
THE EARLY EARTH

Evolutionary astronomers and physicists say that the universe began as a very hot, dense, infinitesimally small dot. Then shock waves of intense energy expanded it like a tsunami. Time and space churned like water at the base of a waterfall. Evolutionary scientists call this explosion of space and time that started everything the **big bang**.

After the first three minutes, the nuclei of the simple elements hydrogen and helium began to form. After 560 million years, gravity gathered gases together, and stars began to wink in the emerging dawn as fusion began. These stars aged and became nurseries of heavier elements, such as carbon, nitrogen, and oxygen. This is part of *chemical evolution*, the naturalistic formation of the elements. As these stars eventually died in violent explosions, they spewed their remains out into the universe. This stardust landed in places like Earth, a ball of dust that had coalesced from a nebula in the aftermath of the big bang.

Though there is not a consensus among evolutionists about the origin of life, they believe that Earth became a warm nursery of life. Amino acids, proteins, and eventually RNA and DNA formed from elements forged in stars over millions of years in the “warm little ponds” on Earth’s surface and began to replicate. Many evolutionists think that lipids began to form and circle into balls that were the predecessors of cells. Eventually, all the chemicals needed for life were there, and the first simple living creatures formed. Evolutionists think that they were probably anaerobic,

one-celled bacteria that could survive in the harsh conditions on Earth’s surface at that point, similar to extremophiles today.



10-12

Two biologists, Harold Urey and his assistant Stanley Miller, simulated the conditions of the atmosphere of an early Earth in 1952 and were successful in producing amino acids. This experiment, though now questioned, was one of the most significant in investigating *abiogenesis*, the transition from nonliving chemicals to living organisms. The drawing above shows the experimental apparatus they used.

THE HISTORY OF CHANGE

Secular scientists say that more and more complex organisms began to form as the earth’s surface began to change. DNA, RNA, and proteins in these organisms mutated to form new traits and variations, which led to newer and more complex organisms that were better able to survive in the slowly changing environment on Earth. Evolutionists call the slow, gradual changes in proteins and genetic material **molecular evolution**. They view proteins and genetic information as a history of an organism’s evolution. Geneticists use the current rate of mutations in DNA and proteins to project how long a certain species

took to evolve. The technique used to find the rate of change in specific genes and proteins found in an existing organism is called a **molecular clock**.

Just as geneticists use proteins, DNA, and RNA to construct an organism's evolutionary history, paleontologists use fossils to construct the evolutionary history of life all over the earth. Beginning with Lyell, evolutionary paleontologists have attempted to associate rock layers called *strata* in different parts of the world with different periods of time in life's evolutionary history. The periods of evolutionary history are called the **geologic time scale**. The rock layers that correspond to these periods of time are called the *geologic column*.

Evolutionists assign ages and names from the geologic time scale to rock layers on the basis of the absolute or assumed ages of nearby strata and the presence of certain fossils of accepted ages called **index fossils**. Sometimes these ages come from **radiometric dating**, a process that analyzes radioactive elements in rocks and uses the rate at which these elements decay to calculate their age. Radiometric dating produces absolute dates in a line of reasoning that is similar to that used for the molecular clock, but for rocks.

Geologists believe that if they know the ages of strata above and below a given stratum, then they can estimate the age of the strata between them. This is called *relative dating*. However, there is no one place on Earth where the entire geologic column exists.

Fossils don't come with date tags! Evolutionists assign ages to fossils by the geologic ages of the rocks that contain them. Generally, paleontologists *expect* to find simple organisms in the oldest and most deeply buried rock layers and more complex organisms in the most recent rock layers. Rocks get their dates by their position in the geologic column, by radiometric dating, or by index fossils. To further complicate interpreting the geologic column, strata have moved as the result of major earth-rebuilding processes called *plate tectonics*. Evolutionary geologists say that plate tectonics has built mountains and spread sea floors over extensive periods of time, moving the continents to their present location. The processes of plate tectonics are the same processes that trigger earthquakes and cause volcanoes to erupt today.

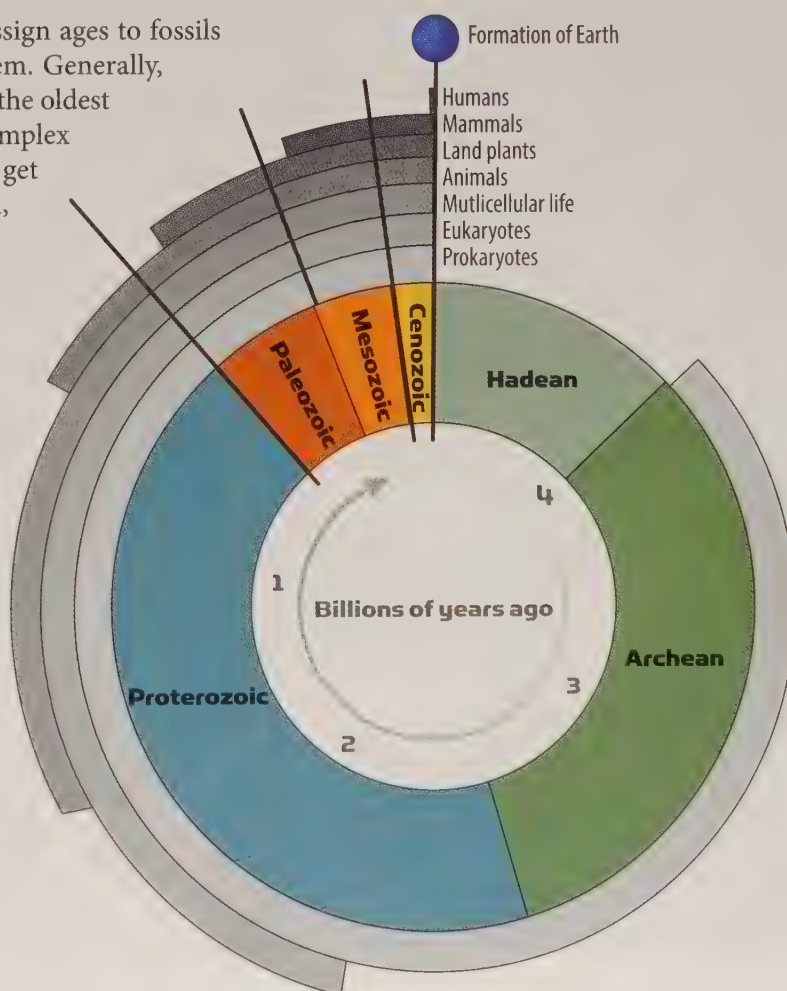
10-14

Notice the ages of each period of time on the geologic time scale. Evolutionists *expect* to find specific kinds of fossils in layers of the geologic column that correspond to these periods of time.



10-13

Using the molecular clock hypothesis, geneticists think that the ancestor of the Haleakalā silver sword (*Argyroxiphium sandwicense*) lived 5 million years ago.





10-15

Paleontologists believe that a large asteroid impact led to the extinction of the dinosaurs.

Microevolution

You might read or hear of terms like “microevolution,” used to mean small, observable changes in populations of organisms over several generations, and “macroevolution,” to mean large-scale changes that take too much time for anyone to observe. When an evolutionist speaks about “evolution,” whether micro or macro, the idea of mutation leading to the development of new traits is usually what he has in mind. However, most of the evidence for what is called microevolution can be attributed to populations adapting to new environments using genes already present in the population. When you see the term “microevolution,” substitute the word “adaptation” and you’ll see that “adaptation” is what they mean, not “evolution.”



10-16

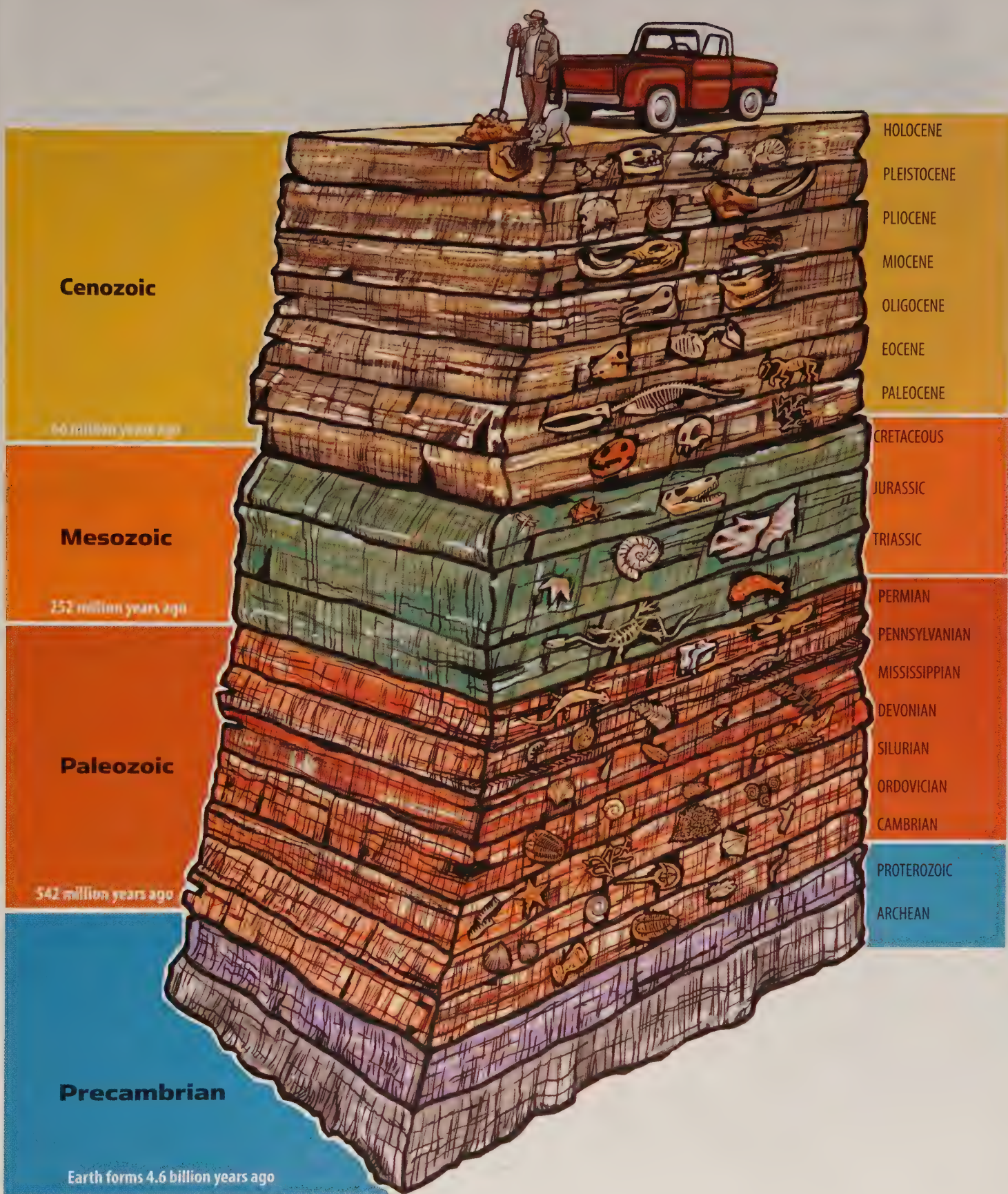
Polar bears and grizzly bears are of the same evolutionary species since they can mate and produce offspring called pizzly or grolar bears.

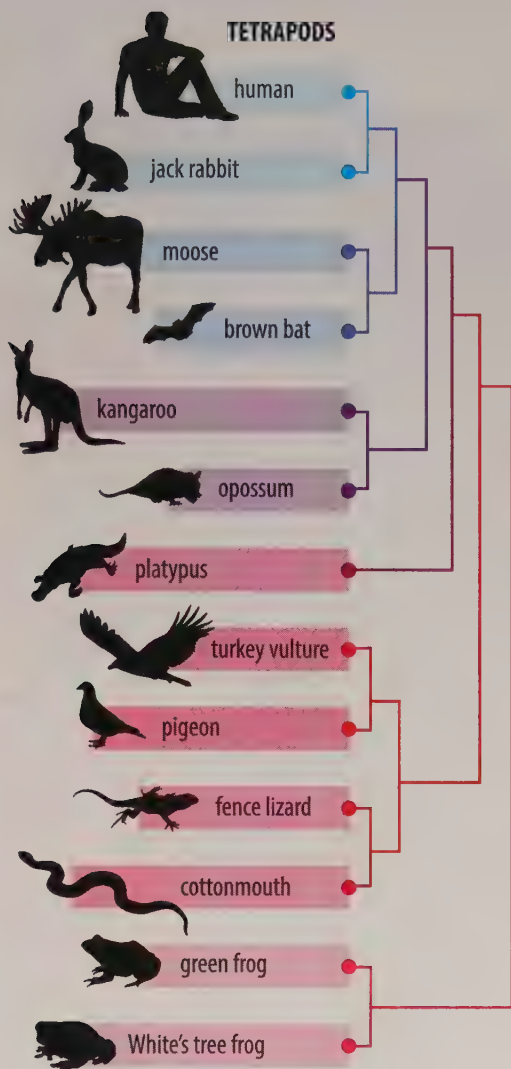
Evolutionists interpret the evidence in the geologic column as supporting biological evolution. This history of change starts with the first molecules evolving to form simple organisms, then plants and animals, and ultimately man through mutations and natural selection. This history has been punctuated with massive catastrophes, such as multiple ice ages, meteoroid impacts, and changing climate, that have caused massive extinctions and shaped the course of evolutionary history. In fact, evolutionists suggest that 99% of all the species that have ever lived on Earth are now extinct.

THE HISTORY OF SPECIES

When paleontologists look at individual fossils, they aren’t thinking about how those specific fossils evolved. Evolutionary paleontologists are thinking about how populations, rather than individuals, evolved. Over the span of millions of years, populations develop mutations, some of which increase their fitness. If these changes are heritable (not all are), they are passed down to the next generation and increase the variation of that population. This is where evolutionists bring in population genetics to investigate how allele frequency, genetic drifts, and the bottleneck and founder effects shift biological evolution. The process of change happens slowly in a population depending on whether that population is in contact with other populations or isolated, such as on an island. Species can change fairly rapidly in small, isolated populations compared to large gene pools where mixing is more free. Natural selection and genetic drift are two ways that allele frequencies change in a population. However, evolutionary biologists say that the process of evolution doesn’t seem to have a particular destination.

When a population develops adaptations, the gene pool changes in a way that affects the variation and allele frequency. The change in the beaks of Darwin’s finches due to natural selection (see Figure 10-6) is an example of adaptation. However, these small changes in a kind of organism are not sufficient to bring life from unicellular organisms to humankind. The formation of new species through these processes via mutations and natural selection is called **speciation**. Organisms of the same kind can successfully mate together to produce offspring. When a new species forms, members of that species usually can’t mate with organisms from the original population to produce offspring. Anything that prevents two species from reproducing with each other is called a **reproductive barrier**. These reproductive barriers could be because of an organism’s behavior, structure, habitat, or the fitness of the offspring produced. Evolutionists say that large changes in populations are the result of many small changes over massive periods of time. These changes, acted on by natural selection and coupled with massive extinctions and genetic drift, produce, not just new species, but also new kinds of organisms.





Evolutionists have brought together genetics, molecular evolution, and paleontology to suggest how organisms that we observe today are evolutionary relatives of each other. Biologists diagram these relations with a chart similar to a family tree called a *phylogenetic tree*. Phylogenetic trees can't show the ages of organisms, and sometimes it is difficult to tell if similar structures in organisms are homologous or analogous. The tips of the phylogenetic tree show known organisms either alive today or known from the fossil record. The places where lines come together indicate a common ancestor of some sort. You'll learn more about phylogenetic trees when we study classification in Chapter 11.

LOBE-FINNED FISH

coelacanth

RAY-FINNED FISH

queen triggerfish

brook trout

CARTILAGINOUS FISH

hammerhead shark

manta ray

THE HISTORY OF MAN

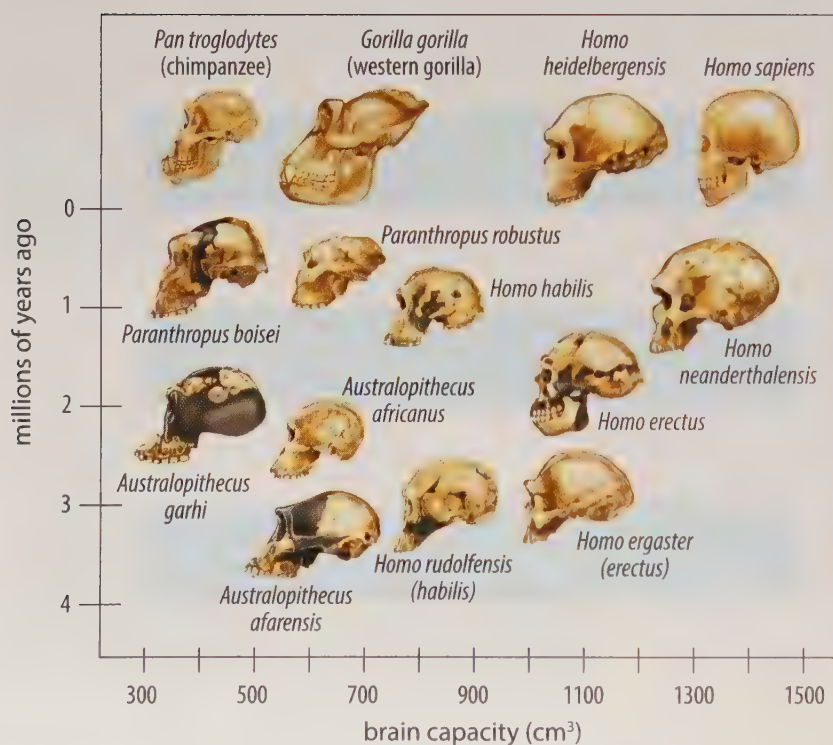
Evolutionists say that man, along with all other living things, has evolved. They relate man to the evolution of mammals, especially primates. Our ability to walk on two feet, our long legs, our barrel-shaped rib cage, and the size of our brain are several factors that evolutionists compare to other members of the phylogenetic tree that includes modern-day humans. Evolutionists credit structures like these to the rise of the humans

(*Homo sapiens*). Evolutionists have found fossils of organisms that they label as predecessors of modern-day humans. They refer to this group of organisms including modern man as *hominids*.

Secular scientists have tried to find where people first came from by looking at mitochondrial DNA, which resides in the mitochondria. Mitochondrial DNA comes from only the mother and it's very important to evolutionists. Their goal is to find the one woman with an unbroken line from whom all people are related. Evolutionists have also used mitochondrial DNA to completely reorganize biology's classification system and build an evolutionary tree for all living things.

10-17

These are the skulls of ancestors in the human phylogenetic tree. Paleontologists find only isolated bones for these species, and they have to figure out whether they are from the same organism or a different one. Notice how *Homo sapiens* is thought to have the largest brain capacity.



10.6 EVALUATING THE EVOLUTIONARY STORY

Evolutionists view their theory as the key to understanding the natural world. They are endeavoring to create a story that explains the natural world without resorting to the miraculous and supernatural. They are operating in a completely naturalistic and materialistic worldview where all that matters is what is natural and material. But a naturalistic worldview has some severe limitations clearly seen in the evolutionary story. While most evolutionary scientists would say that we just need more time to figure out solutions, some of the problems are fundamental.

THE EARLY EARTH

The evolutionary story's difficulties go all the way back to the very beginning. Physicists are struggling to account for the lack of dark matter and dark energy that is supposed to account for the massiveness of the galaxies. Large amounts of mass and gravity are required by the Big Bang theory.

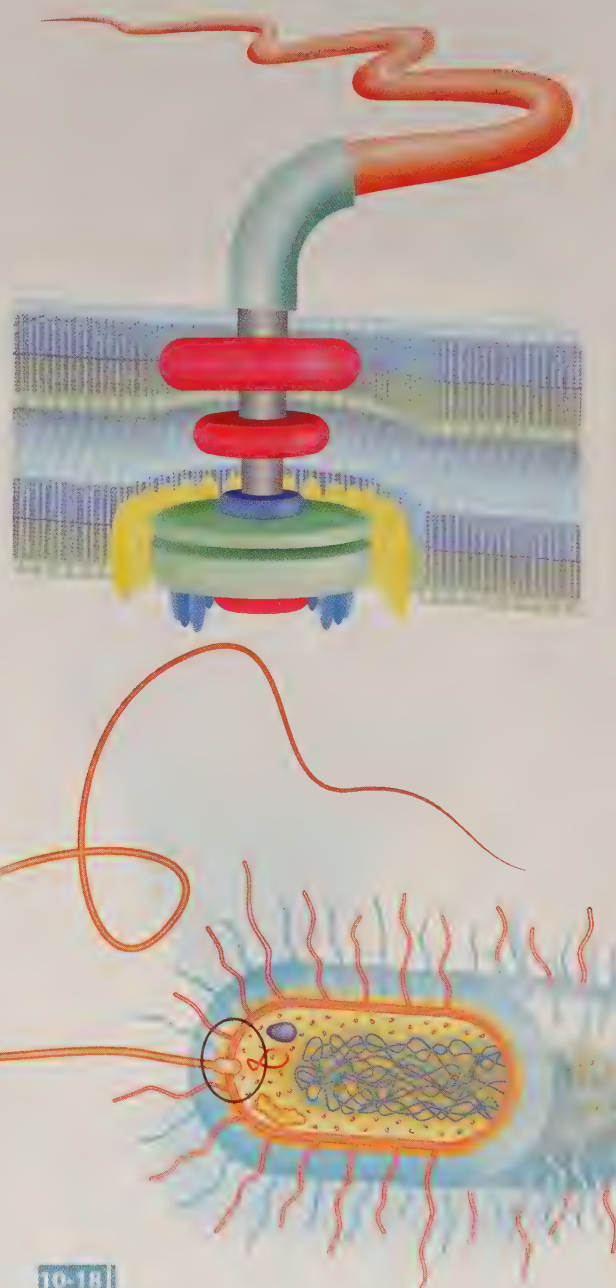
Parts of the evolutionary story, such as the evolution of information-rich molecules like DNA, are still not settled. Even simple amino acids require precise, controlled conditions to form spontaneously, as the Miller-Urey experiment showed (see Figure 10-12). And they do not continue to develop further into the sophisticated molecules required for life. You know from your study of the cell that proteins and DNA have an amazing amount of information packed into them. We don't know about any natural processes that can make them form effortlessly in "warm little ponds."

THE HISTORY OF CHANGE

Evolutionists have not sufficiently explained how life can come from non-life. The construction of the geologic column, phylogenetic trees, and the whole process of evolution is fuzzy and vague, where vast amounts of time sweep away all uncertainty of this process even happening.

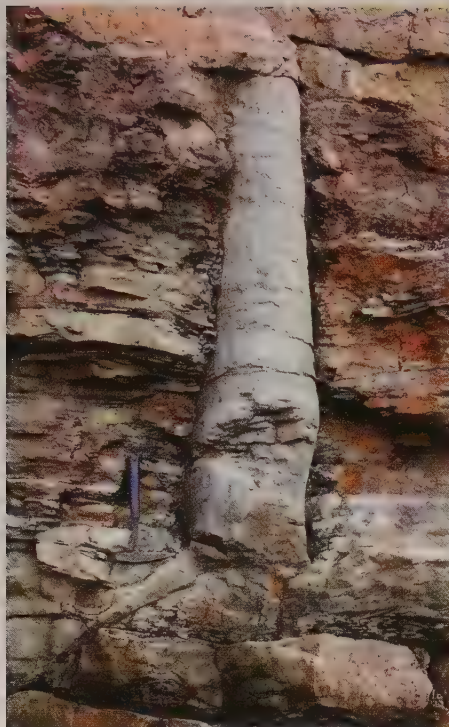
Even the fossil record does not always cooperate with evolutionary paleontologists, as we have seen with the dinosaur soft tissue finds. Evolutionary paleontologists say that about 530 million years ago there was an explosion in the diversity of animals in the fossil record, called the *Cambrian Explosion*. In this event, the strata that contain Cambrian Explosion fossils have simple organisms in higher layers and more complex organisms in lower layers, the opposite of what evolutionists would predict.

We can readily observe adaptations taking place within species. For example, Darwin's finches seem to go through cycles in which the allele frequency can change in just one year. But living cells resist a great amount of change. One kind of animal changing into another kind of animal has yet to be documented, though many evolutionists claim that there hasn't been sufficient time.



10-18

Modern science is revealing the intricacies and machinery of cells such as the flagellum. It is difficult to imagine how this kind of design could spontaneously form from nonlife.



10-19

Some fossils appear to extend through multiple layers of strata. This indicates that they were buried very quickly through a catastrophic event. This fossilized tree found in Nova Scotia is an example of a *polystrate fossil*.

THE HISTORY OF SPECIES

Evolution requires that a small amount of information in a population leads to diversity and large amounts of information. Natural selection requires that large amounts of information be whittled down to a small amount of information in the genes of the fittest organisms. But these two processes happen in two different directions.

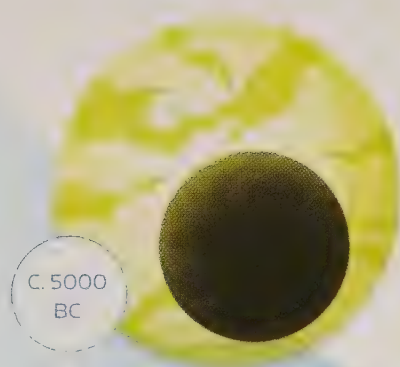
Methods that secular geologists use to date rocks, fossils, and DNA are unreliable and vary greatly. Radiometric dating is based on flawed assumptions, and the molecular clock method of dating is subjective and easily influenced by one's assumptions. The relationships between the dates of rocks and fossils found in the rocks demonstrates circular reasoning—the rocks are used to date the fossils and the fossils are used to date the rocks. There is no outside standard to reference.

THE HISTORY OF MAN

Perhaps the biggest concerns with the materialist worldview are philosophical. Why is there something instead of nothing? How can consciousness be formed from unconsciousness? And how can you have right and wrong when the whole world is headed for oblivion and extinction? Evolution's inability to answer basic questions about human life call into question the materialistic worldview.

The theory of evolution has moral consequences. While most people don't think through evolution this far, it leads to a dehumanized view of people and makes them little more than animals with no moral and spiritual anchor. The ideas of evolution have been applied to society (social Darwinism), resulting in tragedies like the Holocaust and the eugenics movement, the effort to sterilize people who are considered unfit so that they can't reproduce and pass along their faulty genes. While any idea can be twisted for wrong purposes, these tragedies are logically consistent with an evolutionary worldview.

Creation of the world



C. 5000
BC

Floodwaters cover the whole world



C. 3340
BC

God makes a covenant with Abraham



C. 2100
BC

There are scientists who believe that evolution is a theory in crisis. As modern biology reveals the inner machinery of the cell, scientists struggle to find evolutionary theories that explain the complexity they find there. The vast amount of genetic information coded in the cell implies that there is intelligence at work in the cell's design. But there is another story that we can use to understand the world.

10.7 THE BIBLE'S STORY

The Bible's story of Creation, Fall, and Redemption offers a consistent, logical framework to navigate the world of scientific evidence. People who accept the Bible's story work with the same limitations as evolutionists—no human witnesses and incomplete records. But those who believe God's Word have one significant advantage—an infallible account written by God himself.



THE EARLY EARTH

A straightforward reading of Genesis 1 and 2 tells us that God created all things by the power of His word in six normal days. And God created in the order that He spells out in the early chapters of Genesis. (Significantly, the order given there is not how life would have evolved, even if it were possible; for example, the plants were created before the sun!) God stopped creating on Day 7. While there is room for debate, the best Biblical scholarship suggests that Creation happened sometime between about 6000 and 4000 BC.

Natural and specific revelation show us that Earth was designed for life (Is. 45:18). The earth is just the right distance from the sun and has just the right blend of gases for an atmosphere. And God's world was very good. But it didn't stay that way.

10-20

When we approach God's Word with an open mind, our thinking is free to interpret the natural world in the way that God intended.



C. 1000
BC

God makes a covenant with David



C. 30 AD

Jesus dies for the sins of the world

GOD'S REDEEMPTIVE TIMELINE

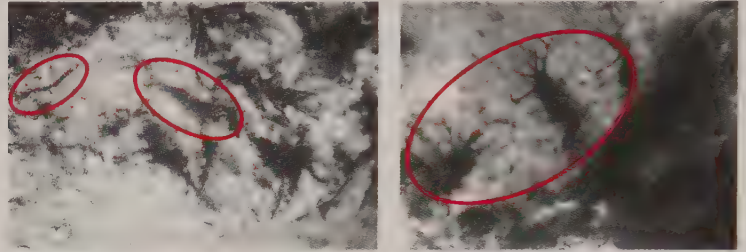
THE HISTORY OF CHANGE

Adam's sin plunged the whole world into its current broken condition. This sin accumulated until God was very grieved to see His once-beautiful world marred by sin. He decided to judge man's sin with a worldwide flood.

The Flood was the most significant physical event in the earth's history after Creation. From what we learn in Genesis 7 and 8, it completely altered the earth's surface. The Great Deluge marks the dividing line between the originally created world and the world that we live in today. Land experienced major reshaping as massive erosion shaped pliable Earth. All land animals not on the Ark died. Most were buried and preserved in rock layers all over the earth, accounting for most of the fossils that we see today.

10-21

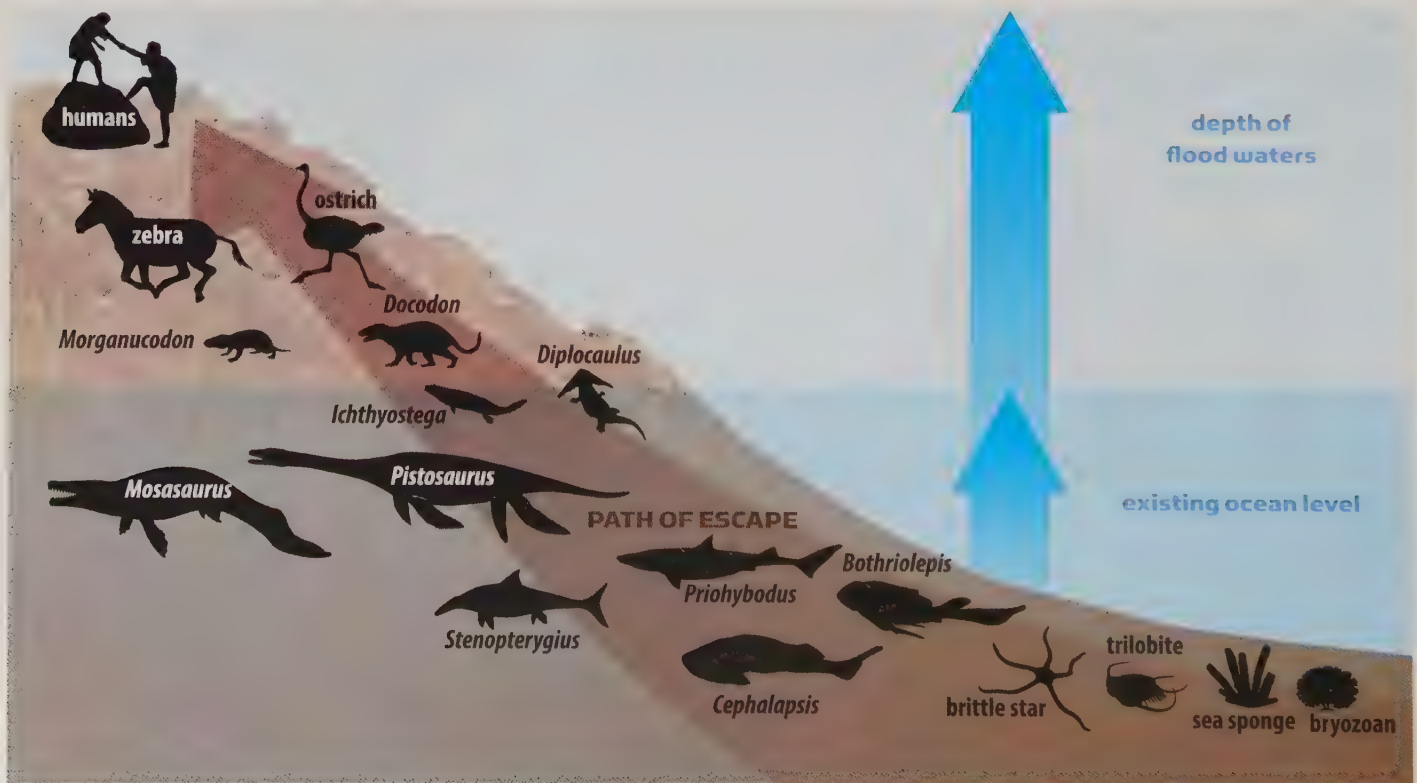
Creation researchers are finding that cells in fossils should decay within 130,000 years, depending on the temperature and conditions in which they are preserved. But when we find cell structures (circled) in dinosaur fossils like this *Triceratops* horn buried in water-deposited rock sediments, the first thing we think of is Noah's Flood.

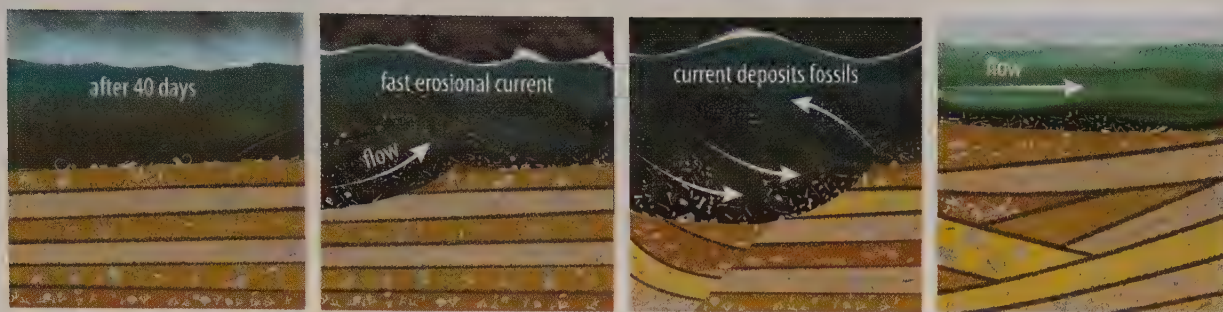


10-22

If the Flood had simply buried organisms as the waters rose, this is the burial sequence we would expect to see.

We can view the different kinds of fossils in each layer of the geologic column in a different way. We can relate the changes in the number and kinds of fossil groups to the Genesis Flood. The geologic column can give us information on the way organisms were carried in the moving water, where they were buried, and the order in which they were buried. This is a model that creation scientists have used to interpret the fossil record.





But the effects of the Flood didn't end when the waters dried up. The changes brought about by the worldwide event greatly affected Earth's weather. Though the Bible doesn't mention an ice age, most creation geologists see clear evidence for a glacial period after the Flood. Some have created models to suggest how the events that resulted in the Ice Age would have unfolded. An ice age would lower sea level, making it easier to repopulate the world after the Flood. It would make Mesopotamia and Egypt wetter and more moderate in temperature, which would explain why people settled there.

Creation geologists agree with their secular counterparts that there is a lot of evidence for the earth-building and earth-shaping processes of plate tectonics and the features that they create, but *when* the events occurred and *how long* they took are key differences. The Genesis Flood created the dramatic features that we see today just thousands of years ago.

THE HISTORY OF SPECIES

Noah took two of all unclean land animals on the Ark, and seven of all clean animals. Males and females were taken, obviously for reproduction. The people were to reproduce as well, as God repeats the Creation Mandate in Genesis 9. Reproduction was a significant part of this command. If the populations of animals today were reduced to these sizes, we would say that every animal on Earth was critically endangered. This bottleneck effect applied to every population of organisms on the planet. But God's mercy preserved life and allowed the earth to dramatically recover after the Flood. Now it teems with plants and animals and is home to over 7 billion people!



10-23

The great tectonic events that seem to have occurred during the Flood could have moved great quantities of fossils back and forth, creating the stratified fossil beds that we see today.

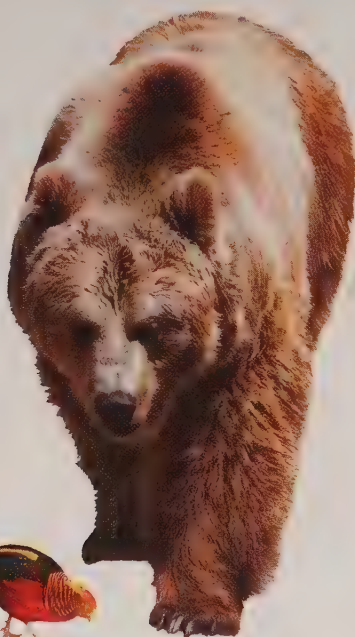
10-24

The Lord remembered Noah.



10-25

The variety that we see in the world today came from the living things that God preserved through the Flood.



Bara- what?

The word "kind" is one that appears in Scripture. The Hebrew word for "create" is the word *bara*, and that for "kind" is *min*. And so we have the term *baraminology*.



We see an amazing diversity of life in land animals and flying creatures in the world today, and it all came from the very small populations of animals that Noah brought on the Ark. As the animals left the vessel, they stepped into a very different world. This earth continued to change as weather patterns probably shifted to produce the Ice Age. God created living things with the ability to respond to a changing environment. Populations of organisms develop adaptations through genetic drift to produce the variations that we see today. Some of these heritable adaptations may have arisen through genetic changes, though more than random mutation and natural selection would have to be involved. The variations that we see in living things are small changes that are just one indication of the genetic variety that God has built into His living creation.

We can agree with Darwin, and modern evolutionists, that there is descent with modification among living things. We have no problem with Darwin's changing finches and de Vries's changing primroses. We observe changes over time happening even today, but these modifications don't turn one kind of animal into another.

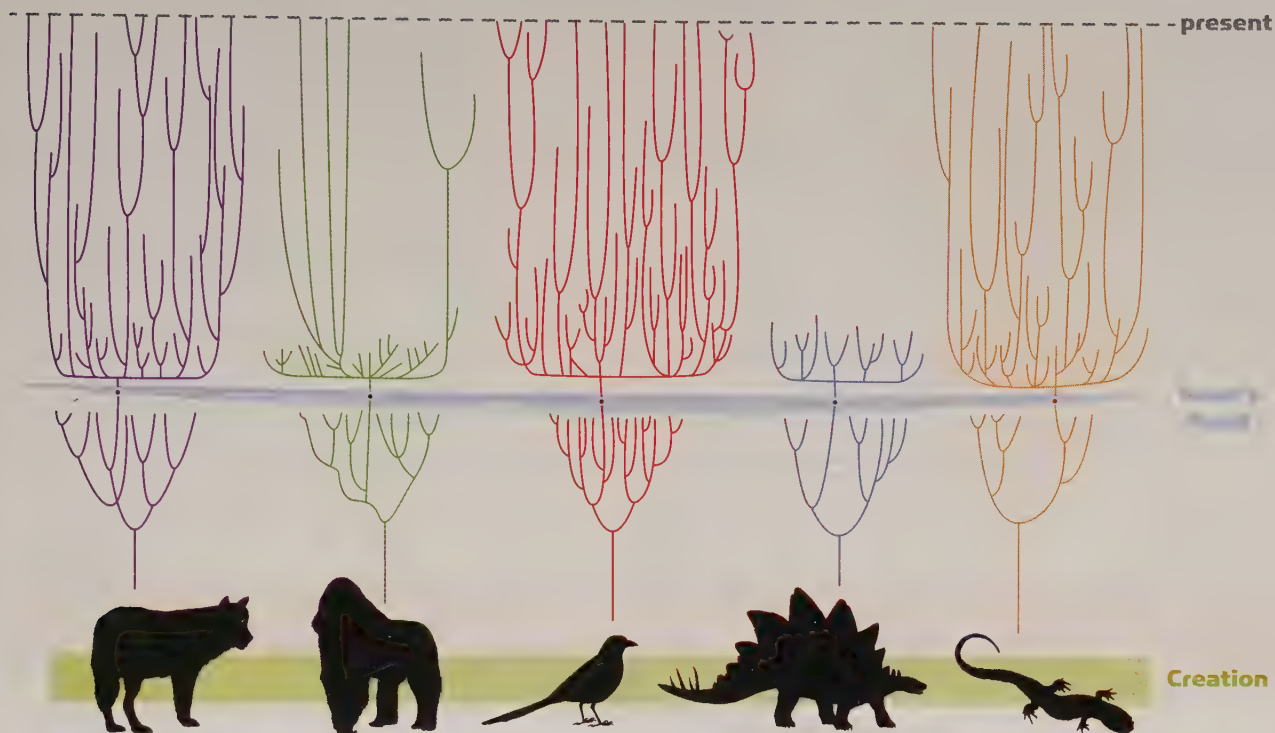
Creation scientists group animals into categories called *kinds* through the tool of *baraminology*, the classification of organisms by kinds. Species and kinds are not the same thing. Species represents a human classification system, and kind represents a divine category of organisms. Some creationists think of a kind as an original combination of traits that other organisms can share. The best way to think about kinds is to think about what makes sense: For example, it's natural to think of cattle, yaks, and buffalo as similar animals. This is similar to the way Linnaeus viewed organisms. Speciation happened as a result of the variation and reproduction of the animals that descended from those that were on the Ark. A recent study by creation biologists estimates that there were less than 15,000 kinds on the Ark, about 30,000 different animals. This doesn't include all of the sea life, which was not taken onto the Ark. Creation scientists estimate that speciation could double the number of species from 15,000 to 30,000, and from there genetic drift could take over to create the variation that we see in the world today. Instead of a tree of life, we think of an orchard of life, where different species come from created kinds.



But we also see the effects of the Fall at work, with many mutations in organisms being harmful. Many species and their genetic information pass into extinction. The overall trend of genetic changes in the world is a loss of genetic information, not the increasing complexity predicted by evolution. In fact, most beneficial mutations would fall by the wayside because of genetic drift in populations.

10-26

The “orchard of life” model of speciation shows how different species can arise from one kind through natural selection after the Flood. The blue line represents the Flood, with branches below representing pre-Flood speciation and branches above the line representing post-Flood speciation.



THE HISTORY OF MAN

Adam and Eve were human, and they were created in God’s image and given the task of filling the earth and wisely using it. We are human as well. In the Bible’s story, there is a sharp distinction between humans and animals. Genesis 1 presents man as the pinnacle of God’s creative work. To be human is not to be a highly evolved, highly fit animal that has clawed his way to the top of the food chain to survive through brute force. To be human is to exhibit God’s image. We are like God in certain relational, emotional, and rational ways. Because of this, we have great worth. God demonstrated the value he places on people when He became a man and suffered and died for our sins.

As we do the work of science, we must view science and the question of origins through the Bible’s story. The theist and the atheist, the creationist and the evolutionist are all pressed to faith. A Christian’s faith leads one to interpret the evidence in the natural world in ways that submit to the established authority for truth, God’s Word.

“Now faith is the substance of things hoped for, the evidence of things not seen...Through faith we understand that the worlds were framed by the word of God, so that things which are seen were not made of things which do appear” (Heb. 11:1, 3).

Adam and Eve’s Genome

Geneticists have taken samples of the human population all over the world and have compared the genomes of many individuals. Using DNA in the mitochondria, they have been able to find the genome for the female common ancestor they call *Mitochondrial Eve*. Using the Y chromosome, they have been able to find the genome for the male common ancestor, whom they called the *Y Chromosome Adam*. While researchers don’t really think there is a historical Adam and Eve, people who view the world through the Bible’s story have no problem viewing the human race as coming from just two people that God made in His image.

10B REVIEW QUESTIONS

1. What is the difference between adaptation and evolution?
2. Review the terms from Chapter 3 on symbiosis, including competition. How could competition play a role in the way populations change?
3. Create a timeline of the evolutionary story, including the big bang, the formation of Earth, the first living cells, dinosaurs, and man.
4. Name two ways through which the genetics of a population can change, according to both evolutionists and creationists.
5. How should a creationist view adaptation and evolution?
6. Compare how a creationist and an evolutionist would view homologous structures in very different animals.
7. The fossil record is usually sorted from simple organisms at the bottom to complex organisms at the top. What are the two different ways to interpret this arrangement of fossils?
8. Compare how evolutionists and creationists think the earth has changed during its history.
9. Compare the early earth in the evolutionary and creation stories.
10. What is one major problem with the “warm little pond” theory of evolution?
11. What scientific breakthroughs have cast doubt on the possibility of evolution?

WORLDVIEW SLEUTHING: *DINOSAUR TRAIN*

Do you ever watch kids cartoons? Maybe you're too embarrassed to admit it! Even something as harmless as a cartoon can shape a child's worldview. In this sleuthing activity, you will critically analyze a children's cartoon series called *Dinosaur Train*. Here's your chance to watch TV for homework!

Introduction

What kind of kids do you interact with— younger siblings, church kids, neighborhood kids? Get an idea of how the media can influence these kids toward a naturalistic, atheistic worldview by using two things that little kids love: dinosaurs and trains.

Task

Dinosaur Train is a cartoon that airs on PBS. This cartoon is aimed at preschool children. Your task is to write a 150–200 word review of an episode of *Dinosaur Train*, examining the scientific claims and worldview content and analyzing it from a biblical perspective.



Procedure

1. Do a keyword search using the words “*Dinosaur Train*.” Read about the series, then go to the PBS Kids website to find the series.
2. Watch one or two episodes. One episode is about 15 minutes long. Have a sheet of paper and a pen with you.
3. Jot down all the scientific claims during the program. After it is done, go back and read the claims and analyze them from the perspective that you've gained in this chapter.
4. Plan, write, and revise your review and critique.
5. Get another student or adult to proofread your review, and publish it on a class website if your teacher gives you the opportunity.

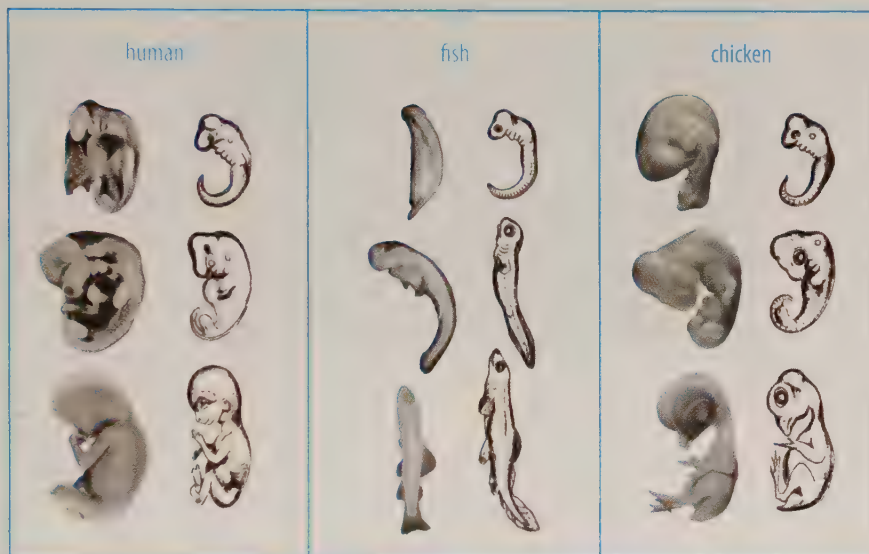
Conclusion

Every episode of *Dinosaur Train* ends with a happy, friendly paleontologist who encourages kids to get outside and explore nature. This program is trying to shape the worldview of young children to regard scientists as the keepers of truth. They haven't yet learned to exercise critical thinking. Parents and teens like you must learn to critically evaluate everything we read, see, or hear to see whether it lines up with the Bible's story of Creation, Fall, and Redemption.

REVIEW QUESTIONS

CONCEPT REVIEW

1. Are Darwin's ideas about descent with modification and natural selection over long periods of time original to him? Explain.
2. What one event do you think changed the course of Darwin's life? Explain.
3. How did Darwin's and de Vries's ideas come together in modern evolutionary biology?
4. Summarize the four basic tenants of evolution in one sentence.
5. Ernst Haeckel, a German zoologist, investigated different embryos in support of the idea that "ontogeny recapitulates phylogeny," or the stages of embryonic development mirror the stages of evolution. Compare his drawings to the actual photographs of embryos below. What do you think of Haeckel's idea?



Key Terms

biological evolution	178
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descent with modification	179
survival of the fittest	179
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artificial selection	179
natural selection	179
mutation theory of evolution	181
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6. Which view(s) of Creation would be most unlikely to acknowledge that Adam was a real person?
7. Which view(s) of Creation would hold that the earth is thousands rather than millions of years old?
8. What are the two main differences between a straightforward interpretation of Genesis and other ideas about origins?
9. What is the main problem for people who don't take the simplest understanding of the first few chapters of Genesis?
10. According to evolutionists, where did the elements that formed the first molecules of life originate?
11. Explain how evolutionists establish dates for the following.
 - a. rocks
 - b. fossils
 - c. ancestors of living organisms



10-27

This albino crocodile lives at the North Carolina Aquarium at Fort Fisher.

12. How do you think an organism is more likely to experience genetic change, through mutations or through normal reproduction? Justify your answer.
13. A crocodile is born with a mutation that causes albinism. This condition makes it harder for the crocodile to hide and catch prey. It is eventually captured and housed at an aquarium, and it mates to produce several generations, including more albino gators. Is this an example of adaptation or evolution? Justify your answer.
14. How can the relationships between individuals in a population affect natural selection?
15. How is the information that we have about cells problematic for evolutionary biologists and geneticists?
16. How should a creationist view fossils?
17. How should a creationist view plate tectonics?
18. How should a creationist view evidence for ice ages, like these oval-shaped hills in Washington state (shown below), which were pushed into place by glaciers?



TRUE OR FALSE

19. Evolutionists have the same ideas about the different parts of the evolutionary story.
20. The most consistent way to interpret the book of Genesis is as a straightforward historical account.
21. Phylogenetic trees show the modern organisms that are related to a common ancestor.
22. The geologic timescale and the geologic column are synonymous.
23. It is unbiblical to say that a population of a species can split into two different species.

CRITICAL THINKING

24. In Chapter 9, you learned that Monsanto found a plant near an herbicide factory that had developed resistance to the herbicide. They are using the genetic information from this plant to genetically modify other plants. How would evolutionary biologists use this to prove their theory? How would you respond?

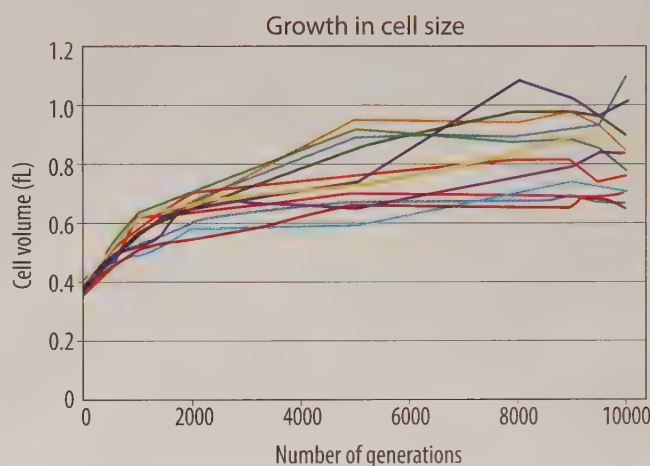
CASE STUDY: EXPERIMENT IN EVOLUTION

One of the major problems with origins theories is that they are hard to test. Evolutionary biologist Richard Lenski has been growing *E. coli* bacteria since 1988. He started with 12 populations. The idea is that each generation of *E. coli* bacteria, which takes only 20 minutes to reproduce, can represent millions of years of evolutionary development in organisms with much longer lifespans. The graph below shows how Lenski's bacteria have changed.



Use the Case Study above to answer Questions 25–27.

25. Read the Case Study and study the graph to the right. How have Lenski's bacterial populations changed?
26. Where did this diversity come from?
27. Why is this study *not* proof for the theory of evolution?
28. Why do you think Christians are willing to work with and be associated with the Intelligent Design Movement?
29. At the time of this writing, a large science museum in London has a page on their website on Haeckel's embryos. It reads, "It seems that an efficient way of marking out the body plan arose millions of years ago and has remained virtually unchanged throughout animal evolution." Why do you think Haeckel's embryos are still referenced in textbooks and museums even though they've been discredited?



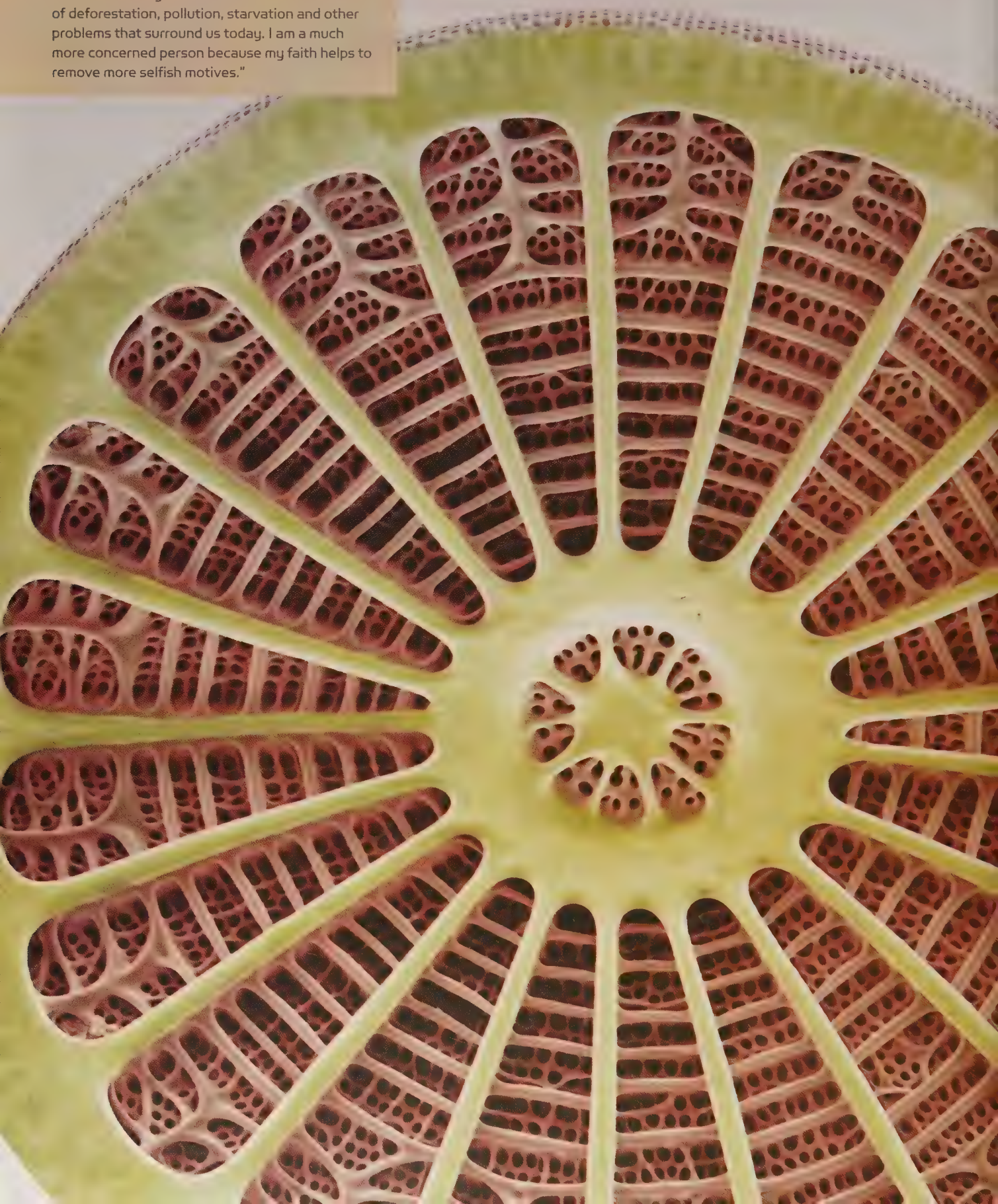
Bacteria and Speciation

Most bacteria reproduce asexually, so the idea of a species being defined by a reproductive barrier doesn't really apply. Scientists get around this by thinking of bacteria from the definition that we gave earlier, i.e., similar organisms with similar characteristics that demonstrate variety through population genetics.

30. Examine the photo of a polystrate tree fossil in Figure 10-19. Identify anything that suggests a catastrophic burial.
31. Do some research on the eugenics movement. What is its relation to evolutionary ideas?

My research interests have been stimulated by my faith. The two aspects that have been most helpful are the study of creation and the Creator, and the biblical basis for justice and equity. It is no longer enough for me merely to classify and describe the plant species of the Amazon forest; I must also use my research data to address issues of deforestation, pollution, starvation and other problems that surround us today. I am a much more concerned person because my faith helps to remove more selfish motives."

SIR GHILLEAN PRANCE (1937-),
BRITISH BOTANICAL TAXONOMIST
AND SCIENCE ADVISOR FOR THE EDEN
PROJECT, AN EDUCATION CENTER
THAT HOUSES THE WORLD'S LARGEST
INDOOR RAINFOREST





3 MICROORGANISMS & PLANTS

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CHAPTER 11

CLASSIFYING LIFE

TAXONOMY 

UNITY AND DIVERSITY 

THE SPECIES POLICE

If you live in Australia, learning the difference between species of hermit crabs is not just a school lesson; it can keep you out of jail! Australian land hermit crabs (*Coenobita variabilis*) are collected and sold to pet shops around the world. But one Australian species, the strawberry crab (*Coenobita perlatus*) is protected because of its threatened status. For collectors, buyers, and pet shop owners, knowing the difference between *C. variabilis* and *C. perlatus* is an important part of their jobs. And in many countries, it's the law. So can learning classification be important for a high-school student like you?

TAXONOMY

Why and how do scientists classify living things?

11.1 WHAT'S IN A NAME?

From hermit crabs to hippos and alpacas to zebras, someone had to study these creatures and give them a name. But what's in a name? Without a way to identify and organize living things, managing God's creation would be almost impossible.

For people to obey God's command to manage the earth, they would first have to figure out what they're managing. One of God's first commands to Adam was to name the animals, which allowed Adam to inspect the creatures under his care (Gen. 2:19–20). He may have studied the animals and compared them to each other, noting that a seagull acts and looks different from a robin, and so gave them different names. He may have realized that even though seagulls and robins are two different birds, they can also be grouped together to show that they share many characteristics. The science of classifying organisms, called **taxonomy**, was a major undertaking for Adam and still is for us today. Man is driven to name things because it helps us use and manage creation better.

11.2 THE HIERARCHY OF ORGANISMS

You're out in the middle of nowhere in Honduras, tagging along with a group of botanists who are looking for new species of *Aegiphila*, plants that are related to magnolias. One of the biologists lets you in on a little secret: a local in a nearby town had shown them a few *Aegiphila* flowers, and they looked like no flowers they'd seen before. You then hear a shout from a botanist farther up the trail. Everyone tramps through the brush to where she is, and you see it—a gigantic flowering plant. It looks a lot like the plants you've seen as you hiked up the trail, but according to one of the biologists, those plants are called *Aegiphila pernambucensis*. The plant in front of you, with its towering limbs and odd flower arrangement, is dubbed *Aegiphila monstrosa*.

If another group of botanists had discovered *A. monstrosa*, they may have given it a different name. And as more information is gathered about this plant, its name may change. That's the nature of taxonomy—the names of organisms and the way they are classified change all the time! It's a model that people have created and can change to make it as useful as possible.

11A Questions

- » Why is classifying useful?
- » How are organisms named and organized?

taxonomy: taxo- (Gk.—arrangement) + -nomy (Gk.—method, system)



11.1

Aegiphila pernambucensis (top) and *Aegiphila monstrosa* (bottom). They are considered two different species because people chose to classify them that way on the basis of the structure of their flowers.

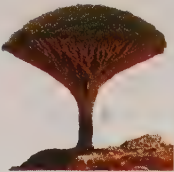
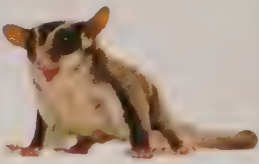


Taxonomy is in a state of flux because scientists are attempting to classify organisms using their genetic information instead of their phenotypes. The most common taxonomic system contains eight classification groups called taxa (s. **taxon**), which scientists use to classify organisms.

Actually, you think like a taxonomist every day. For example, if you were to go to the grocery store to find a specific item such as King Arthur's bread flour, you would need to work through a hierarchy of information. First, you have to find which aisle flour is on, and then which shelf, and then which kind of flour, and then which brand. You're working your way through the taxonomy of the grocery store. If the items in a store weren't organized, you would never be able to find what you're looking for. Table 11-1 shows how several different plants and animals fit into this hierarchy of taxa.

Table 11-1

Taxonomy for Several Plants and Animals

Taxon	 purple passion flower	 dragon tree	 reef octopus	 scarlet tanager	 sugar glider
domain	Eukarya	Eukarya	Eukarya	Eukarya	Eukarya
kingdom	Plantae	Plantae	Animalia	Animalia	Animalia
phylum	Tracheophyta (flowering plants)	Tracheophyta (flowering plants)	Mollusca	Chordata	Chordata
class	Magnoliopsida (dicots)	Liliopsida (monocots)	Cephalopoda	Aves	Mammalia
order	Malpighiales	Asparagales	Octopoda	Passeriformes	Diprotodontia
family	Passifloraceae	Asparagaceae	Octopodidae	Thraupidae	Petauridae
genus	<i>Passiflora</i>	<i>Dracaena</i>	<i>Octopus</i>	<i>Piranga</i>	<i>Petaurus</i>
species	<i>incarnata</i>	<i>draco</i>	<i>cyanea</i>	<i>chilensis</i>	<i>breviceps</i>

DOMAINS AND KINGDOMS

Bi Different Science, Same Evolution

For centuries, scientists used comparative anatomy to support evolution. Once the field of genetics blossomed in the 1970s, scientists saw the potential of using an organism's genes instead of its anatomy to show evolutionary links. Creatures do share many physical and genetic characteristics, so how does worldview affect how a person classifies these creatures, regardless of which branch of science he uses?

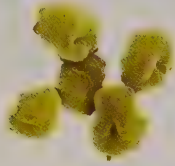
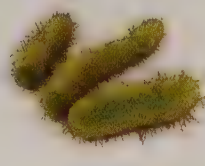
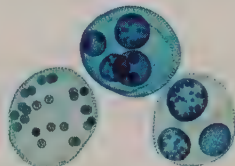
In the fourth century BC, Aristotle created the first taxonomy system, dividing living things into plants and animals. This two-kingdom system remained in place until the 1860s, when Ernst Haeckel, a German biologist and illustrator, proposed a third kingdom to include all the single-celled protists that scientists had discovered with the microscope. In the 1930s, American biologist Herbert F. Copeland removed bacteria from the protist kingdom and created a fourth kingdom for them. In 1969, while the world was watching the first man walk on the moon, the American ecologist Robert Whittaker created a fifth kingdom to separate fungi from plants.

During the 1970s, scientists began looking at the genetics of organisms to see which kingdom an organism belonged to. That's when

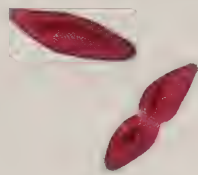
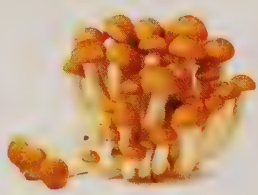
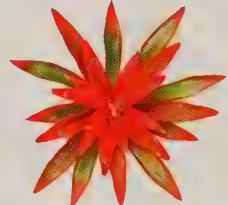
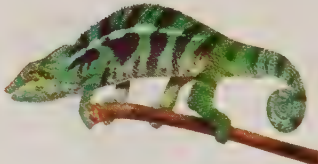
(continued on page 210)

Table 11-2

Domains of Life

	Archaea	Bacteria	Eukarya
Characteristics	prokaryotic cells that don't contain peptidoglycan in cell walls; contain isoprene in cell membranes, which makes them heat resistant	prokaryotic cells that contain peptidoglycan in cell walls, which protects them and triggers other organisms' immune systems	eukaryotic cells
Kingdom	 Archaea	 Bacteria	 Chromista
Defining characteristics	- live in harsh conditions, such as extreme temperatures and acidic or salty environments - unicellular, may form colonies - heterotrophic or autotrophic	- break down materials in the soil for plants; can either cause or prevent disease in other organisms - unicellular, may form colonies - heterotrophic or autotrophic	- plant and fungus-like; have motile gametes (i.e., gametes that move); cell walls made of cellulose - unicellular, colonial, or multicellular (no true organs) - autotrophic, a few heterotrophic
Example	thermophiles, acidophiles, halophiles, methanogens	<i>E. coli</i> , bacteria found in yogurt, <i>Salmonella</i>	kelp and other algae, water molds, diatoms

Eukarya, continued

	Protozoa	Fungi	Plantae	Animalia
Characteristics	eukaryotic cells	eukaryotic cells	eukaryotic cells	eukaryotic cells
Kingdom	 Protozoa	 Fungi	 Plantae	 Animalia
Defining characteristics	- animal-like; motile as adults; covered by a membrane called a pellicle - unicellular or colonial - heterotrophic, a few autotrophic	- cell walls made of chitin - unicellular, with multicellular stage during reproduction; may form colonies - heterotrophic	- cell walls made of cellulose - multicellular, with true tissues and organs - autotrophic	- no cell walls - multicellular, with true tissues and organs - heterotrophic
Example	euglenas, amoebas, <i>Plasmodium</i> (causes malaria)	mushrooms, mildew, truffles, yeast	trees, ferns, flowering plants, mosses	sand dollars, sponges, worms, fish, reptiles, birds, mammals

Working With the Taxa

The eight taxa given above are sometimes divided and given the prefix *sub-* or combined with the prefix *super-*. For example, the phylum Chordata is divided into a subphylum for vertebrates and a subphylum for invertebrates. The four orders of stingrays and sawfish are often combined into one superorder.



11-2

The royal starfish (above) and two-spined sea star (below)—two species in the same genus



Carl Woese, an American microbiologist, made an interesting discovery—organisms that looked like bacteria but had a completely different kind of RNA in their ribosomes. He named them *archaea* (s. archaean), and his work led not only to a new kingdom but to a new taxon higher than a kingdom—the domain—to give genetic differences a place in the hierarchy.

The model continued to change to fit what biologists observed in the world. In the 1990s, British biologist Tom Cavalier-Smith suggested that the protist kingdom, which contained both autotrophic and heterotrophic organisms, be split in two to create a seven-kingdom system.

In the future, the seven-kingdom system may turn into an eight- or nine-kingdom system. Or there could be an entirely new model that scientists use to classify organisms. No system of taxonomy is perfect. The goal is simply to develop a workable model with categories that fit the creatures that we observe in the world so that we may better understand and manage them.

SPECIES

As you discovered in Chapter 10, the term *species* is hard to define. One definition states that a species is a group of organisms that look the same and have the same structure. In Figure 11-2, it's easy to see why the royal starfish (*Astropecten articulatus*) is a separate species from the two-spined sea star (*Astropecten duplicatus*)—they share many characteristics, but they look very different from each other. But the two-spined sea star and the sand sea star (*Astropecten irregularis*, not shown) are two *different* species. Though they look almost exactly alike, they live in two different places—one in the Caribbean Sea, and the other in the Mediterranean Sea. Also, each arm on a two-spined sea star has a pair of spines; sand sea stars don't have these. And that's enough to make these two different species.

Another definition of a species refers to a group of organisms that can produce fertile offspring. But there are many species that can breed with other species, such as macaws. The Harlequin macaw is a product of two species, the blue-and-gold macaw (*Ara ararauna*) and the green-winged macaw (*Ara chloroptera*). The Catalina macaw is also a hybrid produced by a blue-and-gold macaw and a scarlet macaw (*Ara macao*). Hybrid Harlequins and Catalinas can mate to produce Maui sunrise macaws.

Clearly, no definition of *species* can fully describe the distinctions between living things because there are many exceptions to every definition. But organisms are still divided into species because it's convenient for people who seek to organize and understand creation.

11-3

Many macaws have genes from different species of macaws (genus *Ara*).



CASE STUDY: STAR-NOSED NUISANCE



Your dad grits his teeth and sighs loudly as he surveys the pond in the backyard. You look out toward the pond to see clusters of dirt mounds, “Mole hills,” he mutters. He calls an exterminator, who suggests trapping the moles and moving them. He also talks to the neighbors, who have poisoned their moles in the past.

You just learned in your biology class that there are several species of moles in the United States. The most common is the eastern mole (*Scalopus aquaticus*). Another species, which is considered endangered in your state, is the star-nosed mole (*Condylura cristata*). Equipped with your newly found mole knowledge, you ask your dad if it would be okay to trap the moles instead of poison them so that you can see what type they are. He agrees, so the exterminator comes out to set the traps.

11.4

Scalopus aquaticus, the eastern mole (right); *Condylura cristata*, the star-nosed mole (above)

The next morning, you and your dad go outside to check the traps, and one of them has caught something. Your dad pulls the trap out of the ground to see what's inside. “What's wrong with its nose?” he asks. You peer into the trap and quickly identify it as a star-nosed mole. Your dad contacts the exterminator and tells him what was in the trap. Surprised, the exterminator heads to your house to pick up the captive mole. “Good thing you didn't kill it,” the exterminator says. “There's a \$500 fine for killing star-nosed moles around here.” He takes it to a wildlife refuge, where it will be free to tunnel.

Think through these questions.

1. Moles are attracted to sources of water and wet soil that's full of earthworms, grubs, and other insect larvae. Why were moles attracted to the backyard?
2. How did knowing the difference between two species of moles show good stewardship?
3. After the neighbors poisoned their moles, they noticed that the leaves of all their garden plants were being eaten by insects. Why do you think this happened?



11.3 NAMING ORGANISMS

What's the difference between coriander seeds found in curry and cilantro leaves found in salsa? Nothing—they come from the same plant! This plant, popular for its strong, citrusy flavor, also goes by the names Chinese parsley, Mexican parsley, dhanian, and kothmir. So how does anyone know what plant they're eating?

In 1735, Swedish botanist Carolus Linnaeus came up with a solution to that problem. He invented a system, called **binomial nomenclature**, in which an organism would be assigned a genus name and a species name. Linnaeus chose Latin, the language of ancient Italy, for his system because Latin is a dead language. Living languages, like the language that you speak, change over time, and Linnaeus was looking for a language that was more stable. Latin is also a very descriptive language used by scholars. Linnaeus wanted a language that would never change, that could describe every organism discovered, and that was already familiar to people.



11.3

Though people around the world disagree on cilantro's common name, everyone accepts its scientific name—*Coriandrum sativum*.



Clydesdale
(*Equus caballus*)



American saddle horse
(*Equus caballus*)



Mountain zebra
(*Equus zebra*)



Donkey
(*Equus asinus*)



Onager
(*Equus hemionus*)

11-6

The *Equus* genus contains several species. Many of those species, such as *Equus caballus*, have a lot of variety.

The genus-species name of an organism is its **scientific name**. A scientific name is always printed in italics (or underlined if it's handwritten). The first part of the name is the genus name, which is capitalized. The second part of the name, the species name, is lowercased. For example, the scientific name of the plant that produces coriander seeds and cilantro leaves is *Coriandrum sativum*. *Coriandrum* is the plant's genus and is what coriander was called in ancient Italy, and *sativum* is its species and means "cultivated" in Latin. If there's a lot of diversity within a species, then that species may be divided into *varieties*. All dogs are part of the same species, but there are hundreds of varieties—Siberian huskies, bulldogs, corgis, cocker spaniels, and so on.

11A REVIEW QUESTIONS

- How does taxonomy help people fulfill the Creation Mandate?
- Bolocerooides daphneae* was a type of sea anemone discovered in 2006. But in 2014, it was reclassified into a new family separate from sea anemones and renamed *Relicanthus daphneae*. What does this tell you about the nature of taxonomy?
- Which taxon has more species in it: a class or a family?
- In Table 11-1, the reef octopus and sugar glider are classified differently beginning with which taxon?
- Why was the domain added as a taxon?
- Create a timeline that shows the progression from two kingdoms to seven. Include the name of each kingdom, the reason why each kingdom was created, and one defining characteristic that sets each kingdom apart from the others.
- Give three reasons why Linnaeus chose Latin to create scientific names instead of his native Swedish language.
- Which is the correct way to write the scientific name for a moose?
 - alces Americanus*
 - Alces Americanus
 - Alces americanus*
 - Alces americanus

UNITY AND DIVERSITY

How is classification used to support evolutionary theory?

11.4 CHANGING RELATIONSHIPS

The reason that organisms are classified together or separately is usually obvious. Birds are grouped together because they're warm-blooded, have feathers, and lay eggs. Reptiles are grouped together because they're cold-blooded, have scaly skin, and typically lay eggs. So whenever you see a parrot or an eagle, you immediately recognize it as a bird.

But what if someone told you that when you think of an alligator, you should think *bird*? That's what many evolutionists are proposing. The field of **systematics** is the science of classification. Evolutionists engaging in systematics try to piece together the evolutionary relationships between both living and extinct organisms. The idea that birds evolved from reptiles came out of systematics.

Systematics has two sides: **phylogeny**, which deals with constructing the evolutionary history of organisms, and **cladistics**, which is the re-classifying of organisms according to their evolutionary history. For centuries, scientists compared the anatomy and embryos of organisms to determine their evolutionary relationships (see Chapter 10, pages 182-93). Currently, genetics and biochemistry (the study of the chemical processes and products of organisms) are the foundation of evolutionary classification.

Though supporting evolution is the main goal of systematics, scientists have made useful discoveries with genetics as their guide to classification. For example, one genetic difference discovered between domains Archaea and Bacteria is that they react differently to antibiotics, an important fact for physicians as they treat patients with archaean infections. Also, genetics can help us classify organisms that have been difficult to classify in the past, such as pandas. Scientists have always debated whether pandas (*Ailuropoda melanoleuca*) should be classified in the bear family (Ursidae) or the raccoon family (Procyonidae). But a study of the panda genome revealed that they are a type of bear.

But overall, scientists use classification to try to establish evolutionary relationships—leaving its original intent to organize the information of living things in a useful way. So is it scientifically useful to classify birds with reptiles, or is it just a way for scientists to interpret data in a way that supports their worldview?

11B Questions

- » What is the classification model used for today?
- » How does worldview affect the way people classify organisms?



11-7

Evolutionists look for similarities between organisms that can lead to classifications that seem forced rather than useful. Relating reptiles with frills like this frilled lizard (*Chlamydosaurus kingii*) to birds with feathers could fall into this category.

phylogeny (fy LOJ i nee): phylo- (Gk.—class, group) + -geny (Gk.—origin)

cladistics: clad- (Gk.—branch) + -istics (Gk.—specialized study)

11-8

By studying the panda's genes, scientists were able to classify giant pandas (*Ailuropoda melanoleuca*) as a type of bear.





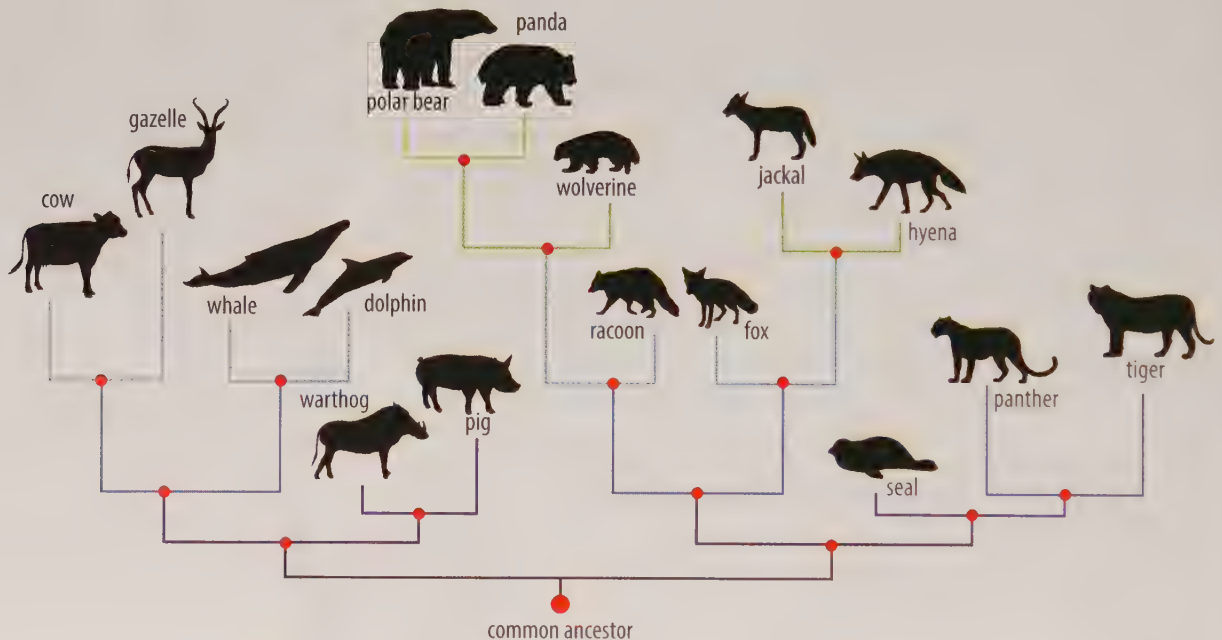
11-9

Instead of classifying this *Dinohippus* fossil as an extinct type of horse, evolutionists classify it as the horse's ancestor—the creature that evolved into a horse.

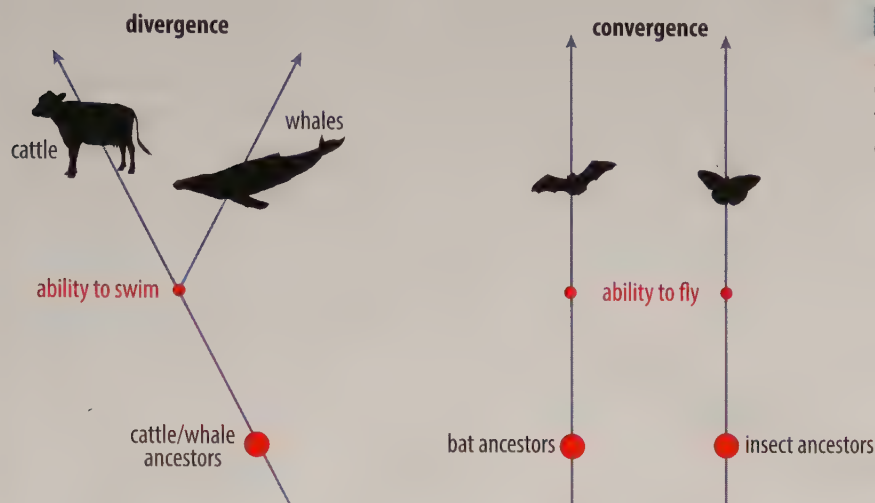
11.5 CLASSIFICATION AND A SECULAR WORLDVIEW

Traditionally, when a biologist discovers a new creature, he compares it to other similar creatures, examining the creature's habits and structure to figure out which taxon it belongs in. Charles Darwin, in his book *On the Origin of Species*, described another way to classify living things. He felt that it wasn't enough to sort and group living things into taxa; he wanted to group them according to their evolutionary history. To do that, he drew a **phylogenetic tree**, often called a *tree of life*, which shows the supposed evolutionary relationships between groups of organisms (see Chapter 10, page 192). These trees map out relationships not only between living organisms but also between living and extinct organisms, creating a timeline of how a simple organism might have evolved into a complex one.

Biologists continue to use phylogenetic trees and have created thousands of them, each one unique because biologists disagree on what they think organisms' evolutionary ancestors are. Each tree is broken up into **clades**—branches of a phylogenetic tree that include all the descendants of an evolutionary ancestor. Look at the clade below, which shows how some scientists believe certain mammals are related.



But why are whales and dolphins so far away from seals in this clade? Evolutionists explain this kind of relationship as **convergence**, the process of two dissimilar species evolving the same derived trait. According to evolutionary theory, convergence is the reason that unrelated species like bats, birds, and insects can all fly—they evolved the ability to fly independently.



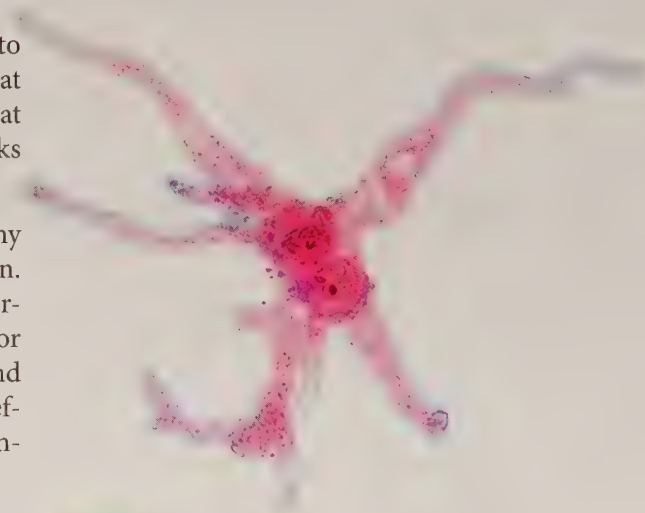
11-10

According to evolutionary theory, derived traits can lead to divergence in related organisms, or they can evolve independently in unrelated organisms in convergence.

GENETICS IN CLASSIFICATION

Classifying an organism using its DNA and proteins can lead to strange connections. In 2013, researchers studying the genes of great white sharks found that sharks produce a lot of the same proteins that humans produce. This led the researchers to conclude that sharks must be closer relatives of humans than previously thought.

So far, comparing the DNA of different organisms has led to many classifications that don't seem to make sense to the average person. Sometimes scientists get conflicting results when they compare different genes, leading to subjective interpretations of classification. For example, scientists group snakes with tuna, penguins with turtles, and rabbits with pigs because they have genes that are similar, all in an effort to unite organisms with completely different genomes by constructing an evolutionary history for them.



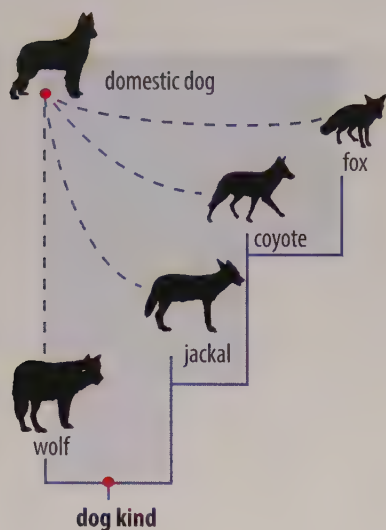
11-11

Some of the simplest organisms, such as a single-celled amoeba, have much more DNA than humans have and also have a more complex gene expression. This information combined with a naturalistic worldview may one day lead scientists to classify amoebas closer to humans on the tree of life.

11.6 CLASSIFICATION AND A BIBLICAL WORLDVIEW

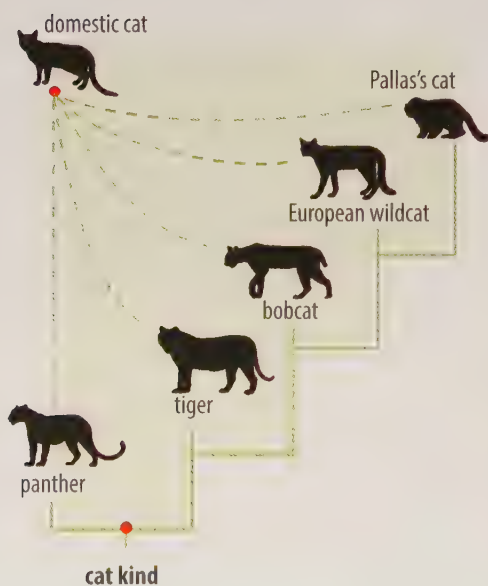
Taxonomy and classification are man-made models designed to help us organize life on the earth. But every model is influenced by a worldview. Though genetics is being used to support a naturalistic, evolutionary view of how life came to exist, it can also be used to support a biblical view.

A view of classification that seeks to group living things in a biblical and more logical and straightforward way is *baraminology*—looking at life on the basis of created kinds. We briefly mentioned this field of study in Chapter 10. Baraminologists use both genetics and physical



features to figure out which species belong within a kind. For example, if you didn't know anything about dogs, you may not think that a tiny Chihuahua and a huge St. Bernard were part of the same dog kind, especially since they can't reproduce naturally. But after studying their DNA, their structure, and their behavior, you would realize that they're both dogs.

The potential for great genetic diversity isn't evidence for evolution; it's a sign that God included a lot of information in the cells of each of His creatures. That information continues to reveal itself in the form of new species and varieties. But the kinds that God created in the beginning remain the same—the dog kind didn't evolve from any other kind. Baraminologists represent this idea with an *orchard of life*, which shows the special creation of each kind and the species that arise within each kind. The diagram below shows how the mammals from an evolutionary clade would be grouped according to their kind.



From a straightforward reading of Genesis 1, we can conclude that each group of common ancestors—the first of each kind—was created by God just a few thousand years ago. God records in Genesis 1:11–12 that He created several kinds of plants, specifying that they would continue to reproduce after their kind. In Genesis 1:21, 24–25, the Bible says the same about the different kinds of animals. That means that the first pigs God created produced a variety of pigs in a short amount of time; whales didn't evolve from the pig kind over millions of years as evolutionists suggest.

On the basis of a biblical worldview, divergence occurs only within a kind. Look at the example trees of biblical kinds. The original cats that were created diverged into a variety of cat species. God not only created each kind with an amazing capacity for genetic diversity, He also made speciation a speedy process. We see today that new species within a kind can appear very quickly. But we don't see evidence of a species, such as a butterfly, diverging into a completely different kind of creature, such as a bat.

What about convergence? The same trait appearing in very different creatures is evidence of design—a Designer chose to give certain traits, such as the ability to fly, to a wide array of organisms so that they could thrive in His world.

Because someone with a biblical worldview knows where life on the earth came from, he can view organisms in a straightforward, organized way, using the taxonomy that scientists around the world use but having a biblical understanding of where the great variety that we observe comes from. Someone with a naturalistic worldview believes that the origin of life is an evolutionary mystery, so he sees classification as a way to figure it out, distracting him from one of the tasks that God gave to all people—naming, cataloging, and wisely managing His creatures.



11-12

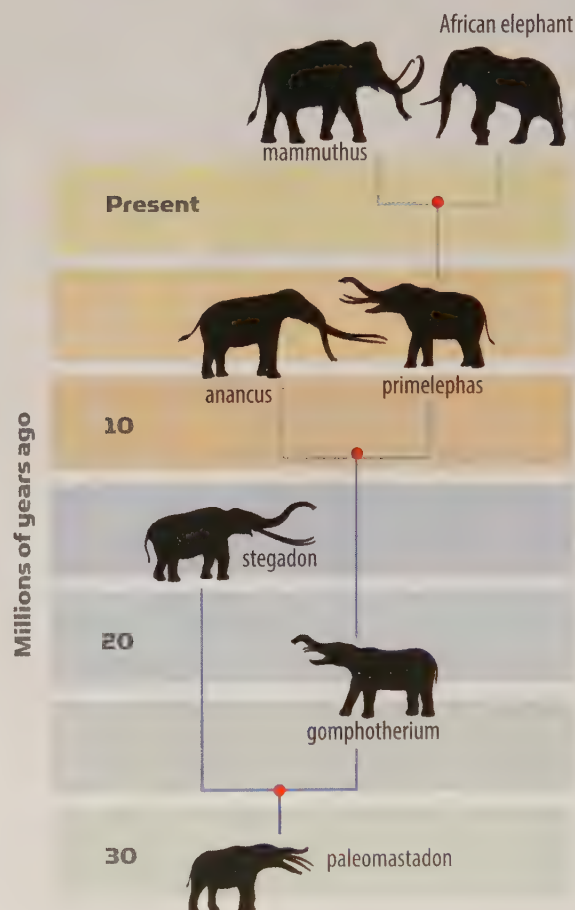
In just a few decades, scientists have observed the Ecuadorian butterfly splitting into two species—one white and one yellow.

11B REVIEW QUESTIONS

- How are organisms classified differently today than they were in the past?
- What two areas of study are the foundation for today's evolutionary classification?
- How is traditional classification different from today's classification? How are they the same?
- Pliohippus*, an extinct genus that evolutionists say lived 15 million years ago, was once thought to be the common ancestor of horses, zebras, and donkeys. But after studying the fossils of several extinct genera, researchers now say that horses, zebras, and donkeys arose from a different common ancestor, *Dinohippus*, which lived 7 million years ago. How does worldview play a part in the researchers' decision after they studied the fossils?
- What is the difference between divergence and convergence?

Use the clad diagram on the right to answer Questions 6–8.

- According to a naturalistic worldview, which animal is the evolutionary ancestor to all the other animals? Which three animals diverged and didn't continue to evolve into modern-day elephants?
- According to a biblical worldview, how should the three divergent animals be classified?
- According to a straightforward interpretation of Genesis 1, how long did it take for the first created kind of elephant to produce the variety of elephants that we observe today? How does this timeline compare to an evolutionary one?



REVIEW QUESTIONS

T Key Terms	
taxonomy	207
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domain	208
kingdom	208
phylum	208
class	208
order	208
family	208
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scientific name	212
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phylogenetic tree	214
clade	214
divergence	214
derived trait	214
convergence	215

CONCEPT REVIEW

1. What is the purpose of classification? How is this purpose in line with fulfilling the Creation Mandate?
2. Using Table 11-2, describe one difference between kingdom Chromista and kingdom Plantae.
3. Which taxon includes both plants and animals?
4. What are two possible definitions for *species*? Why are these definitions not very accurate?
5. Why would the English language not be a good choice for scientific names?
6. A newly discovered mollusk has the species name "harlingae" and the genus name "ittibitium." Write the scientific name for this mollusk, using the correct form.
7. Do some research to find out why *Papaver somniferum*, a species of poppy, is illegal to grow in Canada. Why would it be important to be able to identify this plant?
8. Mention two ways that genetics can be helpful for classification.
9. A paleontologist finds a fossil that has the body of a bird but the head of a lizard. He decides that this creature must have evolved from dinosaurs and is the common ancestor of birds. He then gives the creature the genus name *Protoavis*, which means "first bird," and includes it in class Dinosauria to show its evolutionary relationship to dinosaurs. Which part of this scenario is phylogeny? Which part is cladistics?
10. A seal sharing an ancestor with a panda is part of a(n) _____ worldview, while a seal sharing an ancestor with other seals is part of a(n) _____ worldview.
11. Consider the phylogenetic tree on page 214. Which part of the tree do you think creationists could agree with? Which part could they not agree with? Explain your answers.
12. Why is it difficult to classify organisms using their DNA?
13. Frogs and mice look nothing alike, are genetically very different, and live in completely different environments. Yet evolutionists believe that they both descended from a common ancestor. What would a creationist believe about the ancestry of frogs and mice?

TRUE OR FALSE

14. As more information about an organism is gathered, its classification may change.
15. An order contains many different classes.
16. There can be a lot of variety within one species.
17. Phylogeny creates an evolutionary history for an organism. Cladistics uses that history to reclassify the organism.
18. Systematics is based on data, while baraminology is based on worldview.
19. According to evolutionary theory, a derived trait can lead to a completely new type of animal.
20. There is no place for genetics in baraminology.
21. Baraminology is not a perfect system of classification.

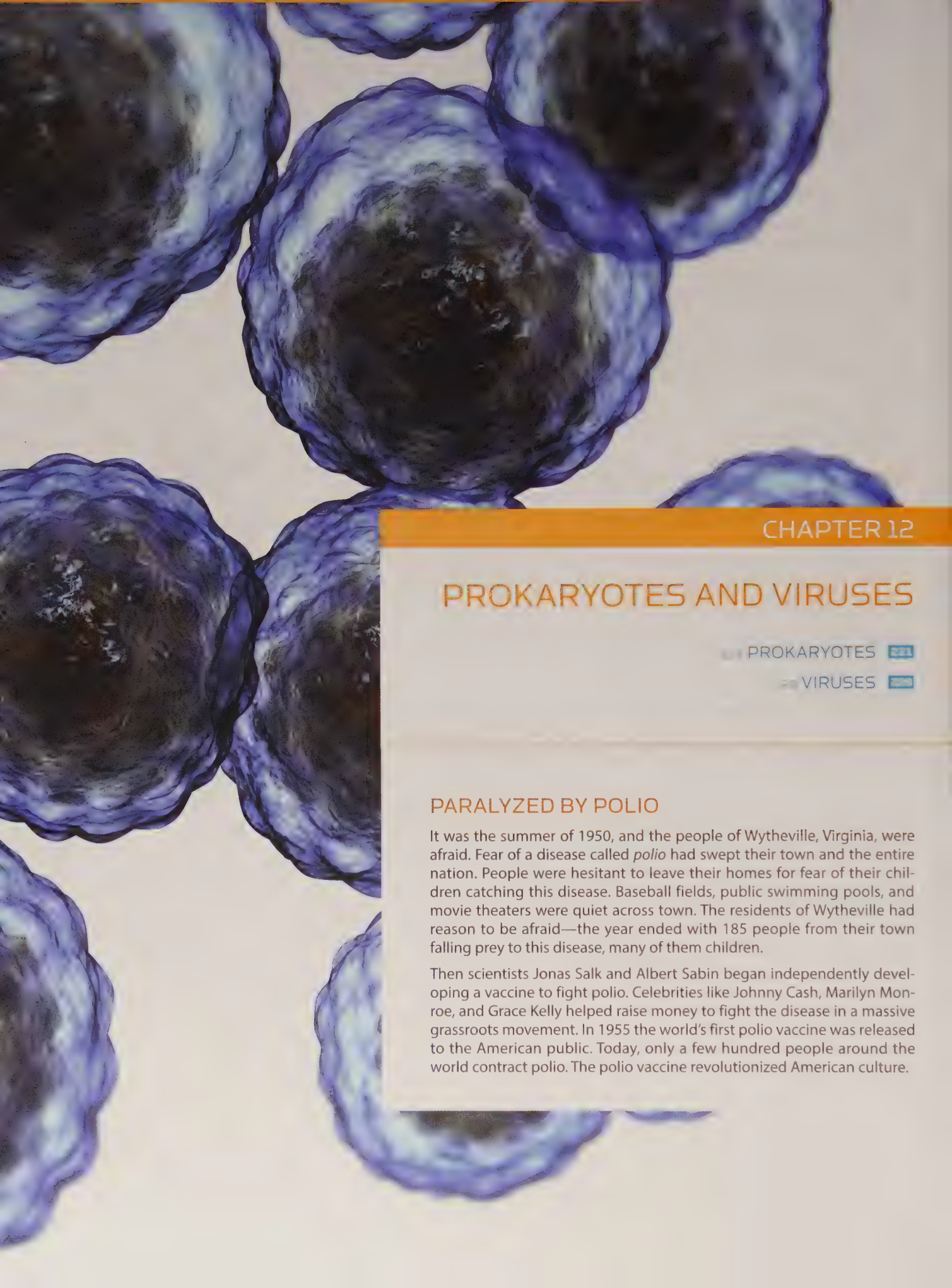
CRITICAL THINKING

22. Look online to find each item: the scientific name for the Ohio buckeye, the common name for *Macropus rufus*, the family that jewel beetles belong to, and the common name for organisms in the genus *Daucus*.
23. Potatoes (*Solanum tuberosum*) used in agriculture are usually produced asexually, so they are genetically identical. From 1845 to 1852, the Great Famine in Ireland was partly caused by a microbe that killed potatoes that were genetically identical. How could a problem like this be avoided in the future?
24. How would you respond to the statement, "Speciation is evidence for evolution"?
25. On the imaginary island of Cornuba, all the seeds are the same size and have hard shells, so natural selection favors the birds with beaks that are the same size. It also favors the insects that have beak-like mouthparts. On the nearby island of Sealey, seeds are either big or small, leading to birds and insects with either big or small beaks and mouthparts. The birds on both islands were once considered one species, and the insects were too, but now they're divided into three species each. Discuss the reasons why someone with a naturalistic worldview and someone with a biblical worldview would divide these species.



11-13

A jewel beetle



CHAPTER 12

PROKARYOTES AND VIRUSES

PROKARYOTES 221

VIRUSES 200

PARALYZED BY POLIO

It was the summer of 1950, and the people of Wytheville, Virginia, were afraid. Fear of a disease called *polio* had swept their town and the entire nation. People were hesitant to leave their homes for fear of their children catching this disease. Baseball fields, public swimming pools, and movie theaters were quiet across town. The residents of Wytheville had reason to be afraid—the year ended with 185 people from their town falling prey to this disease, many of them children.

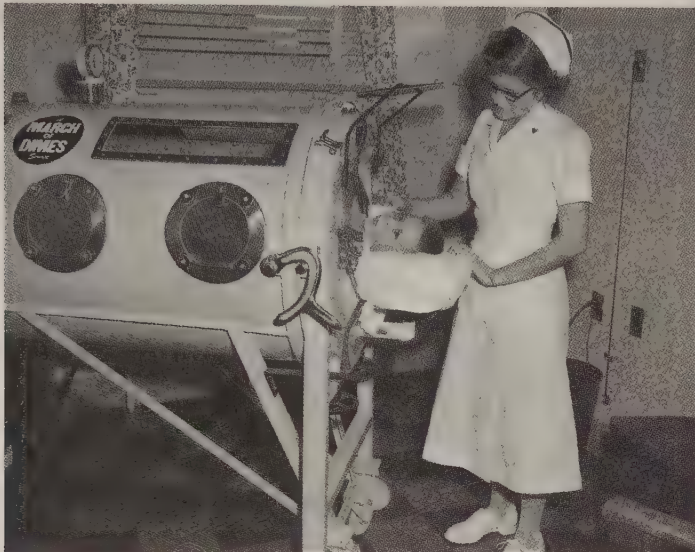
Then scientists Jonas Salk and Albert Sabin began independently developing a vaccine to fight polio. Celebrities like Johnny Cash, Marilyn Monroe, and Grace Kelly helped raise money to fight the disease in a massive grassroots movement. In 1955 the world's first polio vaccine was released to the American public. Today, only a few hundred people around the world contract polio. The polio vaccine revolutionized American culture.

PROKARYOTES

How do prokaryotes live and function?

12.1 DOMAIN ARCHAEA

The world under the microscope greatly affects our world. Diseases like polio are caused by *microbes*, microscopic organisms. Some people that develop the poliovirus infection escape with a mere fever and headache. Others are left with useless limbs or, worse yet, paralyzed lungs that once required a machine to keep them alive. In the 1950s and '60s, Americans feared it as much as an atomic bomb.



Poliovirus is one member of the microscopic world that affects our health and immunity. This is the world of the prokaryotes, including the domains Archaea and Bacteria. **Archaea** are prokaryotes that can act as decomposers in extreme environments. Though archaea are prokaryotes, they share a lot of characteristics with eukaryotes, such as their methods of replicating RNA and producing energy and the complexity of their polymerase molecules. They used to be classified with bacteria until scientists discovered several key differences between bacteria and archaea.

- » Many archaea are found in extreme environments, such as deep sea hydrothermal vents, acidic springs, volcanoes, and salt mines. Many bacteria are not designed to handle extreme environments.
- » The cell walls of bacteria contain the protein **peptidoglycan**, which protects them and triggers other organisms' immune systems. The cell walls of archaea do not have peptidoglycan. Their cell membranes contain different proteins as well as rubbery *isoprene*, which make them more stable and heat resistant.
- » Transcription and translation cell processes in archaea are different from those in bacteria.

12A Questions

- » How are prokaryotes divided?
- » How do bacteria grow and reproduce?
- » How do bacteria interact with people and the environment?

12-1

Patients with an especially debilitating form of polio that attacked the brain were left with paralyzed lungs. A machine called an *iron lung* helped them breathe, but their quality of life was poor.

From Archaea to You

Evolutionists have adjusted their models of classification to fit evolutionary assumptions that eukaryotic organisms, including humans, may have evolved from archaea. The name itself, *archaea*, was chosen to reflect an evolutionary past—it means “ancient” or “primitive.” But what do the similarities really prove? Archaea don’t look or act like half-evolved eukaryotic cells; they are fully formed and have a vital purpose in the environment, revealing the careful design that’s found in all created things.

EXPLORING ARCHAEA

1 Thermophiles live in hot environments. This *Pyrococcus furiosus* lives on deep sea hydrothermal vents that reach temperatures well above water's boiling point. They die if the temperature falls too far below boiling.

2 Methanogens are the largest group of archaea and, like the *Methanosarcina mazei* below, are found in anaerobic environments like swamps and the intestines of animals and humans. They produce the gas methane.



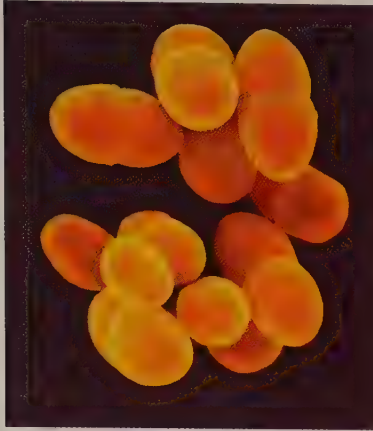
3 Halophiles are found in water that is saltier than the ocean, such as the Great Salt Lake in Utah or the Dead Sea between Israel and Jordan. The halophile *Halobacterium salinarum* is often found in salt-cured ham.

4 Acidophiles prosper in acidic conditions and were the first archaea discovered. *Sulfolobus acidocaldarius*, shown above, thrives in the hot, acidic springs of Yellowstone National Park.

12.2 DOMAIN BACTERIA

Unless you plan to visit extreme environments, you're more likely to encounter bacteria than archaea. Bacteria (s. **bacterium**) are also prokaryotes and often act as decomposers like archaea, breaking down dead materials, such as fallen trees, and returning them to the environment. They also help break down old cells, proteins, and lipids on your skin and in your intestines.

Bacteria are often recognized as having one of three shapes.



coccus



spirillum



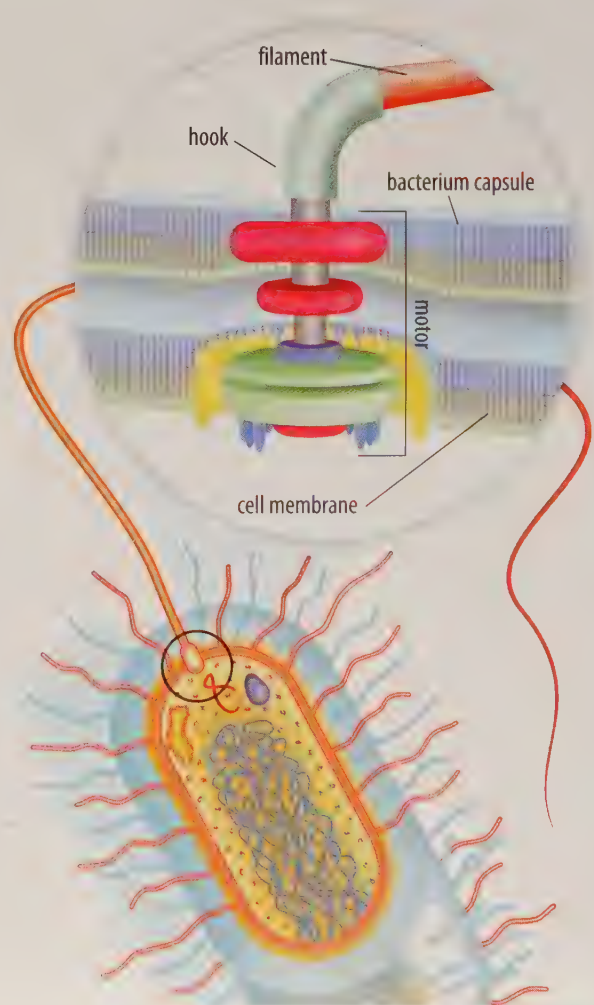
bacillus

Whatever their shape, bacteria share similar structures. They have no organelles that are surrounded by a membrane, and they have peptidoglycan in their cell walls. In a technique called *Gram staining*, scientists use a violet dye to classify bacteria into two groups on the basis of the peptidoglycan in their cell walls. Gram-positive organisms have greater amounts of peptidoglycan and will absorb so much dye that they turn purple. Gram-negative organisms have less peptidoglycan and will absorb only a little dye and turn pink. Certain antibiotics such as *penicillin* are medications that either kill bacteria or slow down their growth. In both cases, antibiotics weaken the bacteria enough for a person's immune system to clear up the infection. They affect Gram-positive organisms by stopping peptidoglycan formation.

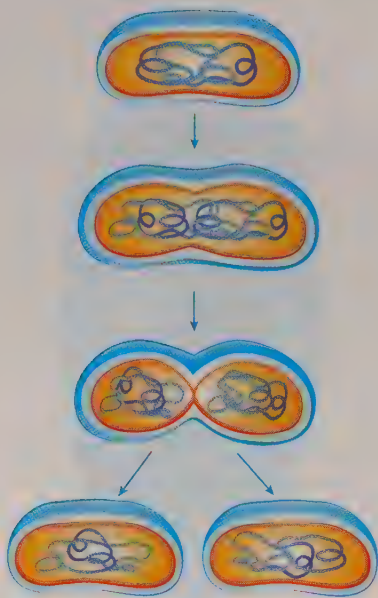
Many bacteria also have **capsules** outside their cell walls, which protect bacteria from drying out. If you've ever had a bacterial respiratory infection like pneumonia, then you may have experienced the protective power of a bacterium's capsule. The capsule makes the bacterial cells slippery and difficult for immune cells to engulf. Antibiotics help the body eliminate bacteria by disrupting the bacteria's metabolism, interfering with its ability to build cell walls. Antibiotics also keep bacterial cells from synthesizing the proteins and enzymes that they need to function. This allows your immune system to jump in and form specific antibodies to remove the bacteria.

DNA can have two forms in a bacterium, both in circular shapes. The DNA region of bacteria, called the **nucleoid**, is made of one circular chromosome. Some bacteria have smaller circular DNA molecules called *plasmids* (see page 158) in addition to their chromosomal DNA. Plasmids are passed between bacteria during reproduction and contain genes that help bacteria during stressful situations. Some plasmids carry antibiotic-resistant genes that allow them to survive when antibiotics are present.

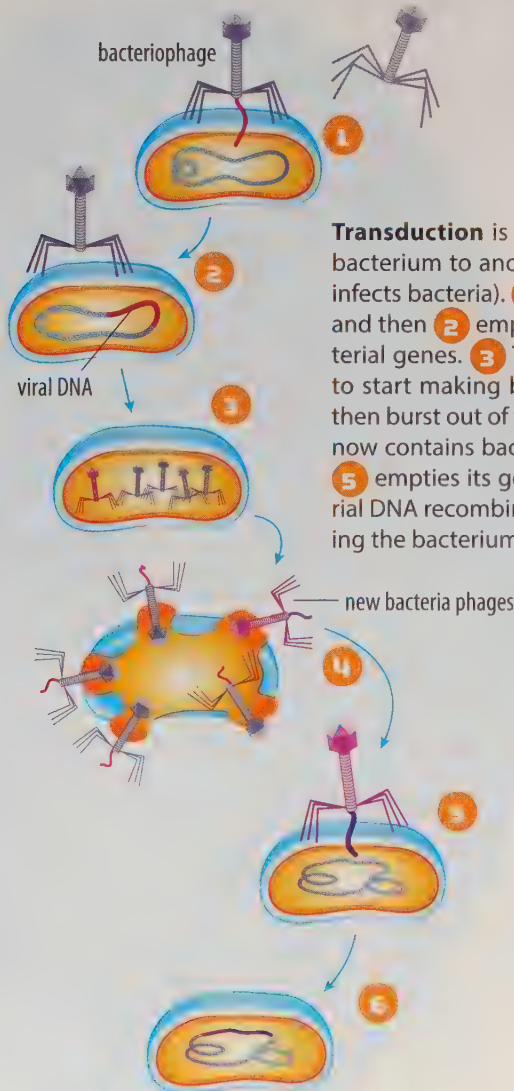
Many bacteria are able to move using a **flagellum**. A bacterial flagellum is typically made of a protein motor, a filament (the propeller-like portion of the flagellum), and a hook (the part that joins the motor to the filament).



12.3 REPRODUCTION AND GENETIC TRANSFER IN BACTERIA

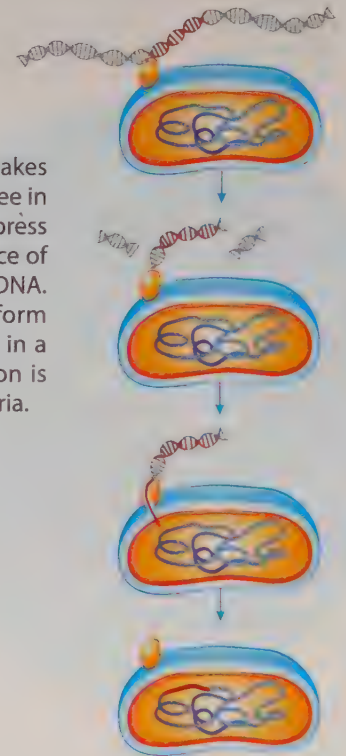


Binary fission, the most common form of reproduction in bacteria, is asexual. The nucleoid replicates and then divides, producing two identical bacterial cells.

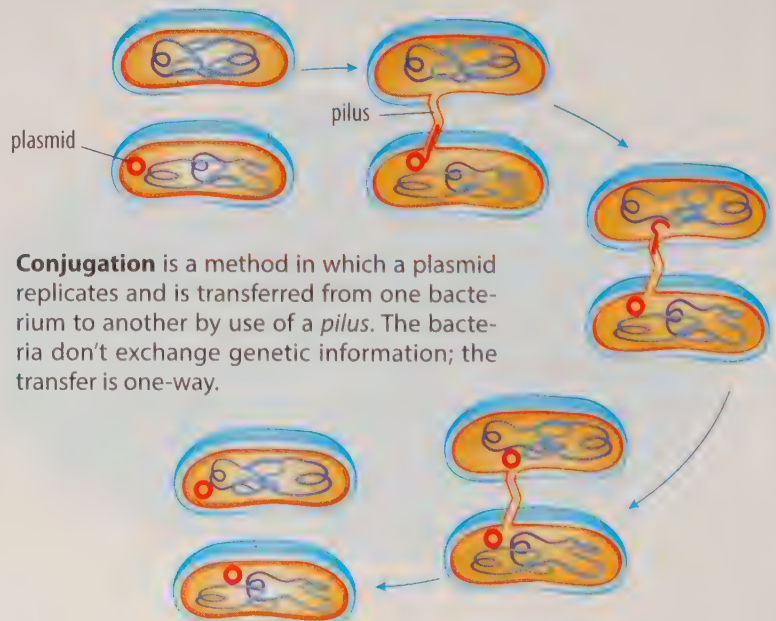


Transduction is the transfer of genetic information from one bacterium to another by way of a **bacteriophage** (a virus that infects bacteria). **1** The bacteriophage attaches to a bacterium and then **2** empties its genetic contents, mixing viral and bacterial genes. **3** The viral genes tell the bacterium's ribosomes to start making bacteriophages. **4** The new bacteriophages then burst out of the bacterium. One of the bacteriophages that now contains bacterial DNA attaches to another bacterium and **5** empties its genetic contents into it. **6** The injected bacterial DNA recombines with the DNA already in the bacterium, giving the bacterium new genes.

Bacteria most often reproduce asexually, multiplying to form genetically identical colonies through a process called *binary fission*. Though bacteria don't have a true form of sexual reproduction, they can exchange their genetic information with neighboring bacteria in three ways—transformation, transduction, and conjugation. In conjugation, a bacterium transfers genetic information to another bacterium, *but it doesn't receive information during the process*.



Transformation occurs when a bacterium takes in a piece of bacterial DNA that is floating free in the environment. The bacteria can then express the traits that are contained in the new piece of DNA if it is incorporated into the bacteria's DNA. For example, a bacterium that couldn't form a capsule before can now do so if it takes in a stray capsule-forming gene. Transformation is known to occur in only a few types of bacteria.



Conjugation is a method in which a plasmid replicates and is transferred from one bacterium to another by use of a *pilus*. The bacteria don't exchange genetic information; the transfer is one-way.

A little bacterium can make a significant impact only when it experiences environmental factors that are favorable to its growth and reproduction. All bacteria require water to grow, though they can survive for short periods without it. Certain bacteria operate best within a specific range of temperatures, usually about 30 °C. For example, the bacteria in your gut do best around normal body temperature (37 °C, 98.6 °F). Though many bacteria can grow in nearly neutral pH conditions, raising or lowering the pH of their environment can kill them. Bacteria also need a food source if they are heterotrophic. Some bacteria grow best without oxygen, some grow best with it, and some can operate in either condition. Others are very picky, operating under a specific set of environmental conditions.

12.4 HOW BACTERIA FUNCTION IN THE ENVIRONMENT

Bacteria are some of the most versatile organisms on the earth. They're in our food, water, air, soil, and even our bodies. Bacteria break down wastes, help plants grow, and keep our digestion balanced. Bacteria are responsible for specific links in the biogeochemical cycles for carbon, nitrogen, and sulfur. Without them the cycles would not continue. Without them, there would be no life on Earth!

GOOD BACTERIA

One of the hottest areas of scientific study today is the **microbiome**—the DNA collected from the microorganisms that live on and in an organism. *Microbiota*—the bacteria of your microbiome—are heterotrophic, obtaining their energy by digesting your food. They remove toxins, prevent disease, synthesize vitamins B12 and K, and absorb many other vitamins and minerals for you.

What you eat determines which bacteria you'll have in your digestive system. Scientists theorize that eating lots of fat and sugar throws off the balance of your gut's bacteria and creates an environment for them to produce toxins and damaging proteins, leading to health problems. Eating a diet high in fiber and vegetables keeps the bacteria in your digestive system on track.

12-2

Bacteria, when combined with other microorganisms and water, can turn a pile of leaves into nutrient-rich compost that will improve the soil for plants.





12-3

Foods like sauerkraut and yogurt (above) contain probiotics, such as *Lactobacillus acidophilus* (inset).

Some antibiotics can destroy good microbes in the digestive system, leaving the body open to harmful microbes called *opportunistic pathogens* that might not cause disease under otherwise normal conditions. Sometimes health-care professionals recommend that people take *probiotics*—microbial cultures that they can ingest—to help prevent the growth of these pathogens and contribute to gut health. Because antibiotics kill normal microbiota, they should be taken only when the body can't fight off a bacterial infection by itself.

Other kinds of helpful bacteria are *decomposers*—bacteria that get their energy from dead and decaying matter. Even if you never raked the leaves out of your backyard, the combination of water and bacteria would break the leaves down, and the nutrients trapped in the leaves would be added back to the soil. But bacteria's usefulness doesn't stop there. Bacteria in the soil can also defend plants against certain fungal infections.

Cyanobacteria are *autotrophic*, getting their energy through photosynthesis. Like decomposers, cyanobacteria help cycle materials such as nitrogen and carbon through the environment. They produce oxygen and are a source of food for many organisms.

BAD BACTERIA

Ever since Adam and Eve fell into sin and brought God's curse on the whole earth, bacteria have also been hurting us. Your microbiome and immune system can't always defend you against every **pathogen**—a substance that causes disease—that comes your way. Pathogens sometimes rely on other organisms for transportation. Organisms that are carriers of pathogens are called *vectors*. There are many more good bacteria in the world than pathogenic ones, but pathogens get more attention.

Table 12-1

Examples of Pathogenic Bacteria

Species	Disease	Always a pathogen?
<i>Streptococcus pyogenes</i>	scarlet fever, pharyngitis (strep throat), necrotizing fasciitis (flesh-eating infection)	yes
<i>Streptococcus pneumoniae</i>	pneumonia	no; can live harmlessly in the nose and throat
<i>Staphylococcus aureus</i>	boils and other skin infections, food poisoning, sinusitis, MRSA	no; can live harmlessly in the respiratory system and on the skin
<i>Listeria monocytogenes</i>	food poisoning, meningitis in newborns	yes
<i>Rickettsia</i> spp.	trench fever, typhus, Rocky Mountain spotted fever	no, though found in many lice, ticks, or mosquitos that act as vectors of bacteria to people
<i>Borrelia burgdorferi</i>	Lyme disease	yes; transmitted to humans by a vector, usually a tick
<i>Mycoplasma</i> spp.	pneumonia	no; can live harmlessly in the respiratory system and urinary tract



12-4

A film of cyanobacteria growing on the surface of the Baltic Sea near Germany

Some bacteria can act as both helpful bacteria and opportunistic pathogens, such as *Escherichia coli* (*E. coli*). They don't cause disease in their normal habitat, but they may in a different environment. Many strains of *E. coli* are helpful, producing vitamin K and fighting off pathogens in the gut. But some strains can cause severe diarrhea and dehydration. And in some cases, a strain of *E. coli* that is helpful in one person can be a pathogen to another. Even a single strain of *E. coli* that is helpful in one organ, such as the large intestine, can be a dangerous pathogen in another part of the body, such as the abdominal cavity.

Cyanobacteria can be bad news as well. Because they typically grow in bodies of water, they can quickly take over a lake or even a section of an ocean, cutting off nutrients to other organisms and producing toxins.

Some bacteria can simply be a nuisance, such as certain strains of *Serratia marcescens*. These airborne bacteria grow and reproduce whenever they enter a moist environment. *Serratia marcescens* appears as a pink smear in your shower and bathroom sink. Since it is airborne, the only way to prevent its pink colonies is to either filter the air or eliminate moisture.



12-5

Serratia marcescens. This is what your shower curtain looks like under a microscope.

12A REVIEW QUESTIONS

1. How are archaea and bacteria similar? How are they different?
2. Which two types of archaea thrive in hot environments?
3. The prefix *staphylo-* means "cluster." What would *Staphylococcus* bacteria look like?
4. Draw a bacterium and label these parts: capsule, cell membrane, cell wall, cytoplasm, flagellum, nucleoid, plasmid, and ribosome.
5. Which type of bacterial genetic replication involves asexual reproduction and is most common in bacteria?
6. How could a harmless bacterium suddenly become capable of producing a dangerous toxin?
7. Why are there bad bacteria in the world?

Use Table 12-1 on the opposite page to answer Questions 8–10.

8. Which two pathogenic bacteria are generally transmitted by a vector?
9. Folliculitis is an inflammation of the hair follicles in skin. One type occurs when your skin is irritated by shaving. Which species of bacterium is responsible for this condition?
10. Thoroughly cooking meat and washing fruits and vegetables can prevent food poisoning from which two pathogens?

VIRUSES

How do viruses reproduce and function?

12B Questions

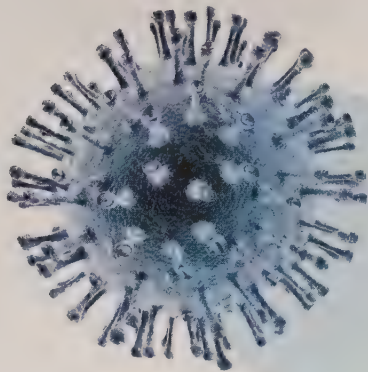
- » How are viruses similar to but different from bacteria?
- » How do viruses grow and reproduce?
- » How do viruses interact with humans and the environment?

12.5 | STRUCTURE OF VIRUSES

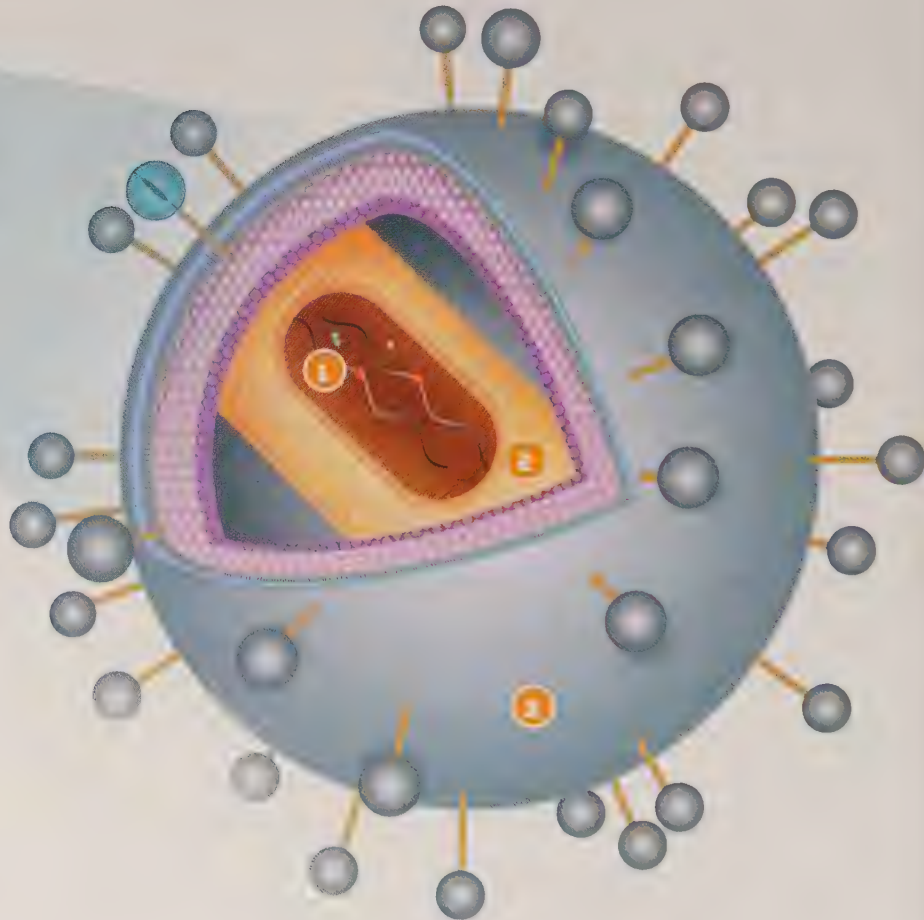
Polio, once a devastating childhood disease, is now close to eradication thanks to the vaccines developed by Jonas Salk and Albert Sabin. Polio is caused by a **virus**, a carrier of genetic information. Scientists are not even sure that these microscopic structures are alive. The poliovirus (*Enterovirus*) causes disease when it spreads from person to person. Sometimes it causes only minor inconvenience, but it can be a serious disease that attacks the central nervous system. It infects healthy cells in the intestines, its RNA core enclosed by a protein coat called a *capsid*.

Like bacteria, viruses can infect living things. But viruses aren't made of cells as bacteria are; they infect a host cell to continue activity. Though viruses aren't cellular, they contain a few parts that resemble structures in cells.

HA flu virus



- 1 nucleic acid**
either DNA or RNA, but never both
- 2 capsid**
protein coat that surrounds the nucleic acid molecule
- 3 envelope**
lipid bilayer that surrounds the capsid; studded with proteins; made from the cell membrane of the cell that it infects; not found in all viruses



VIROIDS AND PRIONS

Viruses are extremely small—the largest virus is about the same size as the smallest bacterium. But there are two pathogens smaller than a virus. **Viroids** are infectious particles that are made of a short, circular strand of RNA. They have no capsid or envelope, but they can still enter cells and disrupt their machinery. Known viroids infect only plants.

Prions are infectious particles made only of abnormal proteins; they contain no genetic information. They are smaller than viroids and tend to infect the brains of animals and people. Prions act as a template for brain proteins, causing healthy proteins to turn into abnormal ones. Prions cause Creutzfeldt-Jakob (KROITZ felt • YAK uhb) disease in humans and bovine spongiform encephalopathy (mad cow disease) in cattle.



12.6 REPRODUCTION IN VIRUSES

You can think of a virus as a flash drive, full of information but unable to do anything unless connected, in the case of a virus, to a living organism. Viruses cannot replicate their DNA, transcribe it into RNA, or translate it into a protein on their own. So how do they pass their genetic information on to other viruses?

Because viruses have no ribosomes and mitochondria for reproduction, they use the few proteins that their genes code for to enter a cell, called a *host*, and hijack its machinery. The virus tells the host cell to begin producing more virus particles. Then the virus tells the cell to *lyse*, or burst open, to flood the surrounding area with new viruses that can infect new host cells.

12-6

In the 1990s, thousands of cattle were killed during an outbreak of mad cow disease in England. Today, governments around the world test cattle extensively to avoid another outbreak of this deadly prion.

To *lyse* is to burst open or destroy a cell. *Lysis* is the process of cell destruction. *Lytic* means “pertaining to the lysis of a cell.”

LYTIC CYCLE

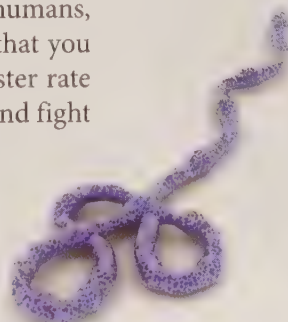
Viruses have a couple of ways that they can enter a cell and use it to produce more viruses. One of those ways is the **lytic cycle**, which is the rapid infection and destruction of a host cell, resulting in more virus particles.

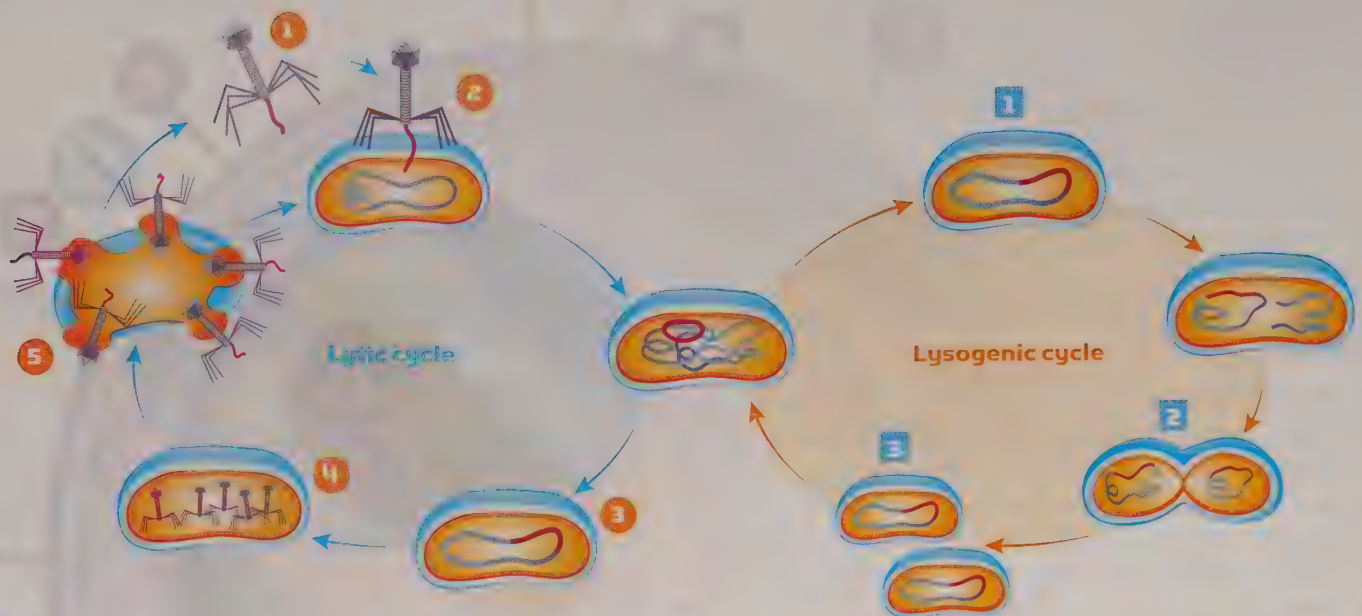
You saw the lytic cycle from a bacterium’s point of view during transduction (p. 224)—a bacteriophage attached to a bacterium, emptied its genetic contents into the bacterium, and forced the bacterium’s organelles to produce virus particles until the bacterium burst open. The lytic cycle also occurs in organisms besides bacteria. In humans, cold and flu viruses attack cells and cause lysis. One reason that you feel tired when you’re sick is that your cells are dying at a faster rate than usual, so your body is working overtime to compensate and fight the virus.

Bacteriophage



Ebola virus





- 1 The virus attaches to a cell.
- 2 The virus secretes enzymes to break through the barriers around the cell before injecting its genetic information.
- 3 The virus's genetic material incorporates itself into the cell's genetic material to produce new viruses.

- 4 The cell is then forced to assemble the virus parts into fully formed viruses.
- 5 When the cell can no longer make viruses, the virus produces more enzymes to cause lysis.

- 1 The virus's genetic material incorporates itself into the cell's genetic material as in the lytic cycle.
- 2 The cell then goes through the normal process of cell division, replicating the virus genes along with its own.
- 3 The cell then goes through the normal process of cell division, replicating the virus genes along with its own.

LYSOGENIC CYCLE

Other viruses will wait inside a cell, sometimes for years, until conditions are right for them to activate. While they're waiting, they go through the **lysogenic cycle**, a process in which a virus infects a cell but does not destroy it, allowing the cell to naturally divide and copy the virus's genetic material.

The lysogenic cycle is related to the second part of bacterial transduction—a bacteriophage emptied its genetic contents into a bacterium, and the bacterium simply incorporated the virus genes into its own. As the bacterial cell divides, virus genes replicate and are passed along through cell division.

Two common viruses in humans that go through the lysogenic cycle are herpes simplex and varicella zoster. Herpes simplex is a virus that can be transmitted by drinking out of someone else's cup or using someone else's lip balm. It then lies dormant in the cells around a person's mouth. Something that throws off the body's homeostasis, such as a lot of stress or a cold, can trigger the virus, which then leaves the lysogenic cycle and begins the lytic cycle. Once this happens, the cells are destroyed, resulting in cold sores. The virus soon returns to the lysogenic cycle in the new cell that it has infected, and the cold sores clear up. However, the viral genes in the host DNA wait for another chance to activate. The virus continues to spread its genes to other cells by host cell division.

Varicella zoster is even more patient than herpes simplex and can lie dormant in nerve cells for decades. Often, the virus is never activated. The infection begins as a lytic one in the form of chickenpox. Once the chickenpox outbreak is gone, the virus enters the lysogenic cycle.

12-71

Some viruses spread their genes quietly during the lysogenic cycle until something triggers the lytic cycle, activating the telltale signs of infection, such as shingles or cold sores (below).



Varicella zoster then reenters the lytic cycle many years later, causing shingles.

Some lysogenic viruses are known as **retroviruses**—viruses that can force a cell to transcribe its RNA into the cell's DNA. Cells usually transcribe DNA into RNA, but retroviruses contain an enzyme called *reverse transcriptase* that reverses the process. The most well-known and well-studied retrovirus is the human immunodeficiency virus, or HIV, which can stay in the lysogenic cycle for many years. If it enters the lytic cycle, it triggers the disease known as acquired immunodeficiency syndrome (AIDS).

12.7 HOW VIRUSES FUNCTION IN THE ENVIRONMENT

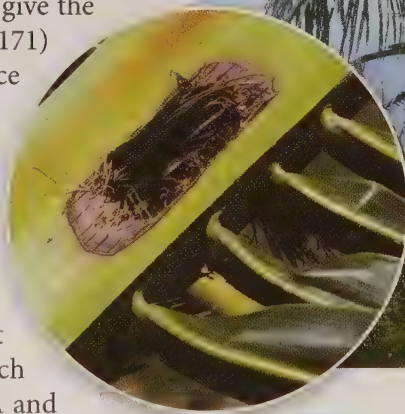
USEFUL VIRUSES

Up until 150 years ago, people didn't know anything about viruses. One of the important contributions of viruses is how they've expanded our knowledge of genetics. Viruses were the first to have their genomes sequenced, unlocking the door to the genomes of living things.

Viruses are also quickly becoming a vital part of medical research and treatment. A virus can have healthy genes inserted into it and then deliver the genes to genetically damaged cells. For example, one virus currently in clinical trials is being used to cure several different types of hereditary blindness. The gene-carrying virus is injected directly into a person's eyes, and the virus inserts genetic material into the DNA to start making the needed proteins to give the person sight. This kind of gene therapy (see page 171) has the potential to cure diseases that were once considered incurable, though there are challenges to overcome to make the benefits of gene therapy long-lasting.

Bacteriophages (p. 224) are increasingly being researched as a new kind of antibiotic. As bacteria become resistant to our current antibiotics, researchers have been working to invent one that contains a bacteria-killing virus, which may help fight against super bacteria like MRSA and drug-resistant tuberculosis. Research has also shown that your microbiota may contain bacteriophages that defend you against pathogenic bacteria.

Viruses are also useful in agriculture. Certain viruses can be sprayed on plants to ward off common plant pests, such as caterpillars, beetles, and even rabbits. And viruses may one day be found in your smartphone. Researchers are working on ways to insert genes in a virus that will allow it to build long carbon molecules. These molecules act like the electrodes in a normal battery, only much smaller and with a much better capacity to hold a charge.



12-8

The holes in the coconut palm shown above were caused by Hawaii's newest invasive species, the coconut rhinoceros beetle (*Oryctes rhinoceros*, below). A pesticide containing a virus has proved to be effective against these destructive beetles.





12-9

Though children in the United States receive the injected poliovirus, many children around the world use the oral vaccine for polio. Pakistan is one of the few countries where the poliovirus still thrives.

HARMFUL VIRUSES

Though viruses have many uses, many more are pathogenic, like the poliovirus. The polio vaccine developed by Jonas Salk in 1951 is still administered today by injection. It uses an inactivated virus that triggers the body to build an immunity, protecting the child from future exposure to poliovirus without actually causing the disease. Albert Sabin's vaccine is also used today. It uses an attenuated or weakened form of the poliovirus that is administered orally to build a child's immunity without causing the disease.

But even today, people in underdeveloped countries get polio, and there is no way to treat them. Until the 1980s, there was no way to directly treat most pathogenic viruses. In 1957, two scientists described a protein called *interferon*. They found that cells produced this protein after they had been infected with a virus.

When the cell was lysed and the virus particles spilled out, the interferon protein was released and signaled surrounding uninfected cells. Interferon signals proteins that block viral replication in newly infected cells.

Interferon has created a surge in modern medicine. Today there are drugs that use this handy protein to treat diseases caused by herpes viruses, HIV, hepatitis viruses, multiple sclerosis, flu viruses, and even cancers. However, compared with antibiotics, there are very few antiviral drugs. It is difficult to find antivirals that are selective for viruses, flexible enough to be effective when viruses mutate, and harmless to their host cells.

But our medical technology can't always keep up with the viruses that are out there. Some viruses seem to appear out of nowhere, decimating a group of people in just a few weeks. Other viruses that were thought to be eradicated through vaccines have made a comeback. These viruses are part of a larger group called *emerging infectious diseases*. One example is the Ebola virus, which emerged in 1976, infecting people in Africa.

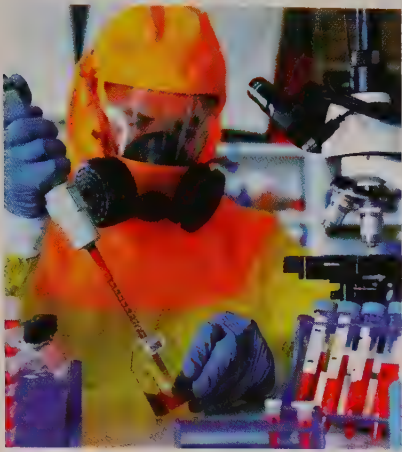


In the 1970s, the first outbreak of the Ebola virus claimed the lives of many people in Africa before it subsided to sporadic cases in the following years. Then in 2014, the virus reemerged in a city where it was harder to contain, leading to the worst Ebola outbreak in history. Unlike the H1N1 flu virus outbreaks in 1918 and 2009, there are no approved vaccines or antiviral treatments for the Ebola virus, so researchers are now seeking a way to fight this emerging disease.

12-10

The 2014 Ebola outbreak began along the edges of a tropical rainforest in remote villages of West Africa. The virus is first transmitted from fruit bats, monkeys, or other animals to a human before it spreads from one human to another.

VIALS OF TERROR



Some of the most well-protected items in our country are not priceless artifacts, jewels, or even people. They're strains of deadly viruses and bacteria, all housed at the Centers for Disease Control and Prevention (CDC) headquarters in Atlanta, Georgia.

Lab technicians at the CDC Labs wear protective suits with air filters when handling

biohazardous materials. Safety and security are foremost on the minds of everyone who works there, yet occasionally something goes wrong—a microbe is mishandled and released, and people die. Why do we not destroy these microbes instead of keeping them to study? Why take the risk that these lethal vials might fall into the wrong hands?

The biggest reason that dangerous bacteria, like anthrax and tuberculosis, and viruses, like smallpox, avian flu, and SARS, are

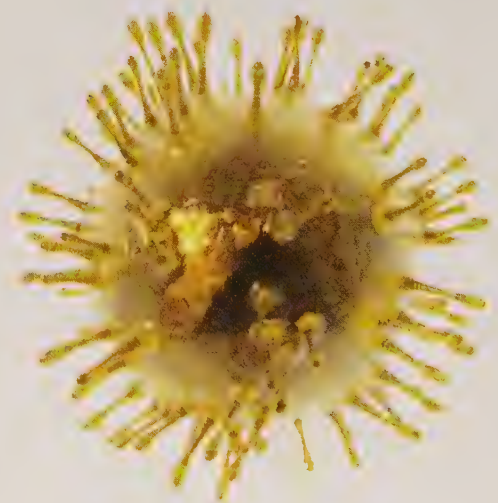
kept alive and accessible is to study them and find defenses against them. Even though it's hazardous, researchers have greatly reduced the risk of diseases like malaria, polio, measles, rabies, tetanus, and influenza because of the tests, vaccines, and treatments that they have invented.

Another reason for keeping these bacteria and viruses around is to combat those who want to turn microbes into weapons. Part of wise stewardship in a fallen world is to prepare for every kind of harmful situation that people may encounter. For example, the bacterium that causes anthrax, *Bacillus anthracis*, has been used by terrorist groups and even disgruntled citizens to wreak havoc. But because of the knowledge gained from studying this bacterium, countries are able to defend against these attacks and treat people who are exposed to anthrax toxins. Some labs, such as the medical center at Wake Forest University, are going a step further. They are using deadly microbes to create antidotes against them.

Labs like the CDC need to keep their bacteria and viruses secure to minimize the damage that they could cause. But researchers also need to learn about them because these microbes aren't just found in labs; they can occur naturally in the environment, and we need to be able to care for God's image bearers when they are affected by the lethal efforts of fallen men.

12B REVIEW QUESTIONS

1. What characteristics of viruses make them seem like living things? What characteristics make them seem nonliving?
2. Draw and label a virus with these parts: nucleic acid, envelope, and capsid.
3. Particles that are similar to viruses but are made only of proteins are called _____.
4. Describe how a virus can duplicate its genetic information and spread.
5. Hepatitis C is a viral infection of the liver that can lie dormant for years before a person ever shows symptoms. While the person has no symptoms, what cycle is the virus in? Once the person begins to show symptoms, what cycle has the virus entered?
6. List three ways that viruses can be useful.
7. You have gone on a mission trip to Ghana in West Africa to help build a new wing on a village clinic. While you're working, you notice that the physicians at the clinic are treating a lot of people with a mysterious illness that no one has seen before. One physician mentioned that he thought it might be Buruli ulcer disease, which is caused by a bacterium and was last seen in Ghana in the 1980s. What kind of disease might this be?
8. Why is it important to study dangerous bacteria and viruses?



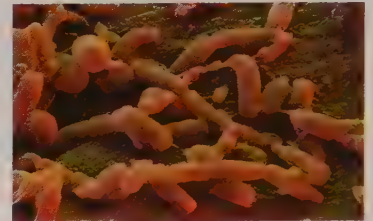
Hepatitis C

REVIEW QUESTIONS

T Key Terms	
archaea	221
peptidoglycan	221
thermophile	222
methanogen	222
halophile	222
acidophile	222
bacterium	222
capsule	223
nucleoid	223
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transduction	224
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virus	228
nucleic acid	228
capsid	228
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viroid	229
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retrovirus	231

CONCEPT REVIEW

1. Create a hierarchy chart relating the following terms: acidophile, archaea, bacillus, bacteria, coccus, halophile, methanogen, prokaryote, spirillum, and thermophile.
2. What shape are the bacteria in the image to the right?
3. Using a Gram stain, a bacterium with a large amount of peptidoglycan will turn a(n) _____ color, and one with little peptidoglycan will turn a(n) _____ color.
4. How does an antibiotic clear up a bacterial infection?
5. What are the three parts of a bacterium's flagellum?
6. What are the two forms that DNA takes in a bacterial cell?
7. What structures do bacteria and viruses have in common?
8. How do bacteria typically reproduce?
9. What is a bacteriophage? What kind of bacterial genetic transfer involves a bacteriophage?
10. List three things that the bacteria of your microbiota do for you.
11. List three things that bacteria do for the environment.
12. Where does a virus get the envelope that surrounds it?
13. How do viruses translate their genetic information into proteins?
14. What is the difference between the lytic and lysogenic cycles?
15. What is the most well-known retrovirus?
16. Name a virus that goes through both the lytic and lysogenic cycles.
17. How might viruses be helpful in the fight against antibiotic-resistant bacteria?
18. The apples on the tree in your yard are being destroyed by codling moth caterpillars, but the apples on your neighbor's tree look perfectly healthy. You notice that your neighbor sprays his tree once a week, but he says he doesn't use chemical pesticides. What might he be using to keep the codling moths away?
19. How does a vaccine work?
20. What protein produced by cells can be used in antiviral drugs?
21. How are deadly microbes and our earthly stewardship related?



TRUE OR FALSE

22. The cell walls of archaea contain peptidoglycan.
23. Archaea can live inside people.
24. Transformation can add a capsule to a bacterium.

25. During conjugation, both bacteria involved receive new genetic information.
26. Good bacteria are part of your microbiome.
27. Bacteria are either good or bad, but not both.
28. Your microbiota contain both bacteria and bacteriophages.
29. Scientists agree that a virus is a carrier of genetic information.
30. Viroids contain no genetic information.
31. A cell that has lysed has been opened and destroyed.
32. When a cell has been infected by a virus but is never lysed, the virus is in the lysogenic cycle.
33. Bacteriophages are being researched as a new kind of antibiotic.

CASE STUDY: TRACKING TUBERCULOSIS

Tuberculosis, often called TB, is a bacterial infection of the lungs that is often fatal if not treated as it attacks and shuts



The lives of two famous authors, Stephen Crane and Emily Brontë, were cut short by tuberculosis.

down a person's lungs. TB became so common in the 1800s that it found its way into literature and popular culture and was romanticized as the disease of artists and authors. But after the advent of antibiotics, better nutrition, and higher standards of hygiene, TB became a manageable disease. Then in the late 1970s, tuberculosis made a resurgence—a strain of antibiotic-resistant TB appeared and began spreading to areas of the world that had been keeping the disease at bay. Today, cases of TB are on the rise in several countries because of drug-resistant strains.

The data on the next page are provided by the Centers for Disease Control and Prevention, showing the number of people in the United States infected with tuberculosis since 1953 and the ratio of people infected per 100,000 people. For example, in a population of 100,000 in 1953, about 53 people would have contracted TB.

CRITICAL THINKING

Use the Case Study above for Questions 34–38.

34. Create a graph that plots the ratio of TB patients per 100,000 people every 5 years, starting with 1953.
35. What does the trend in your graph signify?
36. What happened to the number of TB cases from 1974 to 1975 and from 1988 to 1992?
37. On the same graph that you created in Question 1, plot the ratio of TB patients per 100,000 people from 1973 to 1977 and from 1988 to 1994, using two different colors.
38. Compare the two sets of data on your graph. How does the data for 1973–1977 and 1988–1994 compare with the data from the 1950s and 1960s?

Year	Number of TB cases	Ratio per 100,000 people
1953	84,304	52.6
1958	63,534	36.3
1963	54,042	28.6
1968	42,623	21.1
1973	30,998	14.6
1974	30,122	14.1
1975	33,989	15.7
1976	32,105	14.7
1977	30,145	13.7
1978	28,521	12.8
1983	23,846	10.2
1988	22,436	9.2
1989	23,495	9.5
1990	25,701	10.3
1991	26,283	10.4
1992	26,673	10.4
1993	25,103	9.7
1994	24,205	9.2
1998	18,287	6.6
2003	14,835	5.1
2008	12,895	4.2
2013	9,582	3.0

39. Even though tuberculosis bacteria are getting harder to fight because of their drug resistance, health-care workers and researchers around the world are inventing new ways to diagnose and treat even the most stubborn strains of TB. But these treatments can cost hundreds of thousands of dollars. Because of this, many poor countries in Africa and Southeast Asia have been ravaged by TB. What would be a Christlike response to this situation?

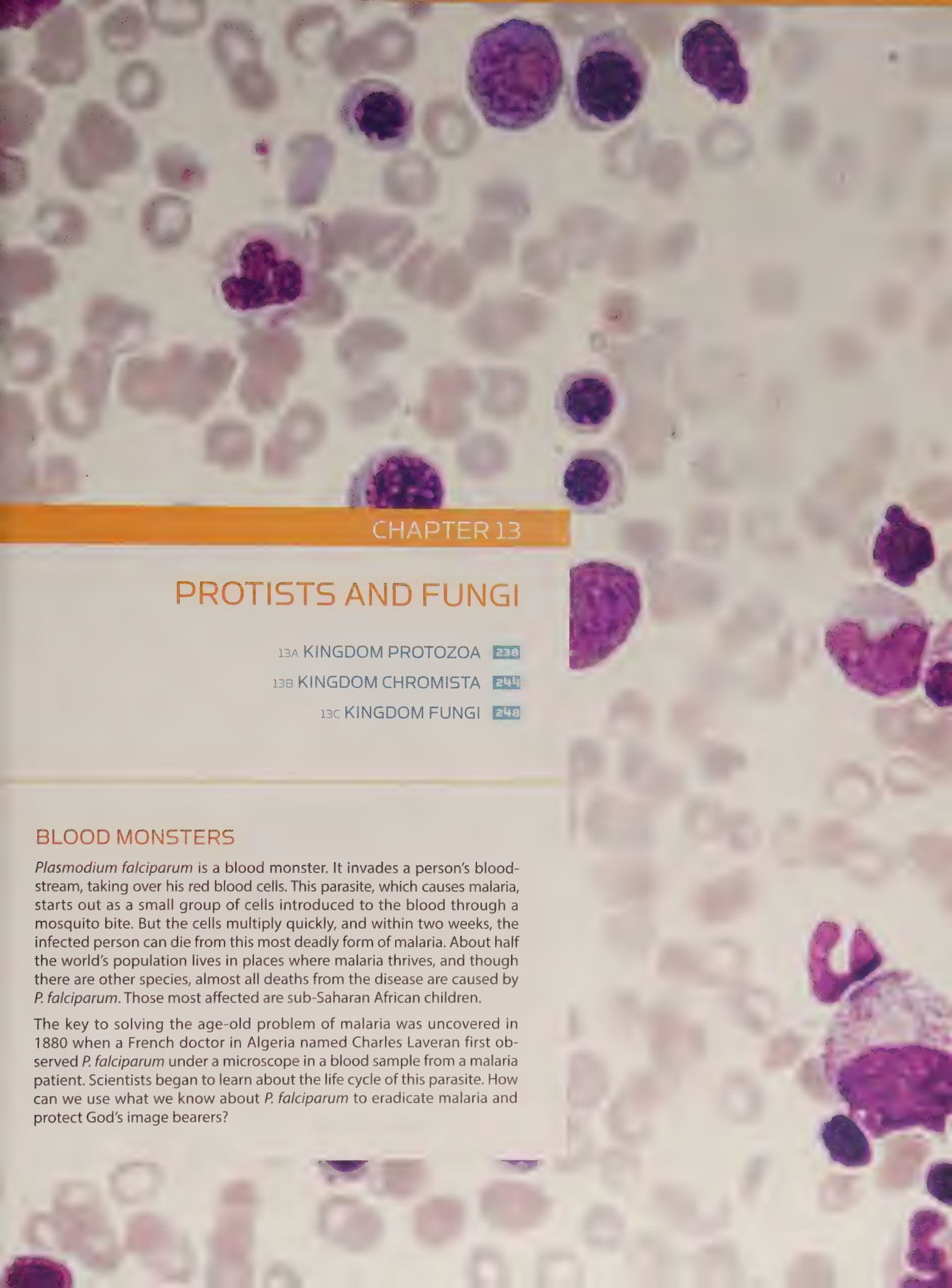
40. In parts of India, tuberculosis is a grave concern. Because of the great number of TB cases there, some physicians prescribe antibiotics to people even if they don't have the disease. Do some research and write a few sentences on how taking antibiotics when they're not needed can lead to drug-resistant strains of tuberculosis.

41. Typhoid fever is a life-threatening disease caused by *Salmonella* bacteria. Infection occurs when a person eats or drinks something that contains the bacteria. Research some ways that typhoid fever can be avoided.

42. Drug-resistant bacteria are often used as evidence of evolution. Does this kind of change in bacteria really show evolution at work? Explain your answer.

43. Suppose you were a scientist who had the goal of developing a new vaccine. As a Christian, why would you do this? What would you need to consider?

44. Considering the attributes of life on pages 6–7, write out an argument for why viruses should be considered either living or nonliving.



CHAPTER 13

PROTISTS AND FUNGI

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13B KINGDOM CHROMISTA 244

13C KINGDOM FUNGI 248

BLOOD MONSTERS

Plasmodium falciparum is a blood monster. It invades a person's bloodstream, taking over his red blood cells. This parasite, which causes malaria, starts out as a small group of cells introduced to the blood through a mosquito bite. But the cells multiply quickly, and within two weeks, the infected person can die from this most deadly form of malaria. About half the world's population lives in places where malaria thrives, and though there are other species, almost all deaths from the disease are caused by *P. falciparum*. Those most affected are sub-Saharan African children.

The key to solving the age-old problem of malaria was uncovered in 1880 when a French doctor in Algeria named Charles Laveran first observed *P. falciparum* under a microscope in a blood sample from a malaria patient. Scientists began to learn about the life cycle of this parasite. How can we use what we know about *P. falciparum* to eradicate malaria and protect God's image bearers?

13A Questions

- » How is kingdom Protozoa distinct from the other kingdoms?
- » How do protozoans grow and reproduce?
- » How can protozoans be useful or harmful to humans and the environment?

KINGDOM PROTOZOA

How do protists live and function?

13.1 CLASSIFYING PROTOZOANS

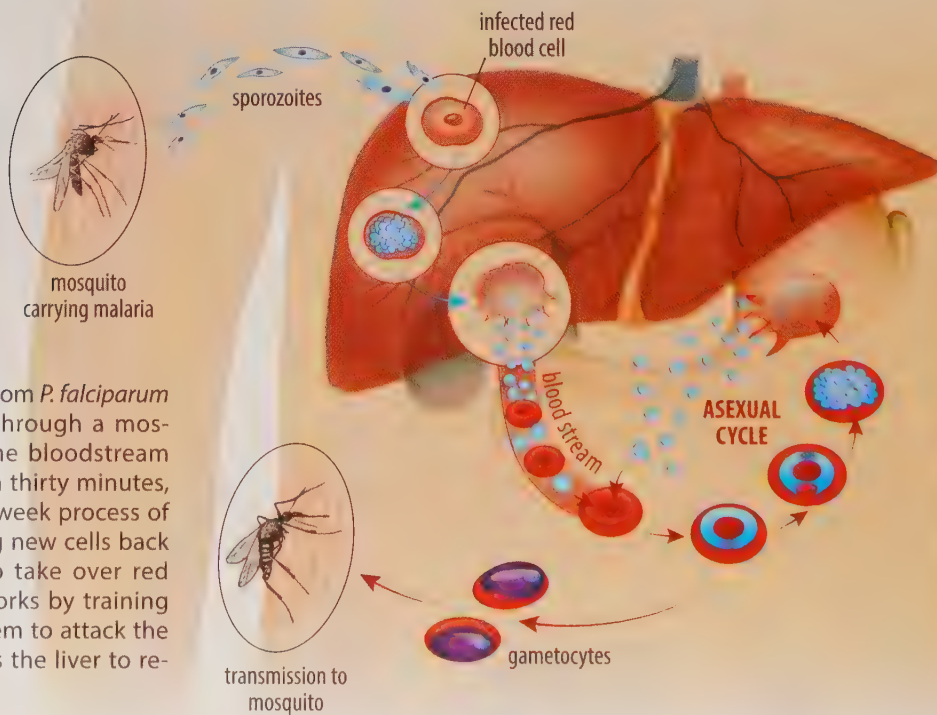
Biologists have probed the microscopic world for centuries to understand, model, and classify microorganisms. Laveran's observations of malaria parasites (see Chapter opener) led to models of how *Plasmodium falciparum* operated and reproduced in the environment of the human body.

In 2015, the very first vaccine for malaria, called *Mosquirix*, or *RTS,S*, was introduced to the world, the first parasite vaccine in history. Billionaires, doctors, and African health agencies teamed up during the thirty-year development of this vaccine to bring help to the neediest people in the world. The vaccine works by taking proteins from the parasite and packaging them up in a protein envelope from a virus. Along with this protein package comes a chemical that boosts the human immune response. The result is that the vaccine helps the human immune system target and kill the malaria parasite. It is about 40% effective in children, and trials have shown that people who do come down with malaria after they get the vaccine have less severe cases. Though *Mosquirix* won't exterminate malaria for good, it is a significant step toward this worthy and biblical goal.



13-1

Children like this one receive the new *Mosquirix* vaccine, which will protect them from malaria.



13-3

Malaria starts when cells from *P. falciparum* enter the bloodstream through a mosquito bite. They leave the bloodstream and enter the liver within thirty minutes, where they begin a two-week process of multiplying and releasing new cells back into the bloodstream to take over red blood cells. *Mosquirix* works by training the human immune system to attack the parasite before it reaches the liver to reproduce.

P. falciparum is one example of a **protist**, a microorganism made of eukaryotic cells. When Dutch biologist Antonie Van Leeuwenhoek observed protists through a microscope he said, “No more pleasant sight has met my eye than this, of so many thousands of living creatures in one small drop of water.” Protists ooze, they propel, they float through their watery environments in the hidden world revealed by the microscope.

The name “protist” comes from an outdated biological kingdom, the kingdom Protista. This kingdom previously served as a kind of catch-all kingdom for organisms that were difficult to classify. Because of genetics and the drive of evolutionists to link classification to the phylogenetic tree, this kingdom has been restructured into several new kingdoms. And classification is constantly changing as scientists get new information about organisms.

Protists are amazingly diverse. Most protists are made of only one cell, but some are made of many cells, forming **colonies**, free-living but related cells of the same kind that interact with each other. Some protist colonies can be large enough to see without a microscope.

Protists are broken up into two kingdoms. Those that are more like animals are grouped in kingdom Protozoa, while those that are more like plants fall into kingdom Chromista (you’ll learn more about them in the next section). Protists that are more like fungi appear in both kingdoms. In general, organisms in kingdom Protozoa are heterotrophs and organisms in kingdom Chromista are autotrophs, although there are many exceptions to this general rule. All protists need water to live and function.

P. falciparum is a protist that is grouped with other animal-like protists in kingdom Protozoa. This kingdom is the first of five kingdoms included in the domain Eukarya. This domain also includes some protists that are more fungus-like. Protists in kingdom Protozoa are referred to as **protozoans**. They are usually *motile*, or able to move, as adults. They can slide around and propel themselves. They are aquatic and often found wherever water abounds—oceans, freshwater ponds, streams, lakes, and even moist soil. They can appear as unicellular organisms or can group in multicellular colonies. Most protozoans are heterotrophs, getting their energy from other organisms, though a few can carry out photosynthesis. Protozoans that are autotrophs are green, while other heterotrophic protozoans come in other colors or are colorless. *Euglena* is autotrophic, containing chloroplasts that make it green. Many heterotrophic protozoans live inside other organisms, carrying out a symbiotic relationship with their host. Some protozoans are parasitic, while others benefit their host organisms. *P. falciparum*, for example, is a *sporozoan*, a protozoan that is parasitic and has no means of locomotion. It relies on its host for movement and nourishment.

protist: protos (Gk.—the very first)

protozoan (pro toh ZOH uhn): protos- (Gk.—first) + -zoia (Gk.—animal)

13.2 STRUCTURE OF PROTOZOANS

13-3

Giardia (*Giardia lamblia*), a protozoan with flagella, lives in contaminated water and can cause diarrhea in humans.

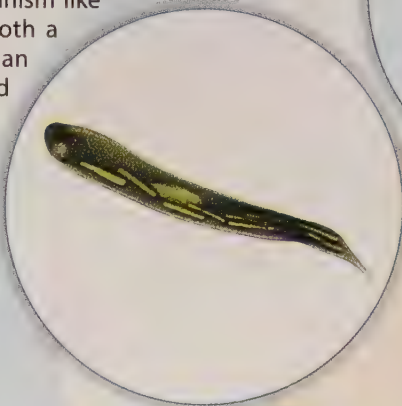


We've seen that many protozoans have the ability to propel themselves. To do this, they must have structures that help them move. Some protozoans have cilia (s. **cilium**), a fringe of hairlike projections that ripple along in rhythmic waves as the protozoan moves. Cilia work in a way that is similar to that of a rowing team on a boat. Some protozoans such as *dinoflagellates* propel themselves with a whip-like structure called a *flagellum* (p. flagella), which acts like a propeller on the back of a motorboat.

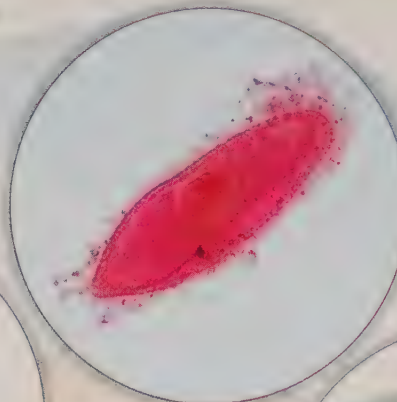
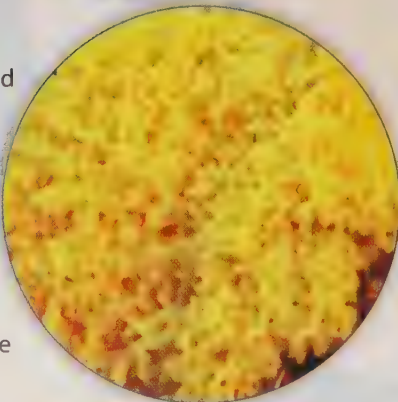
Some protozoans, such as *Amoeba proteus*, have no fixed body shape. To move, they ooze along in what is called *amoeboid movement*. To do this, they develop bulges called pseudopods (s. **pseudopodium**), filled with cytoplasm, that they extend in front of them to pull them along (see Figure 13-4 on the facing page). Amoebas also use pseudopods to engulf their food, forming an enclosure in the cytoplasm called a *food vacuole*. When the food is digested, its nutrients are distributed throughout the cell.

EXPLORING PROTOZOANS

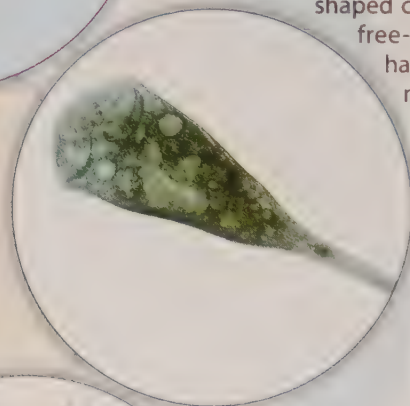
Euglena (*Euglena viridis*, below) is a very common protozoan with a flagellum that lives in fresh and salt water. If the water is calm enough, they can make the surface of a pond appear green. Some euglenas are heterotrophs but also have chloroplasts that enable them to perform photosynthesis. An organism like *Euglena* that is both a heterotroph and an autotroph is called a *mixotroph*.



Dog vomit slime mold (*Fuligo septica*) is a *slime mold* in kingdom Protozoa that consists of one large cell with multiple cell nuclei that form when individual cells merge together. They can get as large as a few square meters.

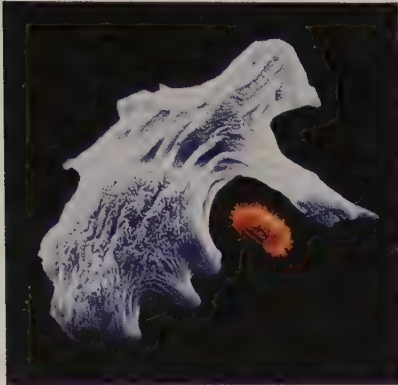


Ciliates are protozoans that are surrounded with hairlike extensions called *cilia*. A paramecium (left) is a classic example of a ciliate. A stentor (below) is another example of a trumpet-shaped ciliate. Both are free-swimming inhabitants of stagnant lakes and ponds.



Radiolarians are protozoans that contribute to the ooze on the ocean floor. They have silicon enclosures, called *tests*, like diatoms. This ooze may be several miles thick in places, with 1 gram of ooze being made of 50,000 radiolarian tests!

Since most protozoans have only one cell, they need a few more organelles to fill their needs. Many protozoans such as paramecia have a *contractile vacuole*, a storage container that rids the cell of excess water to both maintain a healthy pressure and control osmosis in the cell. Contractile vacuoles regulate homeostasis between a protozoan and its environment. Paramecia also have something like a mouth called a *mouth pore*. The cilia sweep the food into the mouth pore, and the food travels down the gullet into a food vacuole. If a paramecium's food vacuole is like a human stomach, then the paramecium's gullet can be likened to a human esophagus. Paramecia also have both a *micronucleus* and *macronucleus* for storing genetic information.



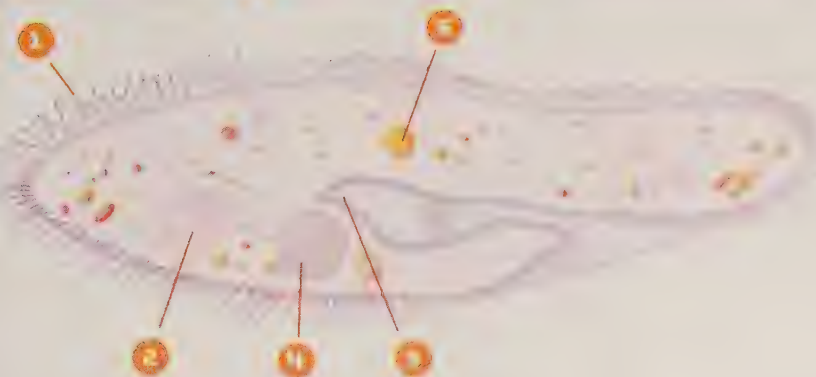
13-4

This *Amoeba proteus* is eating a *Tetrahymena* protozoan by using its pseudopods to form a food vacuole. Biologists call this process *phagocytosis*.

Many species of protozoans have specialized structures that can respond to changes in their environment. Some have areas of pigment called **eyespot**s that can detect light so that the protozoan can move either toward or away from light. Other protozoans can detect and respond to chemical changes in their environment. During times of harsh environmental conditions, many protozoans survive by forming a hard, protective coating called a **cyst**. While in the cyst form, the protozoan's metabolism slows down to allow it to survive without food.



- 1 cilia
- 2 contractile vacuole
- 3 gullet
- 4 macronucleus
- 5 food vacuole



13.3 REPRODUCTION IN PROTOZOANS

Protozoans can form colonies, resulting in quick and efficient reproduction. Some reproduce asexually, others sexually, while many reproduce both ways.

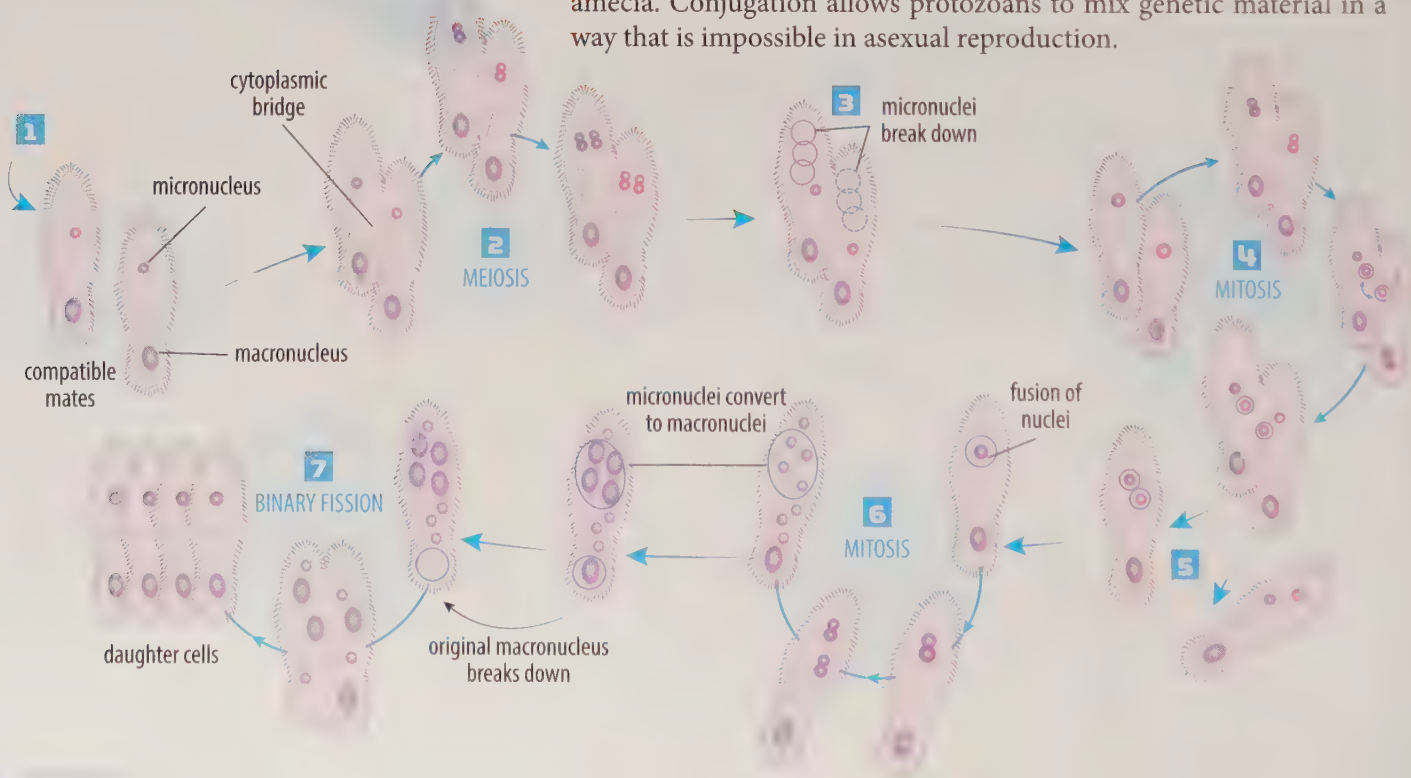
ASEXUAL REPRODUCTION IN PROTOZOANS

Protozoans such as paramecia can reproduce asexually by mitosis just as bacteria do (see page 224). During this process, the micronucleus divides by mitosis, and the macronucleus enlarges and divides in half. Organelles such as the gullet are duplicated, and the cell divides. Other protozoans such as the malaria parasite produce several new nuclei through mitosis before separating into daughter cells. This is called *multiple fission*. This process allows malaria parasites to multiply quickly in the human body (see Figure 13-2).

Some protozoans can use mitosis to form **spores**, reproductive cells that are protected by a thick cell wall. These spores have genetic material that is identical to the parent cell.

SEXUAL REPRODUCTION IN PROTOZOANS

However, protozoans can also reproduce by a type of sexual reproduction called *conjugation*. Note that this is different from the bacterial conjugation that we studied in Chapter 12. For example, when paramecia undergo conjugation, two of them attach at their oral grooves. Each paramecium undergoes a variety of nuclear changes. At some point, they exchange genetic material through the cytoplasmic bridge that connects them, which is similar to the pilus used in bacterial conjugation. The cells separate and undergo more nuclear changes. Finally, each paramecium divides to form a total of four paramecia. Conjugation allows protozoans to mix genetic material in a way that is impossible in asexual reproduction.



13.4 HOW PROTOZOANS FUNCTION IN THE ENVIRONMENT

Protozoans are especially important to an aquatic environment because they serve as decomposers and form a key part of the marine food chain as they transport nutrients in the different zones of the ocean. They also keep bacteria populations in check.

But protozoans also often act as parasites, weakening their hosts. The malaria parasite *P. falsiparum*, mentioned at the beginning of the chapter, and the protozoan *Trypanosoma* that causes African sleeping sickness are examples of parasitic protozoans. Plants, insects, fish, and even humans can suffer from the parasitic effects of protozoans.

Many protozoans are pathogens—disease-causing organisms. For example, *Giardia* and *Entamoeba*, which live in water or in water-dwelling organisms, cause diarrhea and dysentery in humans. So clean, fresh water is a high priority to protect God's image bearers. Managing protozoan populations helps protect the plants and animals that people rely on for their lives and livelihood.

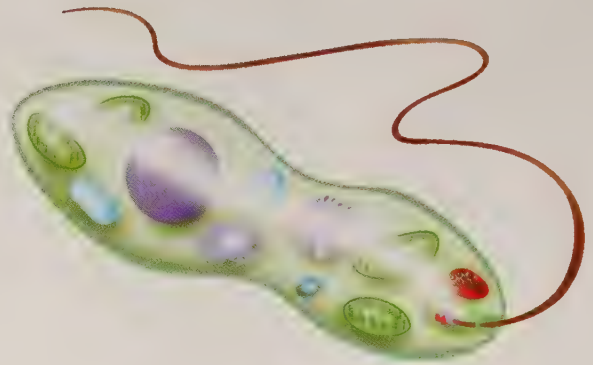


13-5

Several protozoans act as parasites that can produce growths called *xenomas* on their host organisms. On fish, these growths cause gill disease. Fish farmers in hatcheries can vaccinate their fish against xenomas.

13A REVIEW QUESTIONS

1. Using Figure 13-2 as a guide, how do you think malaria spreads from person to person?
2. How do protists, kingdom Protozoa, kingdom Chromista, and domain Eukarya relate?
3. Draw a series of pictures that shows how an amoeba eats. Label each diagram appropriately to communicate the amoeba's motion and eating.
4. Trace or sketch the euglena in the margin on your paper and label the following parts: flagellum, nucleus, chloroplast, contractile vacuole, eyespot, and gullet. (Hint: The last two structures are located near the flagellum.) Compare this diagram with the paramecium on page 241 to correctly label the parts.
5. The euglena has both a gullet and chloroplasts. What does this information tell you about what it eats?
6. What are the different ways that protozoans reproduce?
7. List two examples of a protozoan that is harmful to humans or the environment. Describe their danger.
8. What is the difference between a parasite and a pathogen?
9. A pathogenic protozoan called *Cryptosporidium* has the ability to resist chemicals like chlorine that are often used to sanitize public drinking water. This protozoan is introduced to water supplies through contact with animal or human waste. Suggest one way to limit *Cryptosporidium* in water supplies to provide people around the world with fresh drinking water.



13B Questions

- » How are the kingdoms Chromista and Protozoa distinct from the other kingdoms?
- » How do chromists grow and reproduce?
- » Why are protists important to evolutionary theory?
- » How do chromists contribute to the environment?

chromist: chromista (Gk.—colored)

KINGDOM CHROMISTA

How do chromists live and function?

13.5 CLASSIFYING CHROMISTS

Protists that are plant-like are grouped in kingdom Chromista, making it a kingdom that contains more photosynthetic protists than kingdom Protozoa does. This kingdom is the second of five in domain Eukarya. Protists in kingdom Chromista are referred to as **chromists**. Chromists can be unicellular or colonial. They have motile gametes, and many have cell walls made of cellulose as plants do. Most chromists are autotrophic, although a few are heterotrophic. Many chromists are green, indicating that they are photosynthetic because of the presence of chlorophyll.

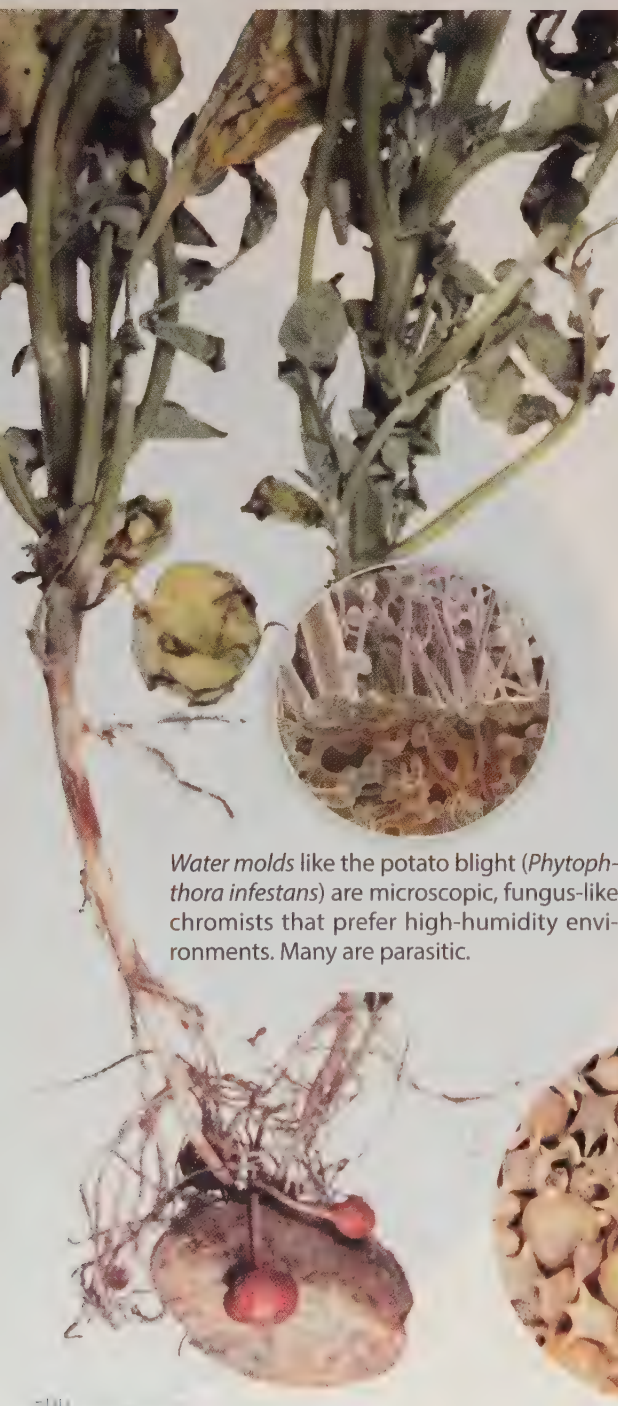
Chromists include all of the algae (s. **alga**)—kelp, seaweed, green algae, and red algae—which are protists that have chloroplasts, making them photosynthetic organisms. Algae are unicellular and can form colonies. Chromists also include *diatoms* (see Unit opener on page 204), found in the oceans and freshwater, and *foraminifera*, which are chromists with shells that are found as fossils all over the world. Some foraminifera can get as large as 20 cm long. Chromists also include one type of slime mold, called a *slime net*, and *water molds*, fungus-like protists that are heterotrophic. The latter have cell walls made of cellulose, and so are categorized in Chromista with autotrophic protists.

EXPLORING CHROMISTS

Algae form a major part of kingdom Chromista. Shown on the right is a colony of *Volvox*, a green alga. Other algae include brown algae (kelp and seaweed) and red algae. Notice that many of the *Volvox* algae in this photo hold daughter colonies.

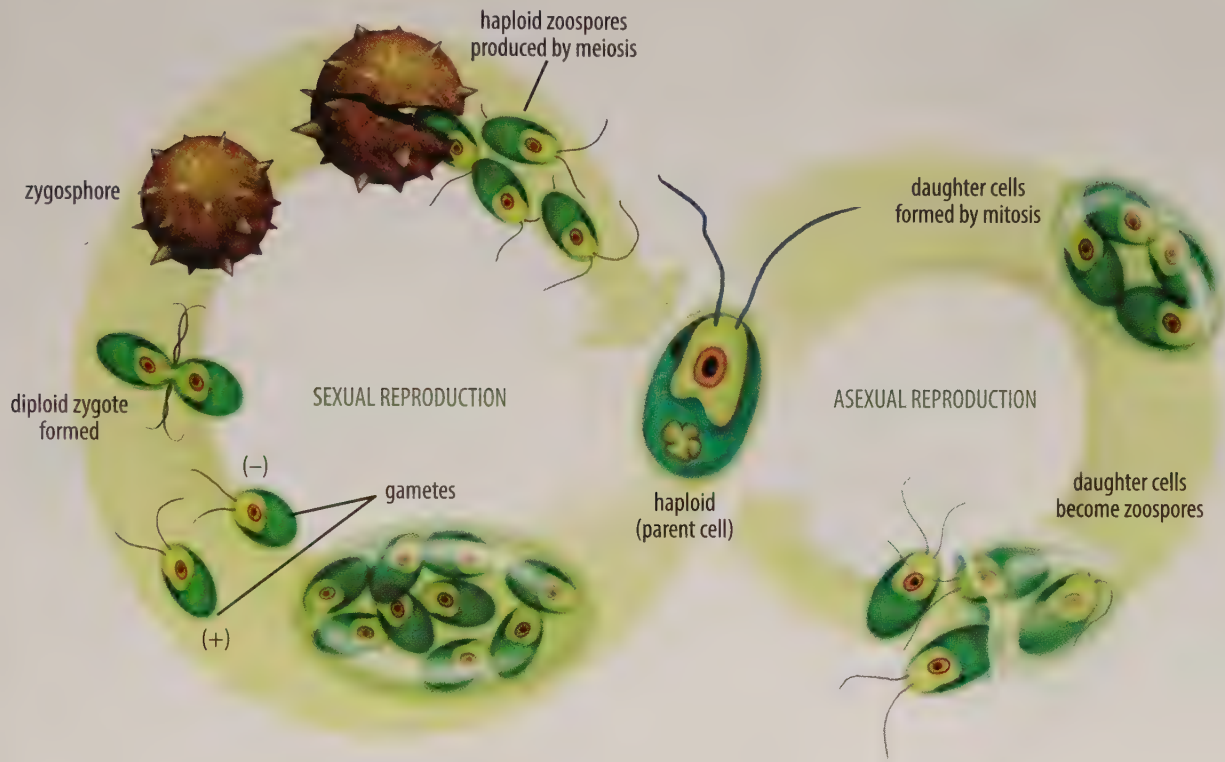
Water molds like the potato blight (*Phytophthora infestans*) are microscopic, fungus-like chromists that prefer high-humidity environments. Many are parasitic.

Foraminifera like the sand star (*Baculogypsina sphaerulata*) shown here are chromists with shells called *tests*. Almost all of them are aquatic. Scientists have found fossilized foraminifera buried in rock strata all over the world.



13.6 STRUCTURE AND REPRODUCTION IN CHROMISTS

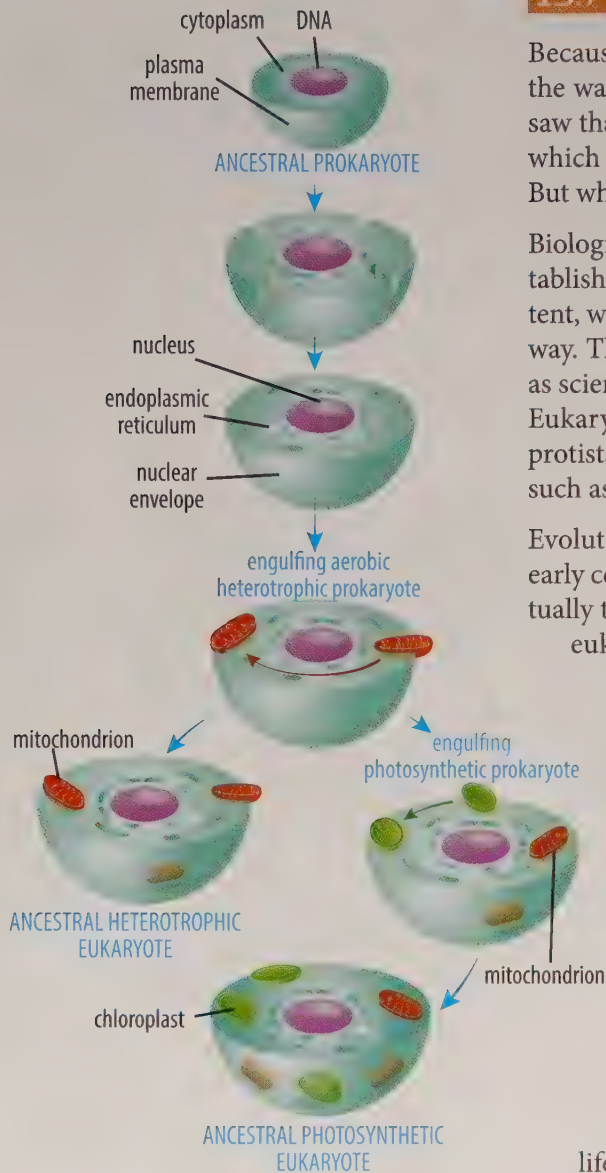
Most chromists lack the specialized structures of protozoans since they are usually autotrophic. Their chloroplasts allow them to respond to their environment to manufacture food for their sustenance. Some chromists such as brown algae form complex structures that allow them to get very large, such as giant kelp. However, most lack cilia or flagella to propel themselves.



Since many chromists form colonies, they reproduce quickly. Chromists can undergo both asexual and sexual reproduction. Like protozoans, they can reproduce asexually using multiple fission and mitosis. However, they can also sexually reproduce through conjugation. Each chromist, such as an alga, experiences a variety of nuclear changes. At some point, two algae cells exchange genetic material through the cytoplasm bridge—called a *conjugation tube*—that connects them during conjugation. The cells separate and undergo more nuclear changes. Finally, each alga divides to form a total of four algal cells. Conjugation allows chromists to mix genetic material in a way that is impossible in asexual reproduction.

Some chromists such as algae can alternate between sexual and asexual reproduction (see image above). The adult chromist is a haploid organism. During asexual reproduction, the cell undergoes mitosis, producing daughter cells that are haploids. In the next generation, haploids can fuse genetic information through fertilization to form diploid zygotes that multiply through meiosis.

13.7 PROTISTS AND BIOLOGICAL EVOLUTION



Because protists are so difficult to classify, biologists often change the way they classify individual organisms. Earlier in this chapter we saw that the word protist comes from the outdated kingdom Protista, which has been replaced by the kingdoms Protozoa and Chromista. But what has driven all these changes?

Biologists have continued to use biological classification to try to establish evolutionary relationships, drifting away from its original intent, which was to organize the information of living things in a useful way. This has led to some confusing findings and bizarre conclusions as scientists have used genetics to create kingdoms within the domain Eukarya. They want to deduce how simple, unicellular eukaryotic protists have evolved into much larger and more complex eukaryotes such as plants, animals, and even humans.

Evolutionists theorize that the earliest life was prokaryotic. These early cells grew, their cell membranes folding as they developed. Eventually these folds of membranes enclosed the nucleus to form the first eukaryotic cell. These organisms engulfed other organisms and turned them into organelles.

So how should a Christian respond to this naturalistic view of protists and of life as a whole? It is important to remember that classification is man's attempt to model the natural world in ways that simplify the world so that we understand it better. These efforts are shaped by assumptions that people make about a world full of life.

Protists are not simple just because many are made of one cell. In fact, some protists represent the most complex eukaryotic cells that we know of. The diversity that we observe in chromists and protozoans are not a testimony to biological evolution; they bear witness to a creative Designer. Let's see how God's design of protists contributes to life on Earth.

13.8 HOW CHROMISTS FUNCTION IN THE ENVIRONMENT

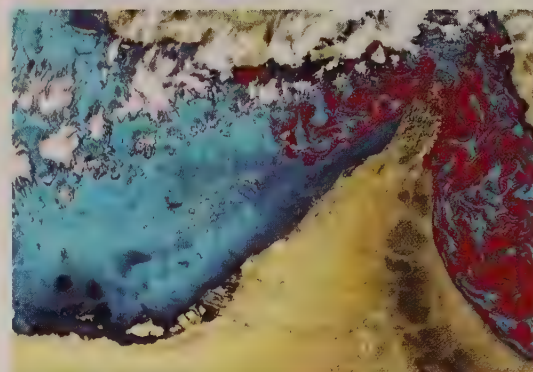
Microorganisms like protists are very small inhabitants of our world, but they can have a big effect on living things around the world. Even the unicellular alga can be part of a bigger colony that produces the oxygen that makes Earth a haven for life. You learned in Chapter 7 that 70–80% of the oxygen that we breathe comes from algae in the oceans!

In the oceans, chromists like algae and diatoms form the base of the marine food chain. Many larger animals such as fish, whales, and some seals eat **plankton**, organisms that float in the ocean and don't swim against the current. Plankton includes two groups: *phytoplankton*, which are autotrophic organisms, and *zooplankton*, which are

heterotrophic organisms, usually protozoans. There are protists in both groups. Algae, diatoms, and dinoflagellates are all phytoplankton that feed jellyfish, krill, and other zooplankton. Zooplankton includes many species of protists such as foraminifera and radiolarians. Some chromists provide shelter for animals, such as otters that attach themselves to kelp to keep from drifting while they eat fish and shellfish. Some algae such as seaweed are edible and are a healthy diet choice for many people.

Under the right conditions—warm water and the presence of oxygen, sufficient nutrients, and sunlight—protists in the ocean such as dinoflagellates can multiply rapidly. This can produce a surge in the population called an **algal bloom**. Though these protists can fill a helpful role in consuming wastes in ponds, lakes, and oceans, algal blooms deplete the water of oxygen and nutrients and can release toxins that are harmful to living things.

Some chromists have symbiotic relationships with other animals. For example, chromists that inhabit the guts of termites enable them to break down cellulose in wood pulp into nutrients that termites can use. Coral reefs have a symbiotic relationship with algae—the algae provide nutrients for the coral and the coral's hard covering provides support and protection for the algae.



13-6

This is a satellite image of an algal bloom, called *red tide*, in the Gulf of Oman. It is caused by a booming population of phytoplankton. This leads to a serious problem for people in this dry area—the red tide clogs pipes used in desalination plants that provide clean, fresh water.

13B REVIEW QUESTIONS

- Identify each of the following protists as protozoans (P) or chromists (C).
 - water mold
 - algae
 - foraminifera
 - ciliates
- Create a table that compares protozoans and chromists. Include the following in your comparison: motility, energy source, and the ability to form colonies.
- How do chromists reproduce?
- Why do evolutionists believe that all life came from prokaryotic cells?
- As a result of their genetic testing to develop the phylogenetic tree for eukaryotic organisms, scientists have found that the malaria parasite *Plasmodium* contains a chloroplast-like plastid. This is an unexpected explanation for the mystery of why medications that attacked chloroplasts were effective in treating malaria. Many scientists are pointing to this finding as a relic of evolution, proof that *Plasmodium* is an evolutionary relative of photosynthetic organisms. How would you respond to this claim?
- Why don't chromists usually operate as parasites in their environment like other protists do?
- Why are chromists in ocean waters important for life on Earth?



13-7

Evolutionists say that eukaryotic cells like *Plasmodium* and even *Euglena* got chloroplasts when they took in a cyanobacterium to form a symbiotic relationship. Over time, this cyanobacterium evolved into a chloroplast able to carry out photosynthesis.



13C Questions

- » How are fungi classified?
- » How do fungi grow and reproduce?
- » How can fungi be useful or harmful to humans and the environment?

13C |

KINGDOM FUNGI

How do fungi live and function?

13.9 CLASSIFYING FUNGI

Do you know what the largest living thing is? It's not an African elephant (*Loxodonta africana*), the blue whale (*Balaenoptera musculus*), or even the Giant Sequoia (*Sequoiadendron giganteum*) named General Sherman. It's a small, humble fungus called the honey mushroom (*Armillaria solidipes*). This huge organism doesn't look so big—it isn't even visible except in the fall when little brown mushrooms push up through the moss and leaf debris on the forest floor.

You see, the part of mushroom above the ground isn't all there is to a mushroom. The honey mushroom creates an underground network that can cover hundreds of acres, even killing stands of trees. In Oregon, there is a network of honey mushrooms so large that it covers over two thousand acres and might be over two thousand years old. That's one humongous fungus!

But what is a fungus anyway? A *fungus* is a member of the third kingdom in the domain Eukarya—kingdom Fungi. Fungi grow from the ground like plants, but they lack chlorophyll and are heterotrophs. Some are parasitic, but many serve as decomposers, filling an important role in the environment by breaking down organic matter in the soil. Fungi have cell walls as plants do, but instead of cellulose, the cell walls of fungi are made of a substance called **chitin**, a large sugar molecule also found in the outer coating of insects. Most fungi are unicellular, but they have a multicellular stage when they reproduce. Similar to many protists, they can form colonies. In addition to the honey mushroom, some examples of fungi include molds, mildew, lichen, and yeast. Fungi are grouped by the kinds of spores that they produce through sexual reproduction.

13.10 STRUCTURE OF FUNGI

Most fungal colonies are made of slender filaments called hyphae (HYE fee) (s. **hypha**) that look like very fine plant roots. Some hyphae have partitions called *septa* (s. *septum*) that create segments made of individual cells, connected by pores to allow the exchange of cytoplasm, organelles, and nuclei. Other hyphae are not segmented like this.

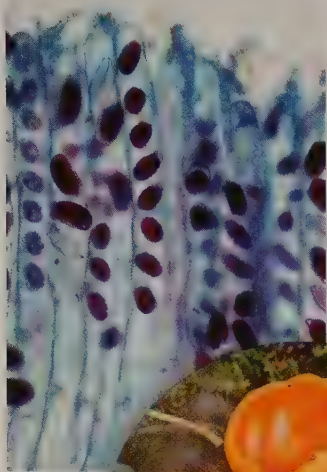
Even large fungi like mushrooms are made of interwoven hyphae called mycelia (mye SEE lee ah) (s. **mycelium**). Mycelia are visible without the aid of a microscope and can be as simple as clumps of bread mold or as highly organized and specialized as morel mushrooms.



13-8

The humble yet humongous honey mushroom

EXPLORING FUNGI



The largest phylum in kingdom Fungi is Ascomycota, or the *sac fungi*. Sac fungi have a tiny pouch called the *ascus* (left) where spores form. These fungi are cup-shaped. *Penicillin* is a fungus in this phylum and produces the antibiotic that bears its name. Shown below is the orange peel fungus (*Aleuria aurantia*), an edible fungus that looks great in a salad!



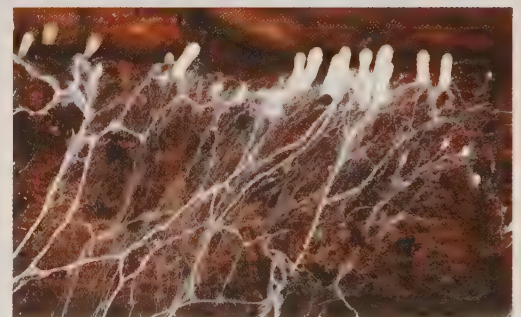
Sometimes mushrooms in wooded areas and grasslands form an arc called a *fairy ring* as their underground network spreads out in an area to feed on decaying organic matter in the soil.

Some fungi produce odors, like this stinky devil's fingers fungi (*Clathrus archeri*) to the right. This fungus is not a sac fungus; it is in the phylum Basidiomycota, which includes the most familiar *club fungi*. This phylum is the only group of fungi that can correctly be called "mushrooms." It includes puffballs, stinkhorns, and shelf fungi. Basidiomycota is the next largest phylum in the kingdom after Ascomycota. Devil's fingers feeds on decaying wood and smells like rotting meat, attracting insects, which spread its spores. It is edible, but who would want to eat it with a smell like that!



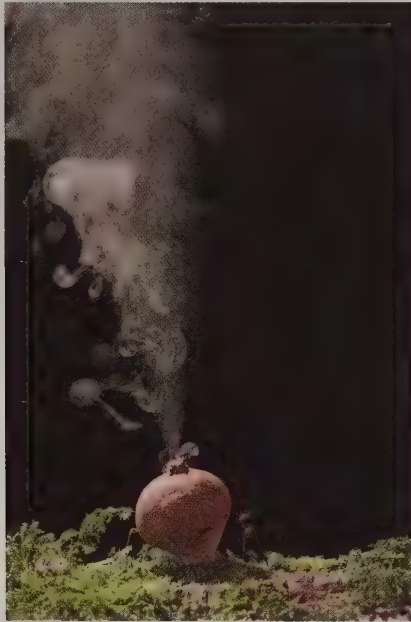
Cordyceps is a family of brutal fungal parasites in phylum Ascomycota. Some fungi have tree or plant hosts; others like this one have insect hosts. The *Cordyceps* fungus turns insects into zombies, absorbing nutrients from its host's internal organs while it is still alive. Eventually, the insect's body is filled with the fungus's reproductive spores. The insect's body eventually bursts to release the spores.

Though hyphae may be present in the ground year round, you might never know a fungus is there until it sends up a **fruiting body**, a special fungal structure made of many hyphae that is responsible for reproduction. In club fungi, which are the only group of fungi that form traditional mushroom-shaped fruiting bodies, the stalk of the fruiting body is known as the **stipe**, and the top of the fruiting body is called the **cap**. The underside of the cap often contains ribs called **gills** that radiate outward from the stipe. The gills can produce thousands of *spores*, reproductive cells that have thick walls and are able to survive a variety of hostile conditions in order to pass on genetic information from the parent organism. Spores are the reproductive units of fungi, just as seeds are the reproductive units of plants. Fungi are just one type of organism that uses spores to reproduce. Most fungi don't



13-9

Note the fine, root-like mycelia that have worked through a piece of rotting wood.



13-10

The "smoke" coming from this puffball fungus isn't smoke at all; rather, it is a cloud of very fine spores that are being released to the environment. Notice that this club fungi doesn't have a cap and stalk.

have gills; they let their spores out through pores in the fruiting body or from knobs that hang down from the cap.

13.11 REPRODUCTION IN FUNGI

ASEXUAL REPRODUCTION

Like protists, fungi can reproduce through sexual reproduction, asexual reproduction, or a combination of the two, though asexual reproduction is most common. Some unicellular fungi use mitosis for asexual reproduction, as some bacteria and protists do.

Yeast cells reproduce by **budding**, a process that involves part of the cell pinching off to produce more yeast cells (see Figure 13-11 on the facing page). The nucleus first divides by mitosis. Then a small pouch forms on the side of the yeast cell and one of the new nuclei moves into it, forming the bud. After a period of growth, the bud usually separates from the parent.

Fungi can also reproduce asexually through a process called **fragmentation**. In this process, part of a fungus that has broken off can form a new fungus as cells multiply through mitosis. Usually a hypha or mycelium is the fragment of a fungus that is used for reproduction. Other organisms, such as some lichens, algae, worms, starfish, and bacteria, can reproduce asexually through fragmentation.

- 1 cap
- 2 gills
- 3 stipe
- 4 hypha
- 5 mycelia
- 6 nuclei
- 7 septum
- 8 new fruiting body



SEXUAL REPRODUCTION

The most common form of sexual reproduction in fungi, however, is the formation of spores. Spores can form sexually through meiosis inside an enclosure or sac, such as in the asci of sac fungi. They can also form sexually outside of a sac in some types of fungi. Some fungi can form spores through sexual reproduction when environmental conditions are unfavorable for asexual reproduction. There are no male and female fungi; instead, they have mating types that are symbolized by + and – signs. Sexual reproduction happens when the hyphae of different mating types contact each other. The fused hyphae produce a fruiting body that forms and releases the spores through sexual reproduction.

Fungi such as sac fungi, club fungi, and yeasts that can produce both sexually and asexually are called *perfect fungi*. However, some fungi have not been observed to reproduce sexually and are called *imperfect fungi*. Some examples of the latter are *Penicillium* and *Candida albicans*, which can live in a person's mouth, and some fungi used to produce cheeses.

13-11

The baker's yeast (*Saccharomyces cerevisiae*) cells shown below are reproducing through budding.



FIGHTING MALARIA WITH A FUNGUS

Malaria, the disease caused by the protist *Plasmodium*, has affected the lives of billions of people for hundreds of years. Even with modern medicine, hundreds of millions of people will be stricken with malaria this year. But there's a light at the end of this very dark tunnel. In 1950, a protein known as the *Duffy antigen* was discovered. Once *Plasmodium* has entered a person's body, it latches on to the Duffy antigen, infecting the person. In 1996, the source of the antigen was discovered: it is produced by the DARC gene (Duffy antigen receptor for chemokines) of human chromosome 1. Researchers have found that if the antigen is turned off in the DARC gene, *Plasmodium* has nothing to latch on to, making a person resistant to malaria. Turning off this tiny protein may become the greatest weapon we have against this devastating disease.

Would it also be possible to defeat the malaria-causing parasites in a mosquito vector by infecting the mosquito with a fungus? This odd idea for killing a parasite is born out of the centuries of frustrating attempts to control *Plasmodium*. Almost all attempts to control the parasite have resulted in either the mosquito or *Plasmodium* developing a resistance to the treatment used. Could fighting a protist with a fungus really reduce malaria?



A team of scientists have genetically engineered the fungus *Metarhizium anisopliae* (pictured), which already infects mosquitoes in the wild. The altered fungus (above, engineered to glow) still likes to infect mosquitoes, but now it targets the *Plasmodium* parasites living inside the mosquito vectors. The result—an effective way to control malaria before the mosquito can even infect a person.

REPRODUCTION IN BLACK BREAD MOLD

Black bread mold (*Rhizopus stolonifer*) is an example of the third largest phylum of kingdom Fungi, Zygomycota. This mold uses a combination of asexual and sexual reproduction to produce spores called *zygospores*.

- Two hyphae from different mating types grow until they touch each other. Nuclei in the tip of each hypha divide several times.



- The hyphae fuse where they touch to form a zygosporangium, a diploid zygote ($2n$), through sexual reproduction. It forms a thick outer covering and enters dormancy.

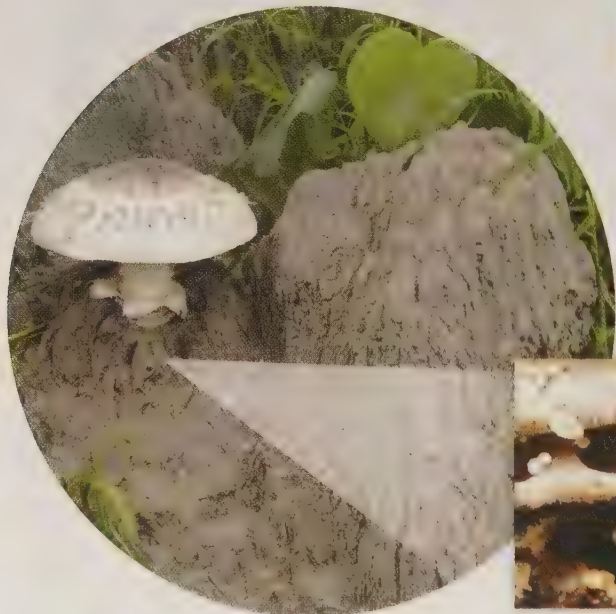
- Zygosporangia can form spores, which undergo meiosis and germinate to form new hyphae through asexual reproduction.

- As hyphae grow, asexually formed spores called *sporangiophores* form and are released.

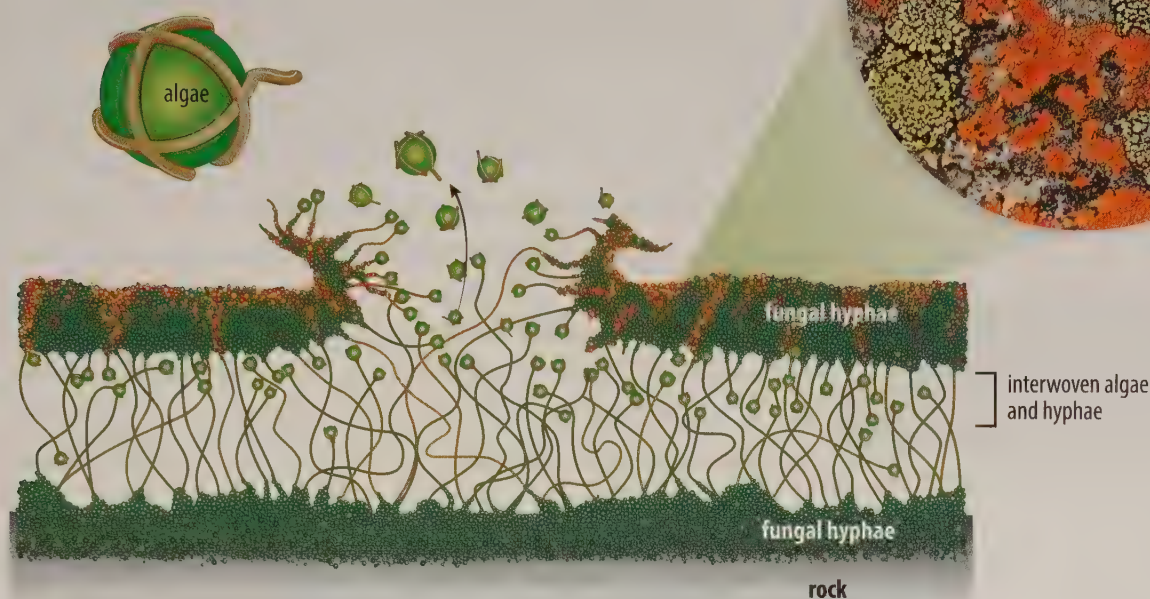


13.12 HOW FUNGI FUNCTION IN THE ENVIRONMENT

Humans aren't the only farmers. There's an unlikely farmer less than an inch long that also builds skyscrapers on the African savanna. It's the African termite. Termites have a symbiotic relationship with a fungus, the *Termitomyces* mushroom. The termites cultivate this mushroom, gathering spores to deposit in their colonies. It's hard work for termites to decompose the cellulose in wood, so they get these fungi to do it for them! The fungi turn the cellulose into sugars, which the termites eat. When things get especially wet in Africa, some of the *Termitomyces* mushrooms become very big (caps 1 m wide!) and start growing outside the termite mound. People gather and enjoy these mushrooms as a culinary delicacy.



Many fungi live with plant roots in a relationship called **mycorrhiza** (mye kuh RYE zuh). Over 90% of plants have fungi associated with their roots. The fungi effectively increase the surface area of a plant's roots to enhance its ability to absorb minerals from the soil. In return, the fungi receive carbohydrates from the plant. This symbiotic relationship allows plants and fungi to live in environments that would otherwise be unable to support them.



A **lichen** (LYE kin) consists of a fungus and algae living in symbiosis. Much like the chromists in a coral reef do, the alga in a lichen captures energy from sunlight and manufactures sugars for itself and the fungus. The fungus provides support and protection for the alga. Lichens are commonly found on tree bark, rock formations, fence posts, and brick walls.

These two examples demonstrate that fungi serve a very important role as decomposers in the environment. They take nutrients and waste products and convert them into a form that other living things can use. It is fungi that are responsible for that distinctive flavor in the mushroom pizza that you enjoy!

But like protists, fungi can have a more sinister role in the environment. They can function as pathogens. Plants get fungal infections from fungi called *rusts* and *smuts* that drastically reduce harvests. Animals and insects get fungal infections that can eventually kill them. Even humans can get thrush, ringworm (*Tinea*), and athlete's foot (*Epidermophyton floccosum*).

With both protists and fungi, we must manage and use their populations in ways that maximize their benefits and minimize their dangers. We can develop treatments for malaria and athlete's foot, grow portabella mushrooms for food, and harness the photosynthetic power of algae to power our homes and cars. When we control and use protists and fungi to wisely manage the resources God has given us to help people, God's image bearers, we bring Him glory.



13-12

The fungus *Ustilago maydis* causes corn smut. But that's not a bad thing in Mexico since the locals prize it as a delicacy! The infected corn is used in quesadillas because it contains more protein than uninfected corn does.

13C REVIEW QUESTIONS



1. List in descending order and describe the three largest phyla in kingdom Fungi.
2. Create a hierarchy chart relating kingdom Fungi and the three phyla from Question 1. Include examples of each phylum in your diagram.
3. How are mycelia and hyphae related?
4. Using the photo of the *Amanita muscaria* (left), draw and label the cap, stipe, and gills on the mushroom. Indicate where you think the mycelia would be.
5. (True or False) Mycelia appear only in the ground below club mushrooms.
6. State the way(s) that fungi can reproduce asexually.
7. State the way(s) that fungi can reproduce sexually.
8. Identify the following as perfect or imperfect fungi.
 - a. *Candida*
 - b. fruiting bodies of sac fungi
 - c. *Penicillium camemberti*, a fungus used to produce Camembert cheese
 - d. budding yeast
9. Why are fungi so important?
10. What harmful effects do fungi have on the environment?
11. What kind of symbiotic relationship (mutualism, commensalism, neutralism, amensalism, parasitism) does each of the following pairs of organisms exhibit?
 - a. humans and ringworm
 - b. termite and the *Termitomyces* mushroom
 - c. algae and a fungus in lichen
 - d. mycorrhizae between fungi and trees

REVIEW QUESTIONS

CONCEPT REVIEW

1. Create a hierarchy diagram that relates domain Eukarya, protists, kingdom Fungi, kingdom Chromista, and kingdom Protozoa. Include ciliates, slime molds, foraminifera, water molds, algae, sac fungi, and club fungi in your diagram.
2. Compare the ecosystems that are home to protists with those that are home to fungi.
3. Why do you think both unicellular protists and fungi form colonies?
4. Draw an amoeba, a paramecium, and a euglena, and use arrows or descriptions to show how they move.
5. When do protozoans need contractile vacuoles?
6. Summarize how reproduction is similar in protists and fungi.
7. How are both protists and fungi harmful to their environment?
8. Why do you think biologists think trees and algae are related to a common evolutionary ancestor?
9. Explain why the term *plankton* includes more than just protists.
10. Summarize the two main contributions of chromists to their environment.
11. What part of a fungal colony is responsible for creating fairy rings? (See page 249.)
12. What kind of fungus has fruiting bodies with caps, stipes, and gills?
13. What is the difference between perfect and imperfect fungi?
14. Name the three ways fungi can reproduce asexually.
15. How do the alga and the fungus in a lichen help each other?
16. Summarize the main contribution of fungi to their environment.

TRUE OR FALSE

17. *Plasmodium falciparum* is a protozoan.
18. Both chromists and protozoans are classified in kingdom Protista.
19. Slime molds appear in both kingdom Chromista and kingdom Protozoa.
20. All protists have some way to propel themselves with either pseudopods, cilia, or flagella.
21. All protozoans are heterotrophs, and all chromists are autotrophs.
22. The only way for protists to exchange genetic information is through sexual reproduction.
23. Some protists are made of very complex cells.
24. Fungi act as decomposers in their environment.
25. All fungi are made of hyphae.
26. All fungi have caps and stipes.

Key Terms

protist	239
colony	239
protozoan	239
cilium	240
pseudopodium	240
eyespot	241
cyst	241
spore	242
chromist	244
alga	244
plankton	246
algal bloom	247
chitin	248
hypha	248
mycelium	248
fruiting body	249
stipe	249
cap	249
gill	249
budding	250
fragmentation	250
mycorrhiza	253
lichen	253

13-13

Some species of mushrooms are naturally bioluminescent and are called *fairy fire*.



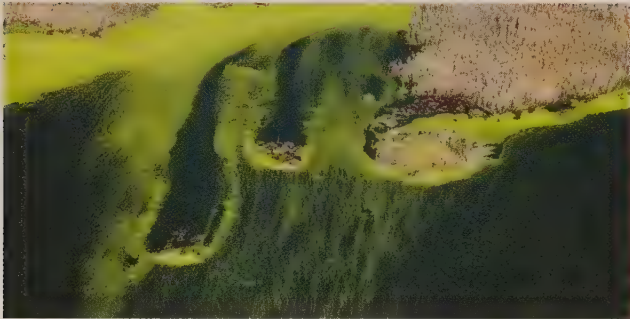
- 27. Male and female fungi form spores through sexual reproduction.
- 28. Only sac fungi produce spores.

CRITICAL THINKING

- 29. *Amoeba proteus*, though a very commonly studied protist, is a protozoan without an assigned phylum. You've learned how this protozoan uses pseudopods to move and capture food. It once had a different Latin name, *Chaos diffluens*. Why do you think this protist is difficult for biologists to classify?
- 30. What does the classification of *Amoeba proteus* tell you about the nature of classification?

Use the Case Study below to answer Questions 31–36.

CASE STUDY: HAB ALERT!



In the Gulf of Mexico harmful algal blooms (HABs) are becoming more frequent. These blooms can have a devastating effect as they produce toxins that poison shellfish, birds, and mammals living in these areas. They also have serious effects on the oxygen content of the waters. The National Oceanic and Atmospheric Administration (NOAA) monitors the Gulf of Mexico to warn about any development of a dangerous algal bloom.

- 31. Using a map of the United States, where do you think algal blooms most commonly occur?
- 32. What do you think would cause algae populations to grow so quickly in these areas? (*Hint*: What makes plants grow quickly?)
- 33. Algal blooms in the oceans can cause large dead zones that contain very little oxygen. Why does this happen?
- 34. Why are dead zones so dangerous to marine organisms?
- 35. Suggest one way that scientists can use technology and scientific models to monitor algal blooms in the Gulf of Mexico.
- 36. How could scientists warn people of a dangerous algal bloom in an area?

Use the Case Study below to answer Questions 37–40.

CASE STUDY: AFRICAN SLEEPING SICKNESS

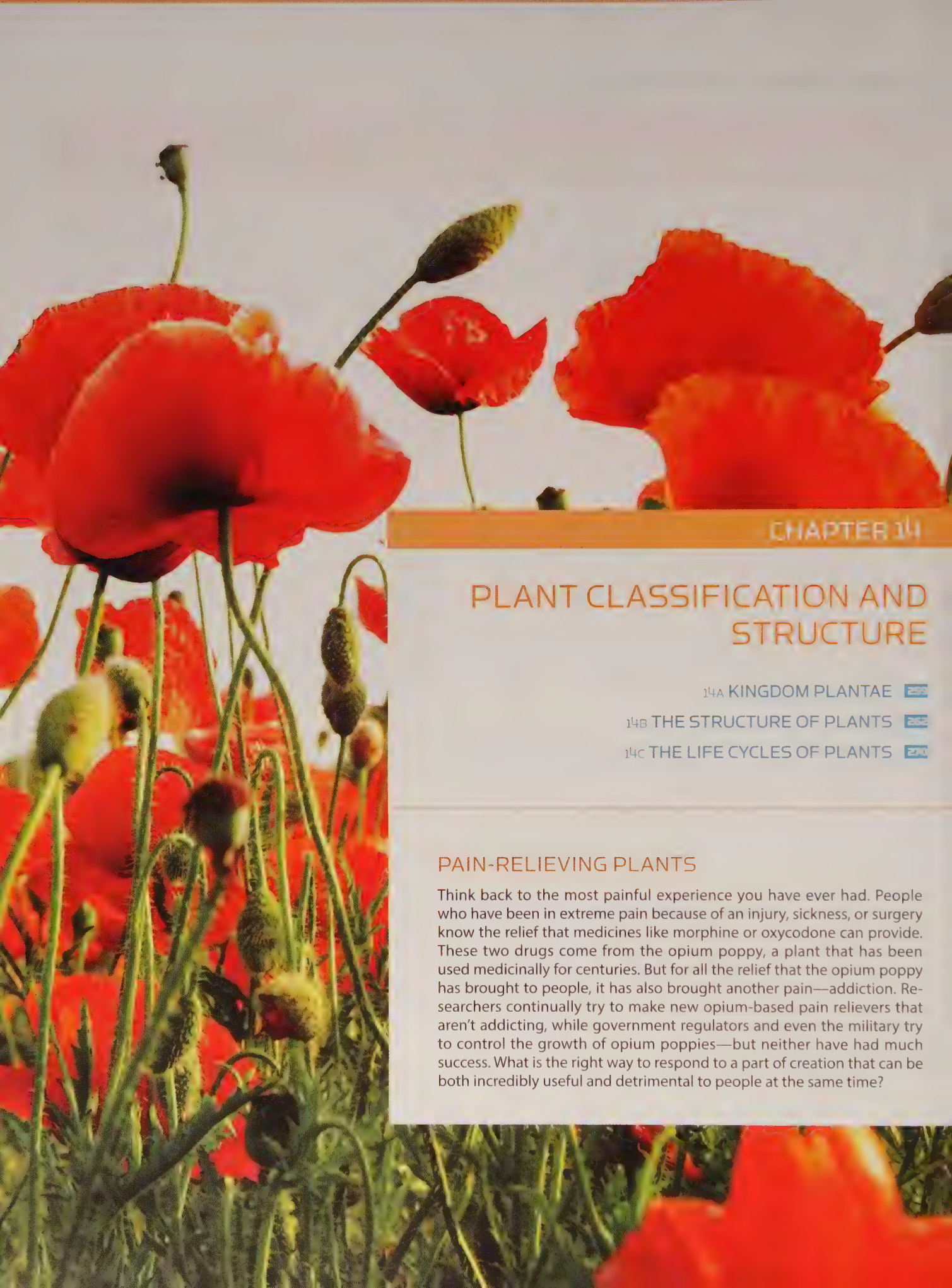


tsetse fly

African sleeping sickness is caused by the flagellated protozoan *Trypanosoma brucei gambiense* (*T. b. gambiense*). The disease begins with joint pain, then over a series of weeks produces confusion and trouble sleeping. Eventually, it crosses the brain barrier and wreaks havoc. If untreated, victims almost always die.

The parasitic protist *T. b. gambiense* is spread through the bite of a large fly called the *tsetse fly*. *T. b. gambiense* has over 9000 genes that manufacture a confusing array of proteins that help it continually change its outer coating to evade the human immune system. There are currently no vaccines available to prevent this disease.

- 37.** On the basis of what you know about malaria, suggest why there is no vaccine for African sleeping sickness.
- 38.** Suggest one way to prevent infection in people in Africa without an effective vaccine.
- 39.** Scientists have found that *T. b. gambiense* uses specific proteins to build its flagellum. Without this flagellum, the protist can't survive in the human bloodstream. How do you think doctors could use this information to treat African sleeping sickness?
- 40.** Doctors do have treatments for African sleeping sickness, but they have bad side effects, and the protozoan that causes the disease seems to be developing the ability to resist the drugs. How could doctors avoid developing resistance in this pathogen?



CHAPTER 14

PLANT CLASSIFICATION AND STRUCTURE

14A KINGDOM PLANTAE 

14B THE STRUCTURE OF PLANTS 

14C THE LIFE CYCLES OF PLANTS 

PAIN-RELIEVING PLANTS

Think back to the most painful experience you have ever had. People who have been in extreme pain because of an injury, sickness, or surgery know the relief that medicines like morphine or oxycodone can provide. These two drugs come from the opium poppy, a plant that has been used medicinally for centuries. But for all the relief that the opium poppy has brought to people, it has also brought another pain—addiction. Researchers continually try to make new opium-based pain relievers that aren't addicting, while government regulators and even the military try to control the growth of opium poppies—but neither have had much success. What is the right way to respond to a part of creation that can be both incredibly useful and detrimental to people at the same time?

KINGDOM PLANTAE

How are plants classified?

14.1 CHARACTERISTICS OF PLANTS

Plants sustain life. God created them to feed every living thing on the earth (Gen. 1:29–30) and to be admired for their beauty (Matt. 6:28–29). But ever since Creation, people have been doing more with plants than just eating them and appreciating their beauty. Your favorite cotton T-shirt, the grounds for your coffee, the aloe vera gel that you put on a sunburn, the paper that you doodle on, the biodegradable containers that your Chinese takeout comes in—all are made from plants.

Plants are a lot like other living things. They are multicellular, and their cells are eukaryotic. But plants have some characteristics that they share with only a few other creatures.

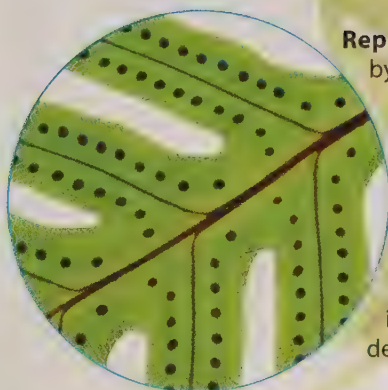
PLANT ATTRIBUTES

Photosynthesis. Almost all plants are autotrophs—they produce their own food through photosynthesis. A few plants are parasitic, getting their nutrition from other living things.



Reproduction. Plants reproduce sexually by **alternation of generations**, which is a cycle that includes a spore-forming stage and a gamete-forming stage.

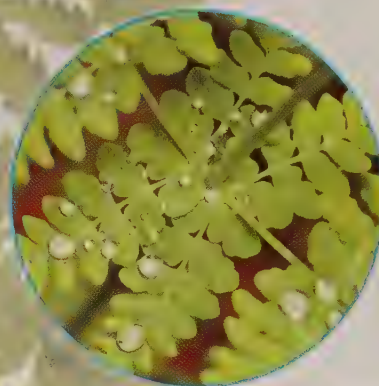
Multicellular Embryo. Plant gametes fuse to form a zygote that develops into a multicellular embryo. The embryo develops into the spore-forming stage.



14A Questions

- » What makes a plant different from other living things?
- » What are the different kinds of plants?

Cellulose. In their cell walls, plants have **cellulose**, the tough fiber that gives plants their rigidity and strength. Cotton and linen fibers are almost 100% cellulose.



Cuticle. The outer surfaces of plants are covered by a **cuticle**, a waxy substance that protects the leaves, green stems, and fruits. The cuticle helps plants keep moisture in and pests and diseases out.

14.2 CLASSIFYING PLANTS

It takes an army of botanists and groundskeepers to maintain the Royal Botanic Gardens, Kew, England, which are home to almost 14,000 different species of plants that come from around the world. But that's only a fraction of the hundreds of thousands of plant species in the world, so the Royal Botanic Gardens are always adding to their greenhouses. The caretakers there have collected some that look



14-1

The two rounded halves of living stones are the plant's two leaves.

so strange that it's hard to think of them as plants, such as the giant water lilies (*Victoria cruziana*) that are native to the Amazon, or "living stones" (*Lithops* spp.) from Africa. With so many species of plants and so much diversity, what's the best way to group them?

A plant is classified in one of several ways. It can be classified as **vascular**, which describes a plant that has tissues capable of transporting water and other materials. Without vascular tissues, tall plants wouldn't be able to carry nutrients from their roots to their leaves. Some very small plants are classified as **nonvascular**, that is, having no vascular tissues. Nonvascular plants must be small

enough to absorb their water and nutrients directly through their leaf-like structures, and they're usually found in moist environments.

Plants are also divided according to whether or not they produce *seeds*—the diploid, multicellular structures that nurture a plant's developing embryos. All plants produce *spores*, which are unicellular and haploid, and *gametes*, unicellular cells that fuse to form multicellular embryos. But nonvascular plants and a few vascular plants don't protect their embryos inside seeds. Vascular plants that do produce seeds can be classified according to whether the seeds are formed in a flower and enclosed in a fruit or are borne in a cone and exposed.

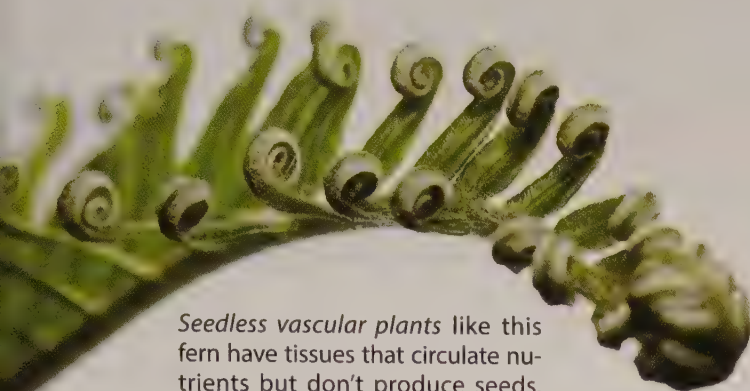
14-2

These bundles of flax (*Linum usitatissimum*) have strings of cellulose in them that will be spun into linen fibers.



EXPLORING PLANTS

Plants can be classified into four groups, primarily on the basis of the way that they reproduce.



Seedless vascular plants like this fern have tissues that circulate nutrients but don't produce seeds. Plants in this category also include horsetails, whisk ferns, and club mosses.



Nonvascular plants like this moss are commonly called **bryophytes**. This group of plants includes mosses, hornworts and liverworts.

Some vascular plants like this pine produce seeds but no fruits or flowers. These kinds of plants, called **gymnosperms**, bear their seeds out in the open on a cone. Gymnosperms also include cycads and ginkgo trees.



Seed-bearing vascular plants that produce flowers and fruits are called **angiosperms**, the largest group of plants. These giant water lilies (*Victoria cruziana*) produce large flowers and leaves that are big enough to support the weight of a person.



14A REVIEW QUESTIONS

1. What characteristics do plants share with many other living things?
2. If you scratched the cuticle off a plant's leaves, what would happen to the plant?
3. How is alternation of generations different from the sexual reproduction in many other organisms?
4. Do seed-bearing vascular plants produce spores? Explain your answer.
5. A pine tree produces seeds in cones rather than in flowers and fruit. Which of the four types of plants is it?
6. How are vascular plants able to grow so large?

14B Questions

- » How do the tissues of plants affect the way they work?
- » How does a plant use its leaves?
- » What does a plant use its stem for?
- » How do roots bring nutrients to a plant?

THE STRUCTURE OF PLANTS

What is a plant made of?

14.3 PLANT TISSUES

How is the exotic jade vine, found deep in the tropics of the Philippines, like your mom's little basil plant that sits in the kitchen window? They are made of the same four kinds of tissue: dermal, vascular, ground, and meristematic.

DERMAL TISSUE

The **dermal tissue** of a plant does for a plant the same thing that your skin does for you. It protects the outside of the plant and helps the plant either retain or release water. In a plant's roots, dermal tissue also aids in water and nutrient absorption.

The outer layer of dermal cells forms the **epidermis**. The epidermis is more than just a passive barrier that insects and disease can easily bypass; it secretes the *cuticle* to seal in moisture and keep out bacteria and viruses, and it produces different kinds of extensions, such as the prickles on roses or the stinging hairs of nettles, to discourage creatures from venturing too close.

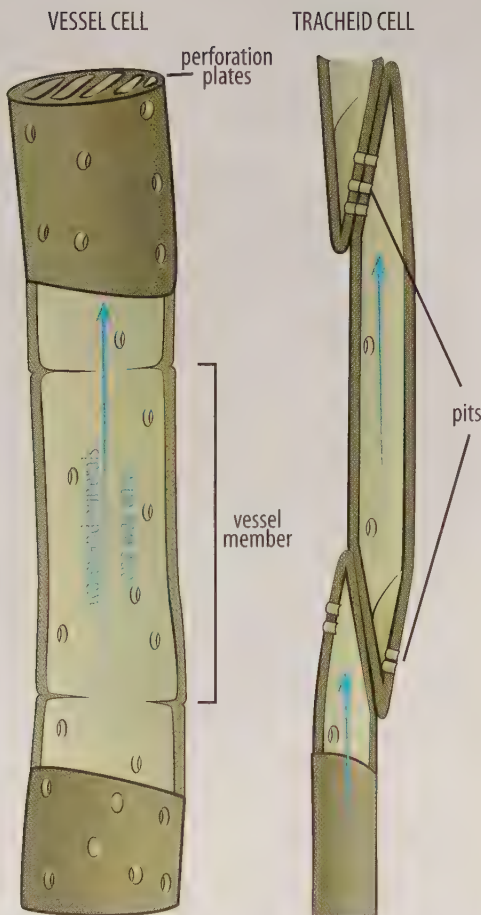
In a plant with woody stems and roots, such as a tree, the epidermis provides another service. The cells of the epidermis die to create thick, tough layers of dead cells called **cork**, which protects and supports the weight of large plants.

VASCULAR TISSUE

Vascular tissue acts as the transport system for a plant, shuttling water (shown with blue arrows in Figure 14-3) and nutrients from the roots, through the stems to the leaves, and then carrying sugar (produced by photosynthesis) from the leaves to other parts of the plant for food or storage.

One kind of vascular tissue, **xylem**, transports water and dissolved minerals from the roots to the rest of the plant. Xylem cells die at maturity, and their hollow cell walls are connected end to end, forming a pipeline for fluids to travel through. The cells also have tiny pits in them that allow fluids to flow between the xylem pipelines. In woody plants, xylem cell walls harden and fill with a polymer called *lignin* to form wood.

Another vascular tissue, **phloem**, transports food (shown with red arrows in Figure 14-4) made in the leaves to the rest of the plant. Like xylem cells, phloem cells are connected end to end, but they contain *sieve plates* at each connection. A sieve plate is similar to the wire



14-3

Xylem is made of two types of cells. *Vessel cells* are wide and hollow with small pits along their sides; grid-like perforation plates can be found between each vessel cell. *Tracheid cells* are slender and hollow; large pits can be found on the sides of and in between each tracheid cell.

mesh that's found at the end of a sink's faucet, which helps control the flow of water from the faucet. Unlike xylem cells, phloem cells are living at maturity.

While xylem carries materials in only one direction—from the bottom of the plant to the top—phloem can carry materials in either direction, depending on the season. While the leaves are actively producing sugar, phloem cells shuttle it to other places in the plant. But after a season of dormancy, such as winter, phloem cells carry sugar and water back to the leaves as the plant gets ready to produce new stems, leaves, and flowers for spring. In some plants, phloem cells form flexible fibers, such as linen from flax and natural rope fibers from the hemp plant.

GROUND TISSUE

Ground tissue is both the workhorse and the packing material of plant tissues, responsible for producing sugar, storing materials, and supporting the plant. The majority of a plant is made of ground tissue.

Ground tissue includes three types of cells. *Parenchyma* (puh RENG kuh muh) cells contain chloroplasts for photosynthesis and then store the products of photosynthesis. The fleshy parts of fruits and vegetables are generally made of parenchyma cells. They also surround the tubes of xylem and phloem to keep them packed together tightly, and they have the ability to divide quickly, which makes parenchyma cells important for healing wounds that a plant may get. *Collenchyma* cells (kuh LENG kuh muh) are very thick and provide flexible support for a plant. They often form long fibers in plants—the “strings” in vegetables like celery. *Sclerenchyma* (skluh RENG kuh muh) cells are thick support cells like collenchyma, but they are much more rigid. When sclerenchyma cells die, their hardened, lignin-filled walls contribute to the woody structures within a plant.

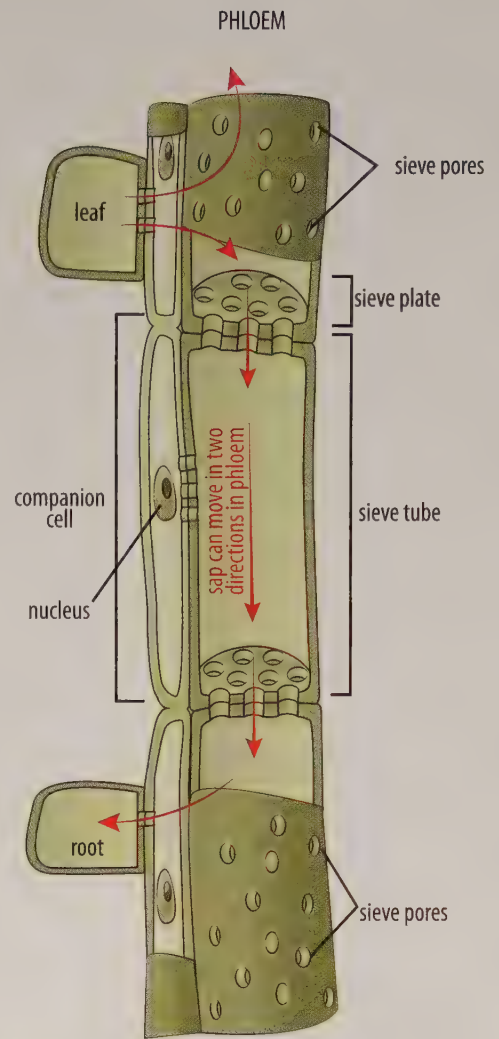
MERISTEMATIC TISSUE

Why do the bushes in your front yard keep growing back, no matter how much you prune them? Plants have the ability to regenerate because of meristematic tissue.

Meristematic tissue consists of undifferentiated cells (stem cells) that can become any type of tissue. They are often found in areas of fast growth, such as new leaves and shoots, flower buds, and root tips. Meristematic tissue is crucial during asexual reproduction, helping a new plant generate leaves, stems, and roots before it breaks away from its parent plant.

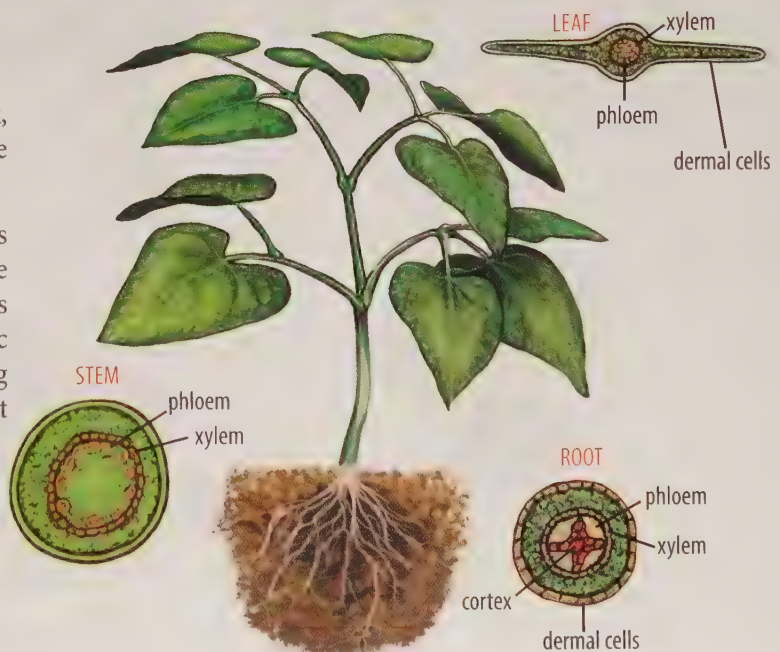
14-5

Three types of mature tissues make up most of a plant's organs. The fourth type, meristematic tissue, is clustered at the very tips of roots, leaves, and stems.



14-4

Sieve tubes and companion cells, which provide nutrients for sieve tubes, carry food around the plant.



144 LEAVES

Leaves are a plant's primary organs for producing energy through photosynthesis and exchanging gases with the environment. Some plants are called evergreens because they retain their leaves throughout the year. *Deciduous* plants lose their leaves each fall and grow them again the following spring. (Leaves are also used to classify plants as either monocots or dicots; see Subsection 14.11.)

The broad part of a leaf is the **blade**. Attaching the blade to the stem of a plant is a tiny stalk called the **petiole**. Many monocots lack a petiole, so their blades are attached directly to the stem. Some leaves have *stipules*, which are tiny leaf-like structures at the base of the petiole. They can protect a newly forming leaf, harden into spines for further protection, produce nectar, or lengthen into tendrils.

VEINS IN LEAVES

Bundles of phloem and xylem form the veins that all leaves have. The arrangement of veins depends on the kind of plant. In monocot leaves, all the veins run parallel to each other; we call this *parallel venation*. In dicot leaves, the veins branch and form a network of smaller veins, a pattern known as *netted venation*.

TYPES OF LEAVES



bipinnately compound—leaf divided into leaflets that further divide into smaller leaflets; mimosa (*Albizia julibrissin*)



pinnately compound—leaf divided into multiple leaflets connected along one main stem called the *rachis*; black walnut (*Juglans nigra*)

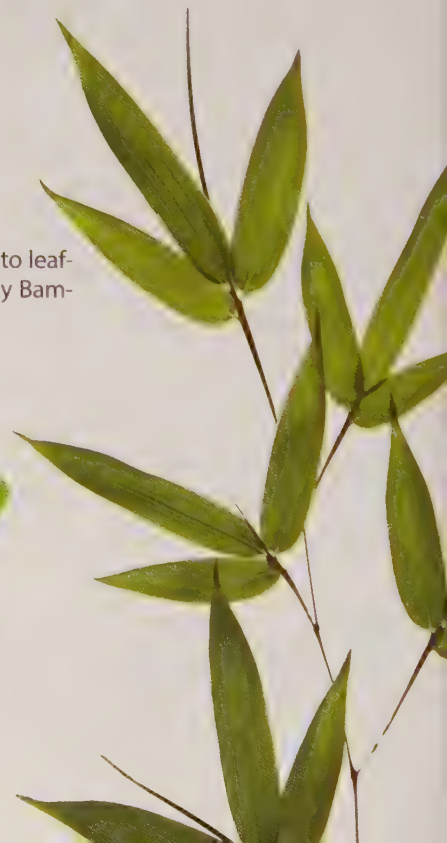


palmate—leaf divided into two or more leaflets connected in one central location; white clover (*Trifolium repens*)



simple—English oak (*Quercus robur*)

simple—not divided into leaflets; bamboo (subfamily Bambusoideae)

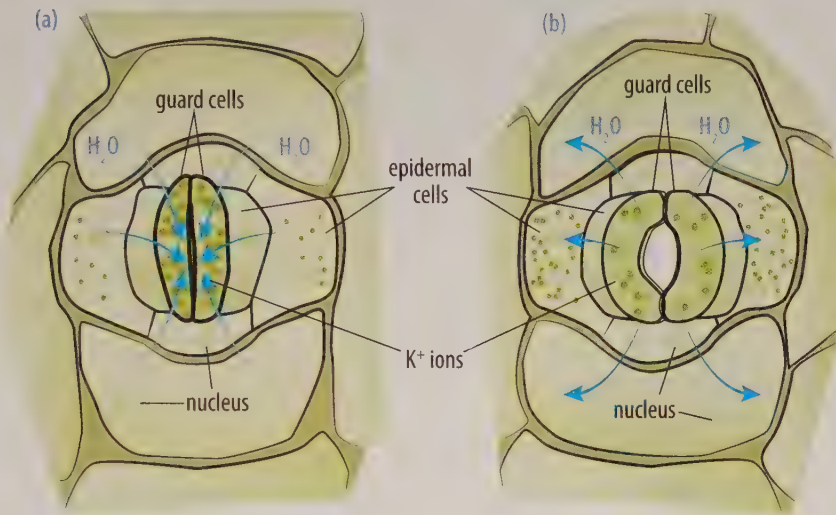


GAS EXCHANGE IN LEAVES

Though plants don't technically breathe, they do have a way to bring in oxygen for cellular respiration and carbon dioxide for photosynthesis and then release oxygen and water vapor as byproducts.

This gas exchange occurs on the underside of each leaf through little openings called *stomata* (s. **stoma**). Around each stoma is a set of **guard cells**, which are modified epidermal cells that open and close a stoma. Through osmosis and active transport, the guard cells swell with water when solutes are pumped into them, pulling them tight and opening the stoma. When solutes are removed from the guard cells, the water goes with them, causing the guard cells to shrink and relax, closing the stoma.

stoma (Gk.—mouth)



14-6

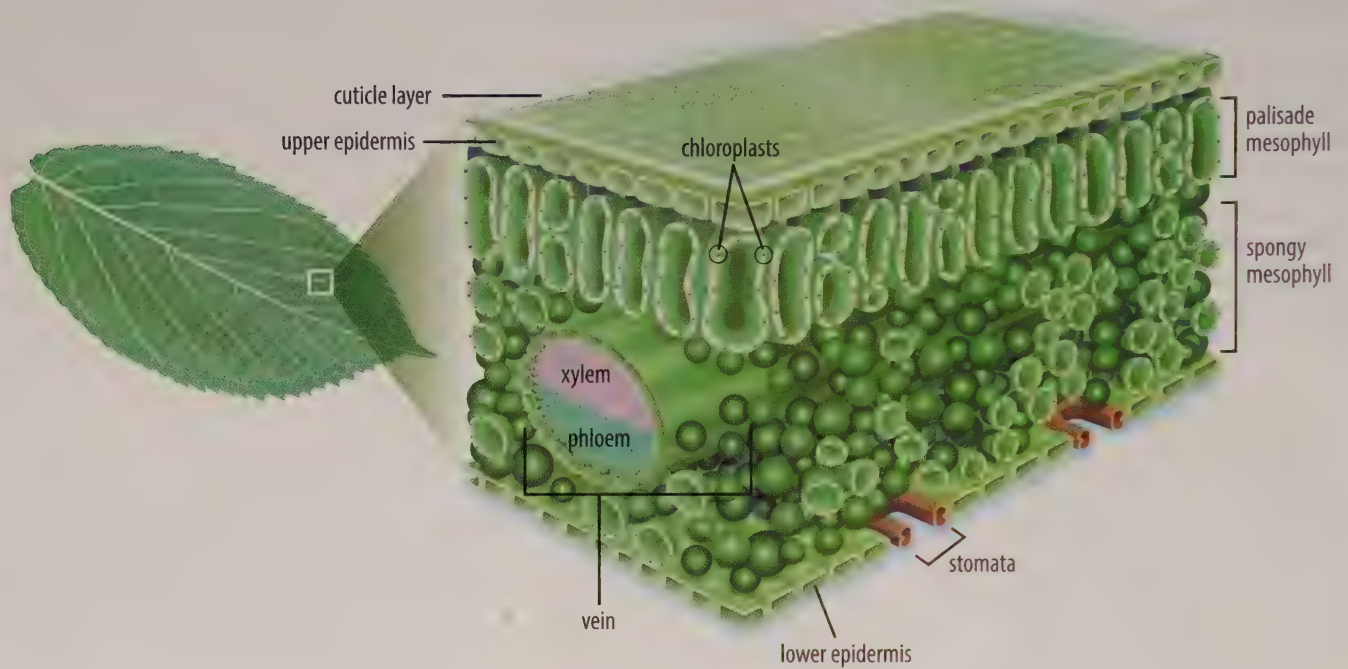
(a) As the plant actively pumps solutes like potassium ions (K^+) into guard cells, water (H_2O) passively follows the solutes through osmosis. (b) When the ions are pumped out, the water follows them out.

STRUCTURE OF A LEAF

Like other plant parts, leaves are made of a mix of dermal, vascular, and ground tissue, with some areas of meristematic tissue. The top-side and underside of a leaf is covered by the epidermis, which secretes a waxy cuticle to seal in moisture. Below the topside layer of epidermis is the palisade mesophyll, an orderly row of tightly packed, column-shaped cells that contain chloroplasts. Chloroplasts circulate from top to bottom within the cells so that each chloroplast can be exposed to the sun. Below the palisade mesophyll is the spongy mesophyll, a layer of irregularly shaped cells that aren't as tightly packed as palisade mesophyll cells. The spongy mesophyll has some chloroplasts, but its main job is to circulate air throughout the leaf by way of the air spaces between each cell. Water moves up the xylem into the spongy mesophyll, and carbon dioxide enters the stomata located on the underside of the leaf. Then both filter through the spongy mesophyll to reach the palisade mesophyll, where they will be used to produce sugar for the plant.

Tubes of xylem and phloem are clustered together in **vascular bundles**, also called *veins*, which run between the middle layers of a leaf.

As the chloroplasts in the palisade mesophyll generate sugar, the cells transport the sugar to phloem cells to be taken to other parts of the plant for food or storage.



14.5 | STEMS

Stems are the highways of plants. They connect leaves to roots and are the avenues that bundles of xylem and phloem travel along. Stems have two main parts: **nodes**, which are the points along a stem that produce leaves, and **internodes**, the region between the nodes. **Buds** are tiny structures at the nodes that will develop into branches.

Though stems vary greatly—from giant tree trunks to tiny stems that hold blades of grass—they can typically be divided into two groups: *herbaceous* stems and *woody* stems.

Herbaceous stems are constructed much like leaves are. They are covered by epidermis, may contain a few stomata, and contain cells for

14-7

Stems get longer through primary growth and thicker through secondary growth.

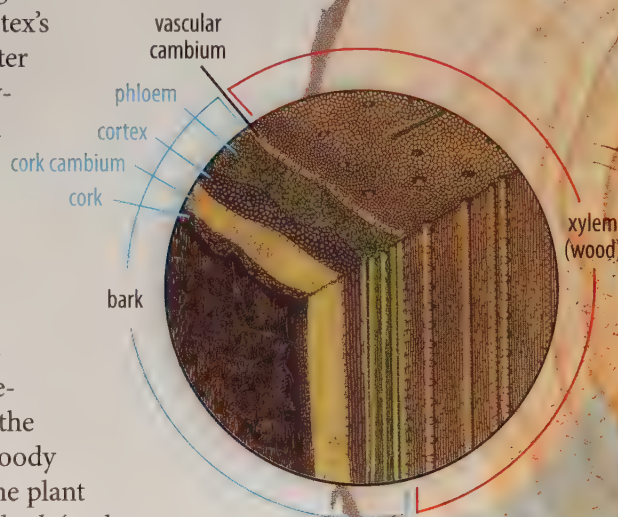


photosynthesis, making herbaceous stems green. Young herbaceous stems are characterized by primary growth—the upward growth of stems that makes them longer. All plants have herbaceous stems at some point in their growth. Most monocots retain their herbaceous stems throughout their lives, but the stems of many dicots turn into woody stems. Once stems become woody, they can continue to grow by secondary growth—an increase in diameter.

WOODY DICOT STEMS

Woody stems have their epidermis replaced by a meristematic layer called the **cork cambium**, which produces cork cells to protect and support the stem. Behind the cork cambium is the cortex, a layer of ground tissue that can fill several roles. In some plants, the cortex acts as storage. In others, the cortex cells have chloroplasts, making them capable of photosynthesis. But the cortex's main function in a stem is to allow water to flow between inner and outer layers of tissue and to exchange air with the environment through tiny pores (called **lenticels**) in the surface of a woody stem.

The next layer in a woody stem is the **vascular cambium**, which is a thin layer of meristematic tissue that produces a plant's xylem and phloem. Despite its thinness, vascular cambium is the most active layer of living cells in a woody stem, producing new cells as long as the plant lives. It also separates a woody plant's *bark* (cork, cork cambium, cortex, and phloem) from the plant's *wood* (hardened, lignin-filled xylem cells).



YEARLY GROWTH OF A WOODY STEM

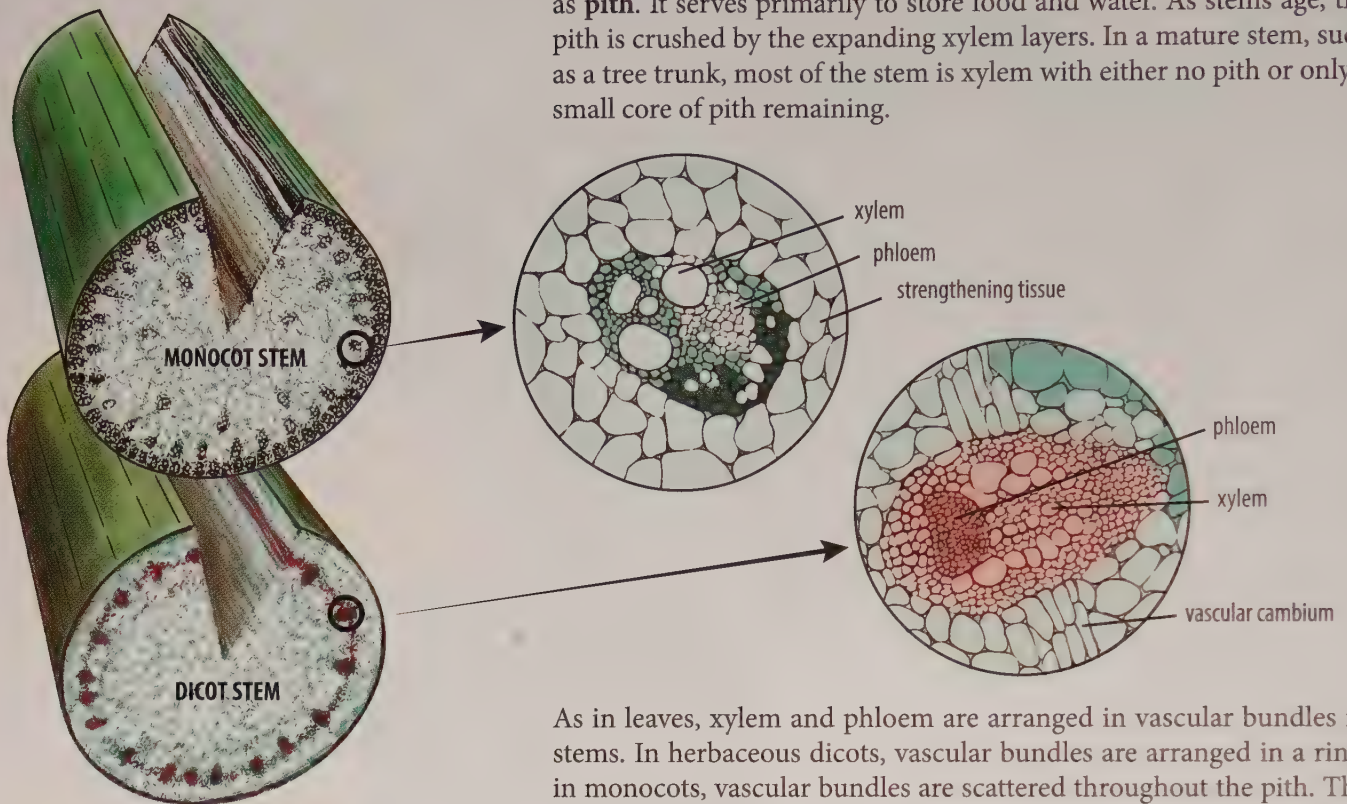
Plants not only put out new primary growth; they also get larger through secondary growth. Each spring, a woody stem produces lots of new xylem to get ready for the flurry of growth that's about to take place, decreasing that production as summer comes on. This difference in seasonal xylem production creates **annual rings** that can give us a good estimate of how old a tree is. Annual rings can also tell the story of a tree. If the tree lived through a very rainy spring, the spring ring for that year will be wide and light colored; we call it *springwood*. As the temperatures get hotter and the rain lessens, the summer ring will be thinner and darker, forming *summerwood*.



Dark summerwood and light springwood rings. One summerwood ring and one springwood ring make up one annual ring.

HERBACEOUS DICOT AND MONOCOT STEMS

The spongy ground tissue in the center of herbaceous stems is known as **pith**. It serves primarily to store food and water. As stems age, the pith is crushed by the expanding xylem layers. In a mature stem, such as a tree trunk, most of the stem is xylem with either no pith or only a small core of pith remaining.



As in leaves, xylem and phloem are arranged in vascular bundles in stems. In herbaceous dicots, vascular bundles are arranged in a ring; in monocots, vascular bundles are scattered throughout the pith. The main difference between dicot and monocot stems is that monocots typically have no secondary growth because they lack a cork cambium, cortex, and vascular cambium. See page 276 for a discussion of monocots and dicots.

14.6 ROOTS

How does a tree that's 40 feet tall stay upright? How do vines of ivy climb walls? They use their roots. Roots are the primary organs for anchoring a plant and normally grow from the stem. They also absorb water and nutrients and store food that was made in the leaves. Roots are also important in asexual reproduction. If you can coax a part of a plant to grow roots, then that part can become a separate plant.

Plants have one of two types of root systems. A **taproot system** consists of one main root—the taproot—and lots of small roots branching from it. Many dicots have taproot systems. Carrots and beets are actually enormous taproots. Monocots typically have **fibrous root systems**, which are many small roots that come straight from the stem and not a taproot.



14.9

The taproot of a carrot and the fibrous roots of grass

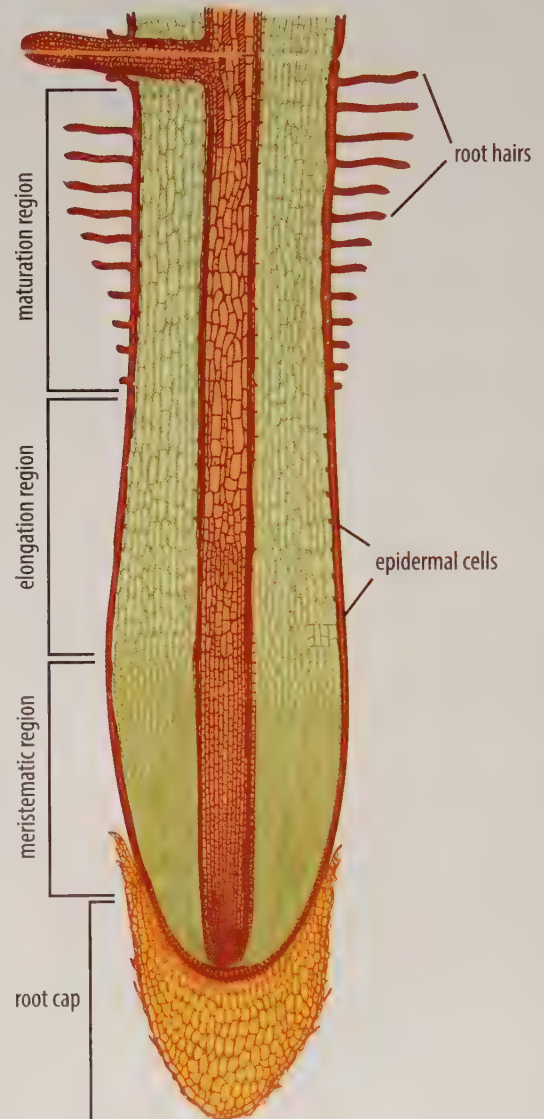
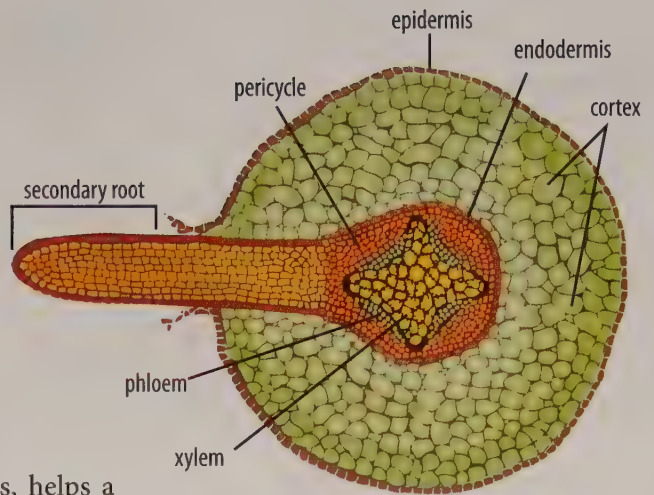


STRUCTURE OF A ROOT

Like stems, roots are capable of both primary and secondary growth. But roots don't have nodes or buds, so their primary growth—elongating the root—is limited to the meristematic tissue at its tip. The root tip is covered by a root cap, which is made of dead cells for protecting the delicate, fast-growing tissue.

Roots are covered by an epidermis. Along certain portions of a root, the epidermis will extend to form root hairs, which are used to increase a root system's surface area, allowing a plant to find and absorb water that the main roots can't reach.

Under the epidermis is the *cortex*, which stores materials, helps a plant take in water and minerals, and is made of ground tissue. Just inside the cortex is the *endodermis*, a thin layer that is considered part of the cortex and is made of tightly packed cells that carefully regulate the flow of materials between the cortex and the vascular tissues. In between the endodermis and vascular tissues is the *pericycle*, a meristematic tissue used to form secondary roots that branch off the main root. The pericycle produces roots that are different from the root hairs of the epidermis: a root that grows from the pericycle will be covered in dead cork cells instead of an epidermis, so they are able to absorb water only through their tips.



14B REVIEW QUESTIONS

1. Determine the tissue type for each plant part in the table.

Plant Part	Structure	Tissue Type
vein	leaf	
cortex	stem	
root tip	root	
spongy mesophyll	leaf	
root hair	root	

2. What would happen if the palisade mesophyll were below the spongy mesophyll?
3. You are asked to identify a plant. Its leaves exhibit netted venation, and it does not appear to experience any secondary growth. Is this plant a monocot or a dicot? Explain.
4. Explain the difference between primary and secondary growth.
5. Why does a woody stem require a cork cambium but a herbaceous stem does not?
6. Why would a long taproot be beneficial for a large woody dicot such as a tree?



14C Questions

- » What are the various ways that plants reproduce?
- » How does a plant grow from a seed and produce seeds of its own?
- » How can the parts of a plant be used for both beneficial and harmful purposes?

14C

THE LIFE CYCLES OF PLANTS

How do plants reproduce?

14.7 ALTERNATION OF GENERATIONS

Unlike animals, which are diploid and produce haploid gametes through meiosis, plants produce an entire haploid structure called a **gametophyte**. The gametophyte then produces haploid *gametes* (e.g., sperm and eggs). These gametes combine to form a diploid *zygote* (e.g., a seed). Once the zygote germinates, the diploid plant that emerges is known as a **sporophyte**. A few cells of the sporophyte undergo meiosis to produce haploid spores. The spores germinate to form a gametophyte, beginning the process again. This is the process of alternation of generations, the sexual reproductive cycle of all plants.

In ferns, cone-producing plants, and flowering plants, the sporophyte stage is dominant and is therefore the most visible. In nonvascular plants like mosses, the gametophyte stage is dominant.

14.8 LIFE CYCLE OF MOSSES

Mosses, the largest group of bryophytes, are incredibly adaptable. They can be found anywhere from the harsh cold of the tundra to the hot humidity of the tropical rainforest. You've likely seen moss growing on a rock beside a stream. The velvet green that's visible is the *leafy shoot* of the moss plant. Leafy shoots are responsible for collecting water and nutrients for the plant, similar to how a paper towel absorbs water. *Rhizoids* are the "roots" that anchor a moss plant in place. They can't absorb water and nutrients like true roots can, so water from the leafy shoots keeps rhizoids moist and nourished.

Leafy shoots are the gametophytes produced during the gametophyte stage. Some of the leafy shoots produce male gametes (sperm), and some produce female gametes (eggs). When water splashes onto the sperm-containing shoots, the sperm are released and the water helps carry the sperm to egg-containing shoots. When a sperm and an egg unite, they form a zygote.

14-10

A moss plant with its sporophyte and gametophyte stages visible



ALTERNATION OF GENERATIONS IN MOSSES

The diagram illustrates the life cycle of mosses, showing the alternation between the gametophyte and sporophyte generations.

GAMETOPHYTE (2n):

- Protonema (young gametophyte):** Develops from a germinating spore.
- Germinating spore:** The spore begins to grow.
- Spore:** The starting point of the gametophyte generation.
- Capsule:** The structure where the sporophyte develops.
- Gametophyte:** The haploid (n) vegetative stage, consisting of a protonema and a mature sporophyte.
- Rhizoids:** Root-like structures that anchor the gametophyte.

SPOROPHYTE (2n):

- Mature sporophyte:** The diploid (2n) stage that grows out of the capsule.
- Young sporophyte:** The early stage of the sporophyte.
- Zygote:** The diploid (2n) cell formed by the fusion of gametes.
- Egg:** The haploid (n) female gamete.
- Sperm:** The haploid (n) male gamete.

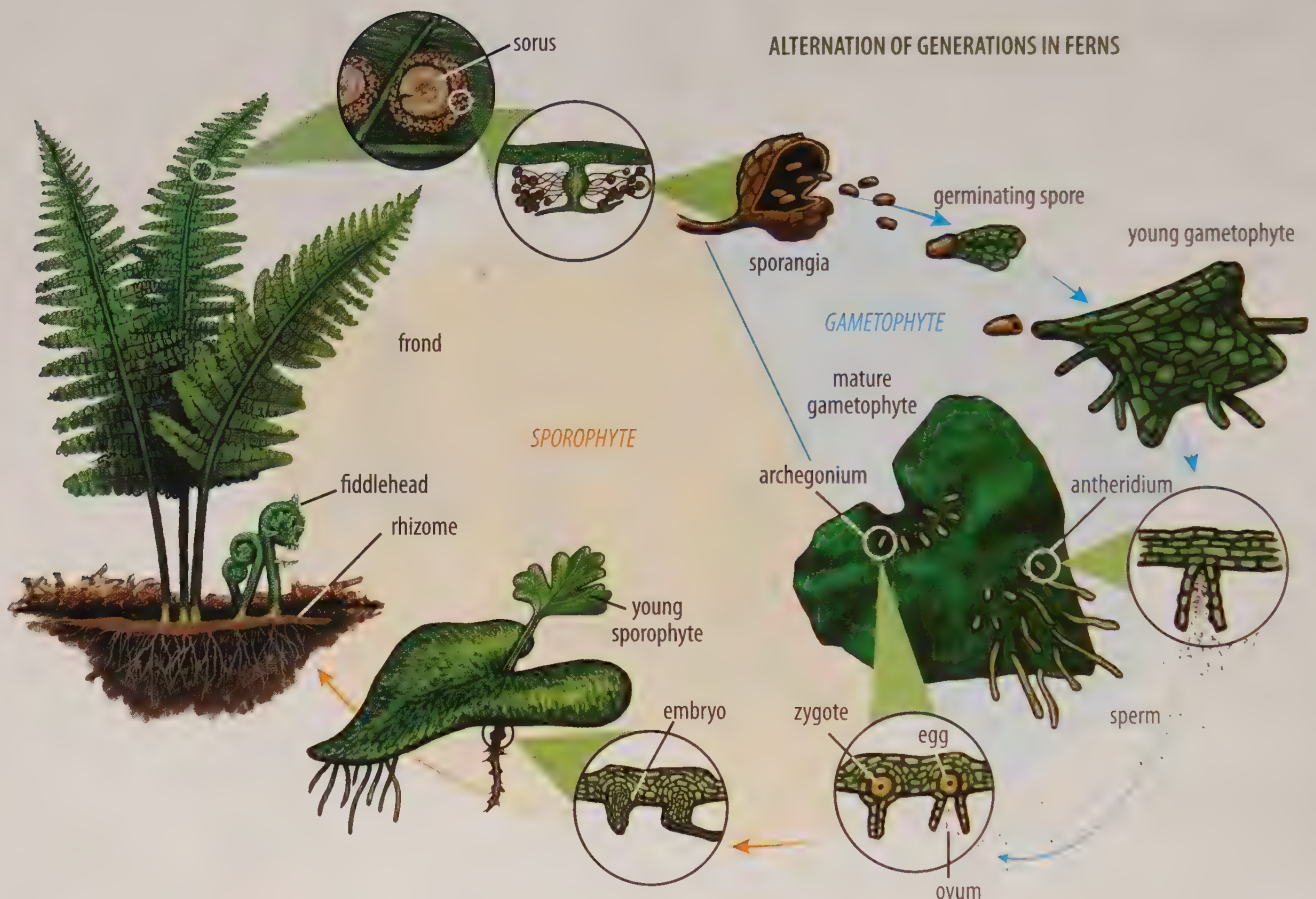
The cycle shows the transition from the gametophyte to the sporophyte and back to the gametophyte.

149 LIFE CYCLE OF FERNS

The leaves of a fern are usually called **fronds**. Fronds are vascular, so they can grow to be quite large in some species. A fern's underground stems are known as *rhizomes*, which produce roots, store nutrients for the rest of the fern, and help the fern multiply and spread through asexual reproduction.

On the underside of fern fronds are rows of tiny bumps called *sori* (s. **sorus**). Sori are structures that house and protect a fern's sporangia (s. sporangium), which produce spores.

After release, the spores germinate to begin the gametophyte stage of the fern's sexual reproduction. The tiny, heart-shaped gametophyte that's produced, the *prothallus*, lies flat against the ground and is difficult to see. The prothallus is designed to live just long enough to form structures that produce sperm and eggs and rhizoids that anchor the prothallus. The sperm swim to where the eggs are and fertilize them, creating zygotes that develop into sporophytes known as *fiddleheads*. The fiddleheads will grow and unfurl into a full-size frond.



14.10 LIFE CYCLE OF GYMNOSPERMS

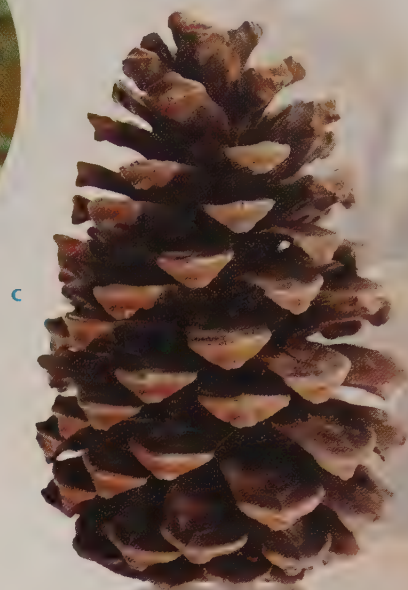
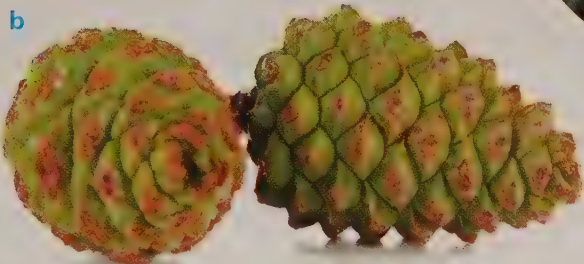
Every Christmas, gymnosperms get plenty of attention as their cones and boughs are used to celebrate the season. Gymnosperms can be found in every climate in the world, but the largest group—the conifers—are famous for enduring bitterly cold, snowy weather. Part of the reason for their durability is that, instead of using fragile flowers and soft fruits to produce and protect their seeds, they make their seeds in hardy cones.

Conifers and most other gymnosperms produce two types of cones. Pollen cones are small male cones that house structures producing sperm-containing *pollen*. Seed cones are large female cones that are made of scales, with each scale containing two eggs. Before fertilization, seed cones are green. As pollen



14-12

(a) Pollen cones, (b) immature seed cones, and (c) mature seed cones



makes its way into seed cones and fertilizes the eggs inside, the seed cone closes to protect the developing zygotes and seeds. Instead of the zygotes turning directly into sporophytes, they remain inside a seed. When conditions are right, the seed cone, now brown and woody, opens up to release its seeds.



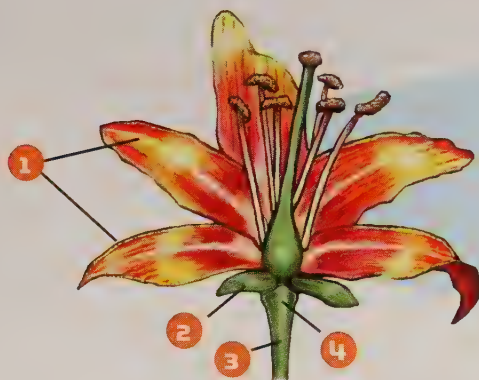
14.11 LIFE CYCLE OF ANGIOSPERMS

Petals 1 are the often brightly colored, scented part of plants and are useful in attracting pollinators.

Sepals 2 are usually green, leaf-like structures that protect flower buds as they form and support the flower's petals after it blooms.

The **pedicel** 3 is the stalk that connects the flower to the rest of the plant.

The **receptacle** 4 is the thickened top part of the pedicel that supports the actual flower parts.

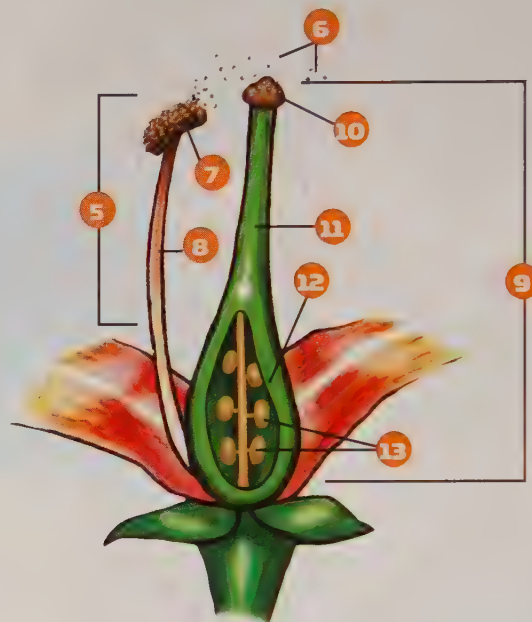


The male reproductive structures of flowers are the **stamens** 5, which produce pollen grains 6 containing male gametes. A stamen has two parts—the **anther** 7, where pollen grains are formed and stored until their release, and the **filament** 8, the stalk that connects the anther to the flower.

The female reproductive structures are contained within the **carpel** 9. At the top of the carpel is the **stigma** 10, which traps pollen with its sticky surface. The **style** 11 is the neck of the carpel that leads to the **ovary** 12, which harbors separate egg chambers called **ovules** 13.

FLOWER STRUCTURE AND FUNCTION

Though flowers come in all shapes and sizes, they have the same general parts.



POLLINATION

The parts of a flower are designed to produce gametes and seeds so that a flowering plant can generate offspring. But how do these parts work together?

Pollen grains leave the anther when carried by the wind, water, or an animal. To attract birds, insects, and other potential pollinators, flowers produce *nectar*, a sweet-tasting liquid secreted at the base of the petals. As pollinators flit from flower to flower drinking nectar, they're brushing against the anthers and taking pollen with them. Plants depend on pollinators because most plants cannot *self-pollinate* (produce seeds from the pollen and eggs of the same flower). They must be *cross-pollinated*, exchanging their pollen with other plants of their species.

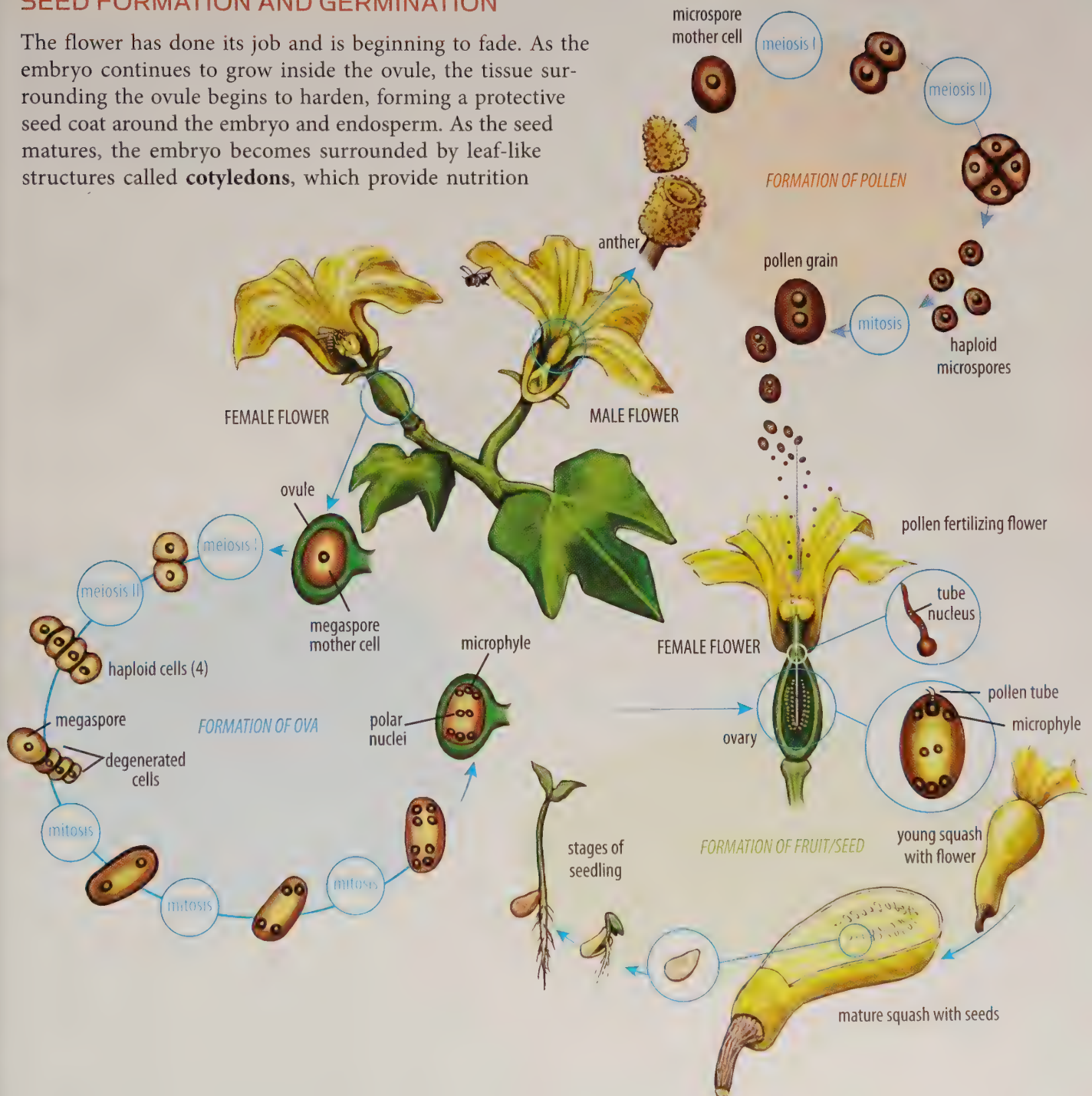
During pollination, pollen grains land on the sticky stigma of a flower and produce a *pollen tube* that begins to tunnel into the style. The pollen tube allows the male gametes to reach the female gametes inside the ovary's ovules. In gymnosperms, pollination is similar. The difference is that pollen forms a pollen tube directly into the ovules of a gymnosperm—there are no flower parts to tunnel through.

FERTILIZATION

Once the pollen tube reaches an ovule, one sperm fertilizes the egg cell (forming the zygote), and other sperm fertilize other cells in the ovule, called *polar bodies*. The fertilization of both the egg and the polar bodies is known as **double fertilization** and is unique to plant reproduction. While the zygote develops into an embryo, the fertilized polar bodies become the **endosperm**, which is the stored food inside a seed that nourishes the embryo.

SEED FORMATION AND GERMINATION

The flower has done its job and is beginning to fade. As the embryo continues to grow inside the ovule, the tissue surrounding the ovule begins to harden, forming a protective seed coat around the embryo and endosperm. As the seed matures, the embryo becomes surrounded by leaf-like structures called **cotyledons**, which provide nutrition



monocot: mono- (Gk. *monos*—one) + -cot (shortened form of *cotyledon*)

dicot: di- (Gk. *di*—two) + -cot

monocot corn seed



dicot bean seed



for the embryo in addition to the endosperm. Once the seed is mature, it will break away from the ovary wall, leaving a scar on the seed called a *hilum* that is similar to a person's navel.

Some differences between monocots and dicots were mentioned in Section 14B. That classification is based on the number of cotyledons that a plant has. Plants that have one cotyledon are **monocots**, while plants with two cotyledons are **dicots**. In most dicot seeds, the embryo uses up all the nutrients in the endosperm and then relies on the cotyledons for its food; a few species use these resources in reverse order. In monocots, the single cotyledon remains small, and the embryo continues to get its nutrients from the endosperm.

From the embryo grows a *plumule*, the structure that will eventually produce the leaves and stems of the plant. The embryo also forms a *radicle*, which will act as the seedling's first root. But before these structures can emerge from the seed, something has to crack open the seed coat. The right combination of three different factors will cause a seed to **germinate**, or sprout from the seed to form a new plant, as explained below.

Temperature—Some seeds need a season of cold followed by a warm season. Others seeds are activated by extreme heat, like a forest fire, which pushes a seed into germination.

Oxygen—Like almost every other living creature, plants need oxygen for cellular respiration.

Moisture—When a seed is placed in a moist environment, it begins to absorb water, causing the seed coat to swell and split and triggering the endosperm and cotyledons to release large amounts of energy for the embryo's growth spurt.



FRUIT FORMATION

While the seed is forming inside an ovule in the ovary, the ovary is forming something else on its own. The ovary grows thicker and thicker to form a **fruit**, which will help a plant protect its seeds and disperse them when the time is right. Some plants, such as apples and pears, form their fruits inside an enlarged receptacle. So when you bite into an apple, you're eating what's known as an *accessory fruit*; the true fruit lies in the apple core where a thin ovary wall protects the seeds.

There are several ways to classify plants according to their fruits. *Simple fruits* form from a single ovary, while *complex fruits* grow from more than one ovary. Simple fruits can be further classified as either *dry*, such as peanuts and sunflower, or *fleshy*, such as tomatoes and peaches.

Table 14-1

Classifying Fruits

Type	Examples
Simple fruit (comes from single ovary)	
Dry fruit (hardened or leathery ovary wall at maturity)	
legume (ovary wall splits in half)	bean, pea, peanut
capsule (ovary wall splits open in many directions)	poppy, mustard
grain (thin seed coat fused to the ovary wall)	corn, wheat
nut (thick, tough ovary wall)	acorn, chestnut
achene (thin ovary wall)	sunflower, dandelion
samara (winged achene)	maple, elm
Fleshy fruit (thickened, fleshy ovary wall at maturity)	
drupe (fleshy fruit with one seed)	olive, peach, coconut
pome (thickened receptacle with a thin ovary wall around the seeds)	apple, pear
true berry (very thin ovary wall)	tomato, grape, blueberry
pepo (modified berry with a hard rind)	squash, cantaloupe
hesperidium (modified berry with leathery partitions and skin)	orange, lemon
Compound fruit (comes from multiple ovaries)	
aggregate fruit (forms from several ovaries within one flower)	raspberry, blackberry
multiple fruit (forms from the ovaries of several flowers that fuse together)	pineapple, fig

14.12 USING PLANTS WISELY

A single plant can be a valuable medicine or an addictive drug, even a deadly poison. The common foxglove (*Digitalis purpurea*) is very poisonous, but its toxin, *digoxin*, is an important heart medicine. Digoxin must be used very carefully since there is only a small difference between an effective dose and a toxic one. Only a trained medical professional should ever prescribe digoxin or any other prescription drug to a medical patient.

The plant that most likely best epitomizes this dichotomy is the opium poppy (*Papaver somniferum*). Opium and its derivatives, like oxycodone, are powerful painkillers that have brought relief to many patients suffering from pain as a result of accidents or surgery. However, many people who are not dealing with pain take these painkillers for the thrill of it or to escape their problems, bringing other and often much more terrible problems into their lives.

Since ancient times, people have used and abused the medicinal power of opium. Researchers have combed through the plant kingdom for centuries to find something to combat the addictive power of opium products, collectively known as *opiates*. During the American Civil War, soldiers were given the opiate *morphine* to treat pain and diarrhea. But so many soldiers became addicted to it that the addiction became known as “soldier’s disease.” So pharmacists created another opium-based medicine that they thought wouldn’t be as addictive as morphine. They named it *heroin*. Within just a few years, physicians realized that heroin was even worse for patients than morphine. In 1924 it was declared illegal.

During World War II, Polish scientist Jack Fishman began experimenting with opiates to see whether he could find a way to keep their medicinal properties and do away with their addictiveness. Fishman came to the United States after the war and soon invented *naloxone*. Naloxone quickly became the most popular drug on the market to fight opiate addictions and overdoses and is still commonly used today because of its relatively low cost and lack of side effects.

Another plant that can both powerfully help and hurt people is the coca plant (*Erythroxylum* spp.), native to South America, used medicinally for centuries by people who chew its leaves or brew it to make tea. Chemicals in coca leaves can relieve altitude sickness, caused by breathing thin air in mountainous regions. The leaves also provide vitamins and minerals that help regulate blood sugar and give colas their signature flavor. But those same chemicals can be extracted and concentrated to form the highly addictive drug *cocaine*.

God created things like opium poppies and coca plants for our good, but in our fallen state we have defiled their good uses. Countries must deal with both the drug cartels that grow these plants to make illegal drugs and the people who fall prey to them. How should we manage something that God created and people corrupted?

Many countries regulate or prohibit opium poppies and coca plants in an attempt to keep the illegal drug trade under control. But the plants



14-13

Poppy seeds grow in pods at the base of the poppy flower. Opium is extracted from a white liquid that leaks out of the pod when it is slit with a knife.



14-14

Most countries have declared coca plants illegal, but they’re still legal to grow in Peru (above) and other South American countries.

then often appear elsewhere. The ultimate solution to living with easily misused plants is Christ. When people rely on Christ's strength, they can resist the temptation to be controlled by drugs and allow Him to lead them out of their addiction. God also uses people to help others, giving scientists the ability to create medicines like naloxone that have helped thousands of people break away from the drugs that held them captive. Naloxone can also be used in combination with pain killers like oxycodone so that addiction never happens in the first place. We should study and wisely use these potent plants so that we can gain the greatest benefit from them and help people fight the corruption that often comes with fallen man's attempts to manage the earth.



14-15

Foxglove produces digoxin, which can be used to prevent heart failure in patients with heart disease.

14C REVIEW QUESTIONS

1. Identify the dominant generation, the gametophyte or the sporophyte, in each of the four types of plants.
2. Place the following structures of a fern in the correct order of its lifecycle, following the fiddlehead: frond, gametes, prothallus, spore, zygote.
3. Are gymnosperm cones part of the gametophyte or the sporophyte structure?
4. List the two types of haploid cells that are fertilized in a plant's double fertilization. What do they form in the seed?
5. How could a forest fire be beneficial to a seed?
6. Pick a fruit not listed on Table 14-1 on page 277. What type of fruit is it?
7. Some states allow naloxone to be sold without a prescription to drug users in case they overdose. However, it is possible that drug users who buy naloxone may be less likely to seek help with their addictions. From a biblical viewpoint, is naloxone beneficial to humans? Explain.

REVIEW QUESTIONS

Key Terms

cellulose	259
cuticle	259
alternation of generations	259
vascular	260
nonvascular	260
gymnosperm	261
angiosperm	261
bryophyte	261
dermal tissue	262
epidermis	262
cork	262
vascular tissue	262
xylem	262
phloem	262
ground tissue	263
meristematic tissue	263
blade	264
petiole	264
stoma	265
guard cell	265
vascular bundle	265
node	266
internode	266
bud	266
cork cambium	267
lenticel	267
vascular cambium	267
annual ring	267
pith	268

(continued)

CONCEPT REVIEW

1. Why did God create plants?
2. What five characteristics distinguish plants from other living things?
3. Do liverworts produce seeds? Explain.
4. Which of the four basic plant tissues would liverworts not have? Explain.
5. What are two differences between a seed and a spore?
6. Copy this table on your own paper. Fill in the blanks of the table with the words nonvascular, seedless vascular, gymnosperm, and angiosperm.

Characteristics

Type

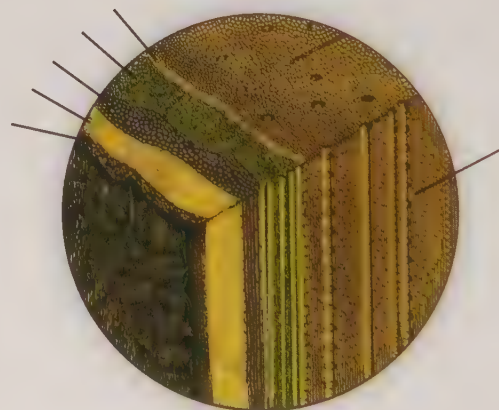
seeds produced without flowers or fruit
always small; gametophyte the dominant structure
largest group of plants
spores produced in sori

7. What type of leaf is illustrated on the right?



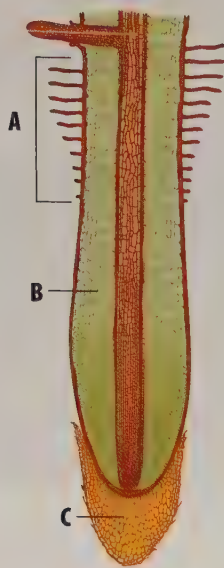
8. Does the palisade mesophyll or the spongy mesophyll have a greater role to play in transpiration? Explain.

Use the diagram below to answer Questions 9 and 10.



9. Draw the diagram on your paper and label the cork, cork cambium, vascular cambium, phloem, and xylem.
10. Is this stem a monocot or a dicot?

11. In the diagram below, correctly identify structures A, B, and C.



12. In the alternation of generations, is the structure that produces spores haploid or diploid?
13. Draw and label a process map of alternation of generations in a moss including the words gamete, gametophyte, spores, and sporophyte. (See Appendix B.)
14. Draw a process map of the life cycle of ferns, using the terms fiddlehead, frond, prothallus, rhizoids, and spore.
15. What is the main structure of the gametophyte in the fern life cycle?
16. Name one similarity and one difference between gymnosperm and angiosperm reproduction.
17. Why do you think seed cones close only after the eggs have been pollinated?
18. Which structures are associated with the pedicel and the petiole? Explain.
19. Trace the diagram below on your paper. On your drawing, label the flower's carpel, pedicel, petals, sepals, and stamens.

Key Terms (continued)

taproot system	268
fibrous root system	268
gametophyte	270
sporophyte	270
frond	271
sorus	272
petal	274
sepal	274
pedicel	274
receptacle	274
stamen	274
carpel	274
ovule	274
double fertilization	275
endosperm	275
cotyledon	275
monocot	276
dicot	276
germinate	276
fruit	277



Use the diagram below to answer Questions 20 and 21.



20. Draw the germinating seed in the figure on your paper. Label the plumule, the radicle, and the one or two cotyledons.
21. Is this plant a monocot or a dicot?
22. Classify a lime as either a simple fruit (specify dry or fleshy) or a compound fruit.

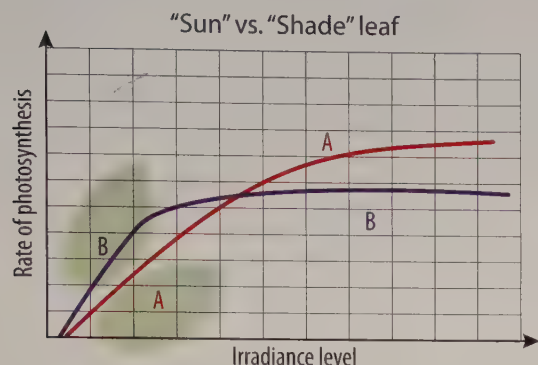
TRUE OR FALSE

23. Sclerenchyma cells provide the plant with structural support even after the cells die.
24. In plants experiencing secondary growth, the vascular cambium lies between the xylem and the phloem.
25. Annual rings are created by alternating layers of xylem and phloem.
26. Secondary roots do not have root hairs.
27. The root's endodermis is made of dermal tissue.
28. Plants produce spores by meiosis.
29. An angiosperm's pollen tube contains only one sperm cell.
30. The pollen comes from the filament of the stamen.
31. Because of the dangers of misuse of drugs such as morphine and oxycodone, believers should not support their use in any situation.

CRITICAL THINKING

32. Would a tree be able to grow tall without cell walls? Explain.
33. Explain the relationship between a moss's small size and its lack of vascular tissue.
34. Do you think a wind-pollinated flower is likely to produce nectar? Explain.

Use the graph below to answer Questions 35–38.



35. These lines represent two different types of leaves and how fast they perform photosynthesis in different levels of light. Sun leaves and shade leaves can be on the same plant. Which is a shade leaf, A or B? How can you tell?
36. Why can the same plant have sun and shade leaves on it?
37. Shade-loving plants have more chlorophyll in them than those of sun-loving plants. Why do you think this is?
38. Sun-loving leaves are thicker and smaller than shade-loving leaves. Explain why.

Use the Case Study below to answer Questions 39–41.

CASE STUDY: YUCCAS AND YUCCA MOTHS

The yucca plant and the yucca moth have a mutualistic relationship. The yucca moth lays its eggs only in yucca flowers and actively pollinates the flower with pollen from a flower on another yucca plant. Neither the yucca nor the yucca moth could survive without the other.



39. What would happen to the yucca plant population in an area if all the yucca moths in that area suddenly died?
40. While most yucca moths mature a year after they hatch from eggs, some individuals mature two or more years later. How does this help both species to survive?
41. Evolutionists claim that the plant and the insect coevolved to support one another. Point out some of the flaws in this idea.



CHAPTER 15

PLANT PROCESSES

TRANSPORTING NUTRIENTS

PLANT RESPONSES

USING PLANTS WISELY

WEEDING OUT THE SUPERVILLAINS

Sam Walter is a soybean farmer who needs a good crop to have the money to support his family. But in years past, every time his plants sprouted, insects ate them before they got a chance to produce beans. And if his plants survived the insects, they were quickly choked by weeds. So for the past few years he has bought the latest in genetically modified (GM) soy plants, which are resistant to pests and to the weed killer *glyphosate*. But the weeds have begun to fight back, and several species are now resistant to glyphosate. Though GM plants seem like the perfect solution to food-shortage problems, many people are fearful of their effects on humans and the environment. Many others balk at the price of GM plants, which can cost twice as much as traditional plants. Is there a way to create safe and inexpensive food crops that will save the day?

TRANSPORTING NUTRIENTS

How do plants get nutrients from the soil to their leaves?

15A Questions

- » How does sap move throughout a plant?
- » How does a plant obtain the nutrients it needs?

15.1 RIVERS OF LIFE

We rely on plants in many ways, so it's important for us to understand them. A plant doesn't have a heart or blood to move nutrients throughout its body. Instead it relies on columns of water in its vascular tissues to transport necessary nutrients. God has designed some marvelous mechanisms for plants to deliver minerals and sugars where they are needed. As you learned in Chapter 14, plants have two types of vascular structures, xylem and phloem. Xylem carries primarily water and dissolved minerals from the soil. Phloem carries sugars from leaves to storage organs or areas of growth. While the fluids in xylem and phloem are different from one another, they are both often called **sap**.

Scientists have created models to explain how xylem and phloem move sap around the plant. While scientists accept these models, they do not always explain all the evidence, but they are the best models currently available. It's always important to remember that models are only representations of reality and so are always subject to revision or even replacement. For this reason, scientists must be careful not to cling to an old model when a better one comes along. Constantly testing and revising models is one of the strengths of science, but it also makes science a poor source for absolute truth. A model that is accepted today may be replaced by another model tomorrow. If you are looking for absolute, unchanging truth, you must look to the Word of God.

15.2 RIVERS FLOWING UPWARD

Somewhere in California's Redwood National and State Parks stands Hyperion. Scientists believe that this coast redwood (*Sequoia sempervirens*), named for one of the gigantic Titans of Greek mythology, is the tallest tree in the world, standing just over 379 feet tall. To survive, this tree's xylem must transport several hundred gallons of water from the ground through its leaves into the atmosphere each day. This process is called **transpiration**.

The roots provide a small portion of the force necessary to move water all the way to Hyperion's highest leaves. The roots' epidermis, especially the root hairs, absorbs water and dissolved minerals from the soil. Root cells use active transport to increase the amount of dissolved minerals inside the root so that osmotic pressure moves water from the soil into the root cortex. The incoming water pushes water already in the root deeper into the cortex. The water is then filtered through the endodermis as it

15-1

Coast redwoods are the tallest trees in the world.





moves into the xylem. The *root pressure* caused by the incoming water will push the water and dissolved minerals up the xylem.

Water's properties also help it rise in the xylem. Water molecules often stick to glass due to the property of *adhesion*, an attraction between molecules of different substances. Adhesion is important to plants because it causes water to rise into a thin tube above the level of the rest of the water. This is called **capillary action** and is greater for a thin tube than for a wide one. Since xylem are very small tubes, capillary action also explains some of the water's movement from the roots to the leaves.

However, root pressure and capillary action can move water only a short distance. If they were the only forces moving the *xylem sap*, the tallest trees would never be more than ten or fifteen feet tall. Any tree taller than that would die because the water would not be able to make it all the way to its leaves. Root pressure and capillary action operate by pushing the water up the xylem from the bottom, but most of the force that moves the water up the xylem operates by *pulling the water up from the top*. Water molecules are attracted to each other because of their strong hydrogen bonds. In chapter 2 we saw this tendency of substances to stick together, a property called *cohesion*. It is responsible for the surface tension that allows water striders to glide across the surface of water. According to the **cohesion-tension theory**, as transpiration occurs, water molecules in the leaves' spongy mesophyll exit the leaf as water vapor through the stomata. More water moves from the xylem into the spongy mesophyll. As these molecules move out of the xylem, cohesion pulls on the other water molecules in the xylem, causing all the water to move up the entire length of the xylem.

As water moves up the xylem, it accomplishes several purposes. Some water enters into cells' central vacuoles. A full central vacuole presses the cytoplasm and cell membrane against the cell walls, maintaining **turgor pressure**, which gives a plant rigidity—and is why a plant that lacks water looks wilted. Some water is used along with carbon dioxide in photosynthesis to make sugar for the plant. The moving water also carries necessary minerals such as nitrates and phosphates from the soil throughout the plant. But as much as 99% of the water is simply released into the atmosphere as water vapor.

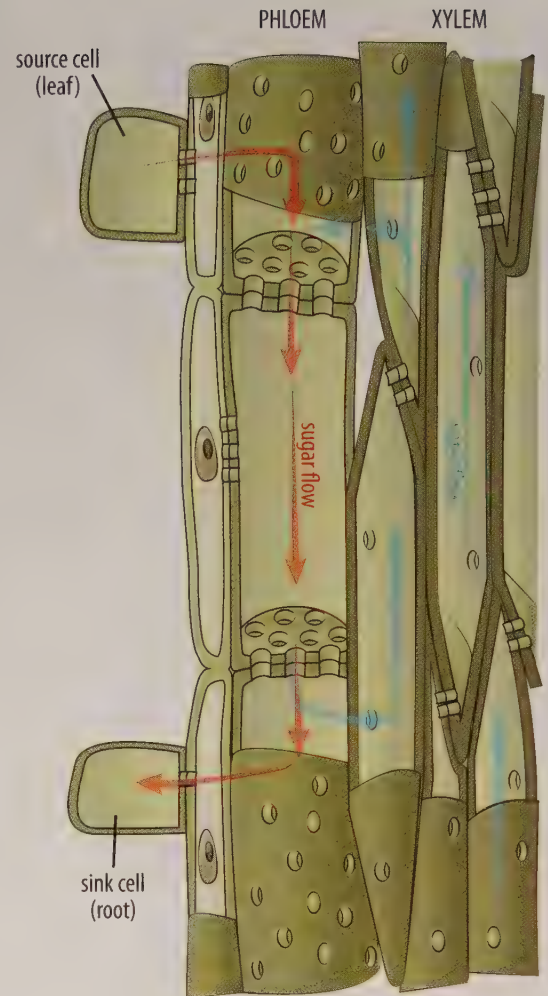
15.3 SWEET RIVERS

Xylem sap flows only upward, but the sugar that the leaves make needs to reach every part of the plant in order to provide all the plant cells with the nourishment they need. Sugars move in the phloem rather than xylem since phloem sap can move upward or downward in the plant. Cells requiring large amounts of sugars are called *sinks*

and are typically either rapidly dividing meristematic tissue or storage structures such as roots and fruits. Cells that make the sugars are called *sources* and are found in the leaves and sometimes in herbaceous stems.

When you connect a hose to a spigot and turn on the water, the incoming water creates an area of high pressure at one end of the hose. Meanwhile, the water flowing out the other end of the hose creates an area of low pressure there. The water flows from the high-pressure area to the low-pressure area. This is similar to what happens in a plant. According to the **pressure-flow hypothesis**, plants move sugars through the phloem in much the same way. Source cells use active transport to move sugars into the water-filled phloem. The higher concentration of sugar in the phloem causes water to move osmotically into the phloem from nearby xylem cells. This influx of water creates an area of high pressure near the source. At the same time, the sink cells remove sugar molecules from the phloem by active transport, and the water in that part of the phloem is directed back into xylem cells, creating an area of low pressure near the sink. This pressure gradient causes the water to flow from the source to the sink, carrying the sugar molecules along with it. In an ongoing process, the sink's cells remove sugar molecules from the phloem, the source's cells export sugar molecules into the phloem, and water enters and exits the phloem, causing the movement of sugars in the phloem from the source to the sink to continue.

Since the flow of phloem sap seems to be driven by a difference in pressures, phloem sap is able to move in any direction toward a sink. So sugars made in the cells of leaves on one branch can be sent to an area of growth at the top of the tree in the late spring, to nearby fruit in the summer, and to storage regions in the roots in the early fall.



15A REVIEW QUESTIONS

1. Is the difference between xylem sap and phloem sap due more to their solutes or their solvents? Explain.
2. What is the main difference between the direction of flow in xylem and phloem?
3. What would happen to water in the stems of plants if water molecules did not exhibit hydrogen bonding?
4. Place these structures in the order that water passes through them during transpiration: endodermis, root cortex, root hair, spongy mesophyll, stomata, and xylem.
5. Does the plant use energy in moving sap in the xylem and phloem? Explain.
6. When farmers apply too much fertilizer to the ground, the solute concentration is higher in the soil than it is in the roots. Explain how this would affect plants.
7. According to the pressure-flow hypothesis, where does the water in the phloem go after the sugar has been removed by the sink cells?

- 15B Questions**
- » How do hormones affect plants?
 - » How do plants respond to their environments?

15B

PLANT RESPONSES

How does a plant respond to internal and external factors?

15.4 HORMONES

All through the cold months of winter, a black walnut (*Juglans nigra*) sapling has stood dormant, half buried in snow. But as the warmth of the spring sun melts the snow, the sapling begins to leaf and grow taller. How does a sapling tell its meristematic tissue to start growing in the springtime? How does a red maple (*Acer rubrum*) lose its leaves in the fall without losing large amounts of sap from its vascular tissues? Plants are able to undergo these kinds of changes through the use of hormones. Plant **hormones** are messenger molecules that are typically produced by one tissue to produce a response in other tissues. While there are numerous plant hormones, many of them can be grouped into one of five major categories: abscisic acid, auxins, cytokinins, ethylene, and gibberellins.

Scientists have learned that plant hormones very rarely work alone. Auxins may cause ethylene production, auxins and cytokinins may work together and against each other in different parts of the plant, and abscisic acid may counteract several hormones all at once. The ways that the different plant hormones affect each other and influence plant cells are still areas of intense research as scientists seek to unravel the intricacies of plants, which show to all the creativity of our Heavenly Father. See the facing page to learn about different plant hormones.

15.5 TROPISMS

Sometimes a stimulus causes a plant to respond without affecting the direction of that response. For example, the leaves of a Venus flytrap always snap shut when triggered by an insect, no matter which direction the insect pressed the trigger hair on the leaf. This type of directionally independent response is called a *nastic movement* and is based on turgor pressure changes. Other responses, however, do respond differently to the same stimulus depending on the direction of the stimulus. These directionally dependent responses are called **tropisms**. While auxins are involved in some way with most tropisms, tropisms are complex processes involving many different molecules.

Since plants need light to conduct photosynthesis, plant stems exhibit positive **phototropism** by growing toward the light. For many years, scientists believed that light caused auxin to concentrate in the dark side of the plant, causing that side to experience greater cell elongation. However, with further experimentation scientists have observed no difference in the amount of auxin on the dark and light sides of the plant. Instead, light appears to cause growth inhibitors to concentrate

(continued on page 290)

PLANT HORMONES

2 Auxins are produced in the apical meristem of a plant shoot. They promote cell elongation and suppress cell division in the shoot. Auxins from the apical meristem suppress development of the lateral buds, so if the top of the main shoot of a plant is removed, the plant often becomes bushier. Auxins also promote lateral root development.



3 Cytokinins promote cell division and work with auxins in controlling the growth and division of cells. They also promote lateral bud development. While scientists have traditionally viewed cytokinins and auxins as working against each other, some evidence suggests that their relationship is more complex.

1 Absciscic acid is an inhibitor of several of the other plant hormones, slowing both cell growth and cell division. It also causes dormancy in buds and seeds. Absciscic acid is the primary reason that seeds do not germinate when they are first released from the parent plant. A variety of factors such as heavy rains or a period of cold removes the absciscic acid from the seed, allowing gibberellins to cause the seed to germinate.



4 Ethylene, unlike the other hormones, is a gas. It causes fruit to ripen and trees to form abscission layers between twigs and leaf petioles that allow leaves to drop in the fall. It also is responsible for many of a plant's responses to stress, such as injury or dehydration.



5 Gibberellins are a large group of plant hormones that are produced in the plants' roots. Their primary purpose is to encourage stem elongation and cell division in the shoots and leaves. They are also involved in fruit formation and seed germination. Various families of plants produce slightly different gibberellins.





15-3

A morning glory vine uses thigmotropism to climb higher.

on the light side of the plant. The auxin, therefore, has a greater effect on the dark side of the stem. The lengthening of the dark side of the stem causes the plant to bend toward the light. Roots, on the other hand, bend away from the light, exhibiting negative phototropism.

Light isn't the only stimulus that plants respond to. Remember from Chapter 14 that a germinating seed produces a radicle and a plumule, the plant's future root and stem, respectively. When a seed germinates, its radicle must grow downward and its plumule must grow upward, or the young plant will die. However, the seed is underground, so phototropism cannot guide the radicle or the plumule. Instead, the radicle grows toward the pull of gravity, exhibiting positive **gravitropism**. The plumule exhibits negative gravitropism, growing against the pull of gravity. Adult roots and stems continue to exhibit gravitropism throughout the plant's life. Auxins are involved in gravitropism, but scientists are still investigating the mechanisms that God created to ensure the survival of plant seedlings.



15-2

Gravitropism of corn seedlings. Stems exhibit negative gravitropism, while roots exhibit positive gravitropism.

All plants exhibit phototropism and gravitropism, but some plants, primarily climbing plants such as vines, exhibit **thigmotropism**. Plants such as the grape (genus *Vitis*) have specialized stems called *tendrils*. When a tendril touches an object the cells on the side opposite the object elongate so that the tendril begins to bend around the object. Eventually, the tendril twines itself around the object, providing support for the entire plant. Some vines, such as morning glories (family *Convolvulaceae*), don't have tendrils, but their entire stems demonstrate thigmotropism by wrapping around other objects.

Of all the tropisms, **hydrotropism** is the least understood. While several scientists studied it in the nineteenth century, very little further research was conducted on the ability of plant roots to grow toward water until the twenty-first century. A root's positive gravitropism is much stronger than its positive hydrotropism, making hydrotropism hard to study. But with the ability to create mutants lacking gravitropism as well as the opportunity to grow plants in microgravity environments such as the International Space Station, scientists have begun to take another look at hydrotropism. Like the other root tro-

pisms, much of the ability to sense water appears to be concentrated in the root cap, but how the root senses water remains a mystery. When the root cap encounters water in the soil, the root bends so that it begins to grow toward the water. In order to sense the presence of moisture, the root cap needs to be very close to the water. Plant roots can't sense moisture from feet or even inches away.

15.6 PHOTOPERIODISM

Plants can't live without light. Light provides the energy that drives photosynthesis, and phototropism causes stems to grow upward and roots to grow downward. But light has an even greater effect on plants in controlling the time of year they flower. You could plant chrysanthemums early in the spring, hoping to have some nice blossoms for July 4th. However, your mums are far more likely to bloom for the autumnal equinox, since they flower according to the length of daylight and darkness, a phenomenon called **photoperiodism**.

Some plants won't flower until nighttime is longer than a certain critical length of time. The exact length of time the plant needs to be in darkness varies from one species to another. Early researchers thought that the plants required light for less than a specific amount of time, so they called them **short-day plants**. We now know that it is the length of the nights and *not* the days that controls photoperiodism. If a bright light shines briefly on a short-day plant during the night, it will not flower. It perceives the interrupted long night as two short nights separated by a short day. In the world's temperate regions, some of the most familiar fall flowers—such as chrysanthemums, goldenrod, and aster—are short-day plants.

Long-day plants won't flower until the length of nighttime is less than a certain amount. Just as with short-day plants, the critical length of time varies from one species of plant to another. If a bright light is shined on a long-day plant at night, it may induce it to flower by fooling it into thinking that it has experienced two short nights separated by a short day. Long-day plants such as irises, sunflowers, and clover typically blossom in early summer when the nights are shortest.

The way that a plant responds to photoperiodism is a complex process, but much of it is controlled by pigments called **phytochromes**. The phytochromes active in photoperiodism exist in two different forms, Pr and Pfr. Plants produce Pr, and light converts it into Pfr during the day. At night, the Pr becomes far more abundant, as Pfr either reverts back to the first form or is torn apart by the plant's enzymes. The exact ratio of these two forms of phytochromes present in the plant controls when it flowers. This system is very precise, sometimes preventing flowering if the dark period is as little as a minute too short or too long. A single night of the correct length is enough for some plant species to begin blossoming, while several nights of the correct length are required by other species.



15-4

The aster shown above will not bloom until the nights are longer than a certain number of hours, making it a short-day plant that blooms in the fall. Red clover (below) is a long-day plant that blooms in early summer.





While many plants are affected by photoperiodism, other plants will grow until they reach maturity and then will blossom regardless of the length of day or night if other conditions such as moisture and temperature are right. These plants are called **day-neutral plants** and include tomatoes (left), beans, and dandelions.

15B REVIEW QUESTIONS

1. From what you have learned about the effects of ethylene gas on plants, what would be the most obvious characteristic of a yellow birch (*Betula alleghaniensis*) that did not produce ethylene? Explain.
2. Would an acorn without abscisic acid be likely to produce an oak tree? Explain.
3. What two plant structures tend to exhibit opposite tropisms? Explain.
4. Would a mutant plant without growth inhibitors experience positive phototropism? Explain.
5. Why is thigmotropism not a nastic movement?
6. Your friend tells you that last year a plant in his yard began to flower after a night that lasted eleven hours. Can you assume that it is a long-day plant? Explain.
7. Is a mutant variety of a long-day plant without Pfr likely to survive in the wild? Explain.

Bulbs, underground buds like those of an onion, produce bulblets that become new plants.



USING PLANTS WISELY

How can we use plants to help others and protect the environment?

15.7 ASEXUAL PLANT REPRODUCTION

In Chapter 14 we discussed sexual reproduction through the uniting of pollen and egg in the plant's flowers, but some plants also reproduce asexually. Asexual reproduction in plants, also called **vegetative propagation**, produces a **clone**, an organism that is genetically identical to the parent plant. Many plants reproduce asexually using specialized underground storage structures such as *bulbs*, *tubers*, or *corms*.

Tubers produce new plants by sending out buds, such as the eyes on a potato. Tubers are underground stems that swell to store nutrients.

15C Questions

- » How can plants be produced without seeds?
- » Why are plants important to people and the environment?

Corms, underground stems, such as those on a crocus plant, often produce small cormlets that become new plants. Corms are solid, while bulbs have scales or layers. Compare the inside of the crocus corm with the inside of the onion on the facing page.





Other plants, including the strawberry shown above, produce specialized stem structures called *stolons* that form new plants that take root some distance from the parent plant. Other plants produce new plantlets that drop off from specialized stems or leaves and take root right next to the parent plant. While many plants use stem structures to reproduce asexually, many trees, like aspens (seen in the photo below), use their roots to send up new shoots. As a result, whole groves of trees may be clones of the original tree connected to each other through a vast underground root system. Sometimes adjacent groves may have slight genetic differences that cause them to undergo seasonal changes at slightly different times, making the boundaries of the clonal groups obvious.

New plants rarely grow from leaves. However, the leaves of a few plants, such as the African violet (*Saintpaulia* spp.), will produce new plants when they are placed in soil. Dipping the leaf in rooting hormone greatly increases the leaf's chances of forming a new plant.

15.5

The genetic differences between the groves of aspens causes them to change colors in the fall at different times.

15.8 PEOPLE AND PLANTS

When God gave the Creation Mandate to Adam and Eve and their descendants, His command included using plants. Plants fulfill many human needs. Houses are made from wood, long grasses, or refined materials made from other plant products. Some clothing is made from cotton fibers and linen from the flax plant. In much of the world even today, people keep their houses warm by burning wood or other plant products. However, plants' most significant contribution to our wellbeing is in the production of food.



Most plants that we eat typically reproduce through sexual reproduction. Sexual reproduction can create a problem for farmers since it almost always results in a mixing of alleles. As a result, a farmer who plants seeds hoping to grow a whole crop like the parent plant will probably end up with plants that are very different from each other and from the parent plant, unlike the trees in the orchard shown below, which are probably genetically identical to each other and to an original parent plant.



While it is possible to completely isolate a crop from other varieties of the same species so that the seeds will produce offspring just like the parents, this presents several major problems. To isolate a group of plants, you would need to place them inside a greenhouse. But since the greenhouse will also keep out both the wind and pollinating insects, you would have to hand-pollinate the plants. And if the plant in question is a tree like an apple or pear, then the greenhouse really isn't feasible even if hand pollination is used because the tree will get too big to be enclosed. Furthermore, some plants, including many fruit trees, will not form fruit or seeds if pollinated by a plant of the same variety. As a result, some crops, such as potatoes, are raised entirely by asexual reproduction. When a farmer wants to grow a crop of potatoes, he just plants other potatoes. Or if he is concerned about plant diseases ruining his crop, he can buy seed potatoes—ordinary potatoes that have been certified to be free of disease.

Asexual reproduction is natural to potatoes, but some other crops present more of a challenge. Since most fruit trees must be cross-pollinated by a tree of another variety, a fruit tree of the parent's variety cannot be grown from a seed. Instead, when an orchardist wants to plant a new apple tree, he uses a technique called *grafting*. A branch called a *scion* is cut from a tree and inserted into a rooted sapling, called the *stock*, during the dormant period. Different types of trees require different grafting techniques, but in all of them the goal is to connect the xylem and phloem of the scion and the stock. The scion then grows to be a tree using the stock's root system. Typically, only the scion grows, and any branches and leaves of the stock are pruned, but some orchard companies sell apple trees that have branches of several varieties of apple trees grafted together. At least one company even sells a fruit tree that bears apricots, peaches, and plums on different branches.



15-6

Grafting allows a fruit lover to grow more types of fruit in a small space.



15-7

If GM crops are safe, why do researchers wear protective clothing? Researchers who wear Personal Protection Equipment (PPE) are usually required by federal regulations to do so when working with certain chemicals that are used with both GM and non-GM crops, including some organic crops.

Some plants are produced by *layering*, a process in which a branch of the plant, usually a bushy plant such as a holly or azalea, is bent to the ground and a portion of it is buried. The remaining part of the branch is staked to force it to grow upward. Often the underground part of the branch is cut to induce root development. The branch continues to receive nourishment from the parent plant until sufficient roots develop. At that time, the new plant is cut from the parent plant.

Some of the plants that people use would not be able to survive on their own without human intervention. (See the Worldview Sleuthing box on page 299.) As you learned in Chapter 9, bananas are triploid, which causes them to have no seeds. While this is good for banana lovers, banana growers must grow new banana plants from small daughter plants that the parent plant produces. Seedless watermelons are also triploid plants and cannot reproduce at all.

Vegetative propagation may cause other problems too. It produces a large group of plants with identical genotypes. Because of the limited genetic diversity, these plants are very susceptible to diseases. A disease that kills one plant may very well kill most of them. In a species propagated with seeds, the larger amount of genetic diversity makes it much more likely that some plants at least will be resistant to a particular disease or pest.

The **Green Revolution** of the early to mid-twentieth century changed the way people all over the world practice *agriculture*, the science of farming. Intensive crossbreeding projects created new varieties of wheat and rice that produced much higher yields. Many credit these new grain varieties with saving millions of lives, especially in the poorer regions of the world where starvation and malnutrition is still a problem. Today, some see genetically modified plants as a possible source of a new Green Revolution. Genetic engineering involves taking genes from one organism and inserting them into the genome of another organism, so a plant may carry genes from a bacterium that allows it to produce substances that kill insects. While GMOs have the potential to be a great blessing to mankind, there is still much work to be done to ensure that this new technology is used responsibly. The

Creation Mandate justifies the effort to find new ways to use plants, including the use of genetic engineering. At the same time, man is to wisely take care of God's world with a mind for the future, so we should not recklessly push forward with a new technology without taking into consideration its safety and long-term effects.

15.9 PLANTS IN THE ENVIRONMENT

Besides providing us with food, clothing, and shelter, plants also serve an important role in ecosystems. Transpiration releases water from the ground into the atmosphere where it joins water evaporated from oceans, lakes, and rivers to form clouds. In addition to being a major part of the water cycle, plants also help to filter water, especially in watersheds. Often fertilizer and other nutrients enter runoff water from fields. When plants absorb the water, they also use these nutrient molecules. While these nutrients help plants, unabsorbed fertilizer pollutes **aquifers**, underground water reservoirs that are the source of water for most wells. Plants filter water before it enters aquifers, streams, and lakes, helping to ensure that people have clean drinking water.

Plants can also have a huge effect on local climate. In cities, the absence of plants and the large areas covered by buildings, concrete, and asphalt cause the temperature in urban areas to be significantly higher than the temperature in the surrounding rural areas. To counter this, urban planners in recent years have increased the number of green spaces in cities. Some are even growing plants on top of buildings.

In another role, plants greatly help in controlling erosion. Their roots hold soil particles in place, lessen the force of moving water, and act as windbreaks. For example, during the 1920s, many farmers on the Great Plains plowed up the grasslands to plant wheat. But a series of droughts during the 1930s killed the wheat, leaving only dry, bare ground. Then strong winds picked up the dry soil and blew it away, sometimes as far as New York City and Washington DC. Many farmers in the Great Plains were forced to abandon their farms. The Dust Bowl, as these events have been named, is an example of massive wind erosion. Erosion occurs when loose soil is moved from one place to another, typically washed away by water or blown away by the wind.



15-8

Massive amounts of erosion as a result of poor farming techniques and several years of drought ruined many farms in the Great Plains region of the United States during the Great Depression.

Areas that lose soil often cannot support plant life for some time, and eroded soil causes other problems ranging from landslides to large amounts of fertilizer in runoff causing algal blooms in lakes and rivers. Farmers use plants' ability to stop erosion by planting cover crops in the winter to hold the soil in place.



Virtually all the organisms on the earth depend on the sun to keep a supply of energy entering the ecosystem. However, many organisms can't directly use sunlight. Plants use the sun's energy to power photosynthesis, producing sugars that they can store in tissues to feed animals and people. Plants also use carbon dioxide and release oxygen during the photosynthetic process to replenish the atmosphere for people and animals to breathe. You can see that without plants, life on Earth would be difficult, if not impossible. God has given mankind the gift of plants to wisely use and manage for His glory and for man's good.

15C REVIEW QUESTIONS

1. What is the primary distinction between a plant produced by vegetative propagation and one produced by sexual reproduction?
2. Corms, tubers, and stolons are technically examples of what plant structure?
3. List three ways that people use plants other than for food.
4. Why are most apple trees produced by grafting rather than by planting apple seeds?
5. If you were a gardener who wanted to collect seeds from a zucchini, what steps could you take to prevent the zucchini flowers from being pollinated by another variety of squash?
6. From a biblical worldview, what should a Christian think about GM crops?
7. How do plants help keep fertilizer and other pollutants out of aquifers?
8. How do plants help prevent erosion?

WORLDVIEW SLEUTHING: GOING BANANAS

The popularity of bananas owes much to the fact that domesticated varieties have no seeds, unlike wild varieties. This means that they must be propagated. In the 1950s, the primary variety of banana, the Gros Michel, and the banana industry that depended on it in South America, Africa, and Asia, were all but wiped out by Panama disease, which is caused by the fungus *Fusarium oxysporum*. It was discovered that another variety, Cavendish, was resistant to the fungal disease, so most of the banana industry began growing the Cavendish variety.

However, in the latter part of the twentieth century, a new strain of *F. oxysporum* appeared that attacked even the Cavendish banana. This variety of Panama disease has already spread throughout Southeast Asia and parts of Australia and is threatening the banana growers of Africa and Latin America. While the destruction of bananas would be only an inconvenience in Europe and the United States, it would be a disaster in Africa and Latin America. Bananas are a major part of the diet in those countries, and the banana industry employs millions of workers throughout the world.

Introduction

You, as a researcher at the Dutch Wageningen University and Research Center, must try to craft a plan to deal with this new threat from Panama disease. You are working with other researchers and several major banana producers to find a way to save the banana.

Task

Your mission is to research possible ways to save the banana industry. You will present your findings in a 4–6 minute speech.

Procedure

1. Research the term *Panama disease*, especially how it affects banana plants and how it spreads.
2. Research some possible solutions to the issue and some of the research being done in those areas.
3. Plan your presentation. Describe what you think is the most promising solution and what additional work needs to be done to implement it.



4. Create your presentation and show it to another person.
5. Deliver your presentation to your class or family.

Conclusion

You can see in this example the long-term effects of modifying and vegetatively propagating plants, especially those used for food. While currently there is no cure for Panama disease, much research is being done to find a solution to the problem. Given that bananas provide livelihoods for millions of people and are a major source of nutrition for millions more, investing in this research is a good example of using science to show love to our fellow human beings.

REVIEW QUESTIONS

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CONCEPT REVIEW

- Which of the two types of vascular tissue is more likely to carry phosphates from fertilizer? Explain.
- If xylem and phloem are analogous to the human circulatory system, what in a plant is analogous to human blood?
- What property of water molecules causes sap to rise in xylem? Explain.
- Would the xylem or the phloem be more directly affected if a plant's stomata permanently closed? Explain.
- Plants keep runoff water from reaching aquifers. What happens to most of this water?
- What type of movement of water is essential for phloem moving sugars between sources and sinks? Explain.
- Is a fruit a source or a sink? Explain.
- Create a concept map of the pressure-flow hypothesis using these terms: water, high pressure, low pressure, xylem, sugar, source cells, and sink cells.
- If a plant's apical meristem produces a large amount of auxin, what general shape will the plant have?
- Which plant hormone is most likely to be used to determine if two plants are in different families? Explain.
- What would be most obvious about a mutant grape vine lacking thigmotropism?
- Would a plant's stem and roots grow in opposite directions in a microgravity environment such as on board the International Space Station? Explain.
- Several plants of one species are provided with plenty of nutrients and have reached maturity without blooming in a greenhouse where lights are used to keep darkness for eight hours a day. When the period of darkness is increased to nine hours, they flower. What type of photoperiodism do these plants exhibit? Explain.
- A mutation to what substance is most likely to change a plant's photoperiodism? Explain.
- Two strawberry plants growing side by side are attacked by a fungal disease. One is genetically resistant to the disease and recovers while the other dies. Were these two plants produced from stolons from the same plant? Explain.
- The potato is a specialized form of which plant structure?
- Does an apple tree produced by grafting most resemble the stock or the scion? Explain.
- Could an apple tree that bears two different kinds of apples on different branches be produced by sexual reproduction? Explain.
- How could a farmer use plants to prevent excess fertilizer from washing out of his field into a nearby stream?

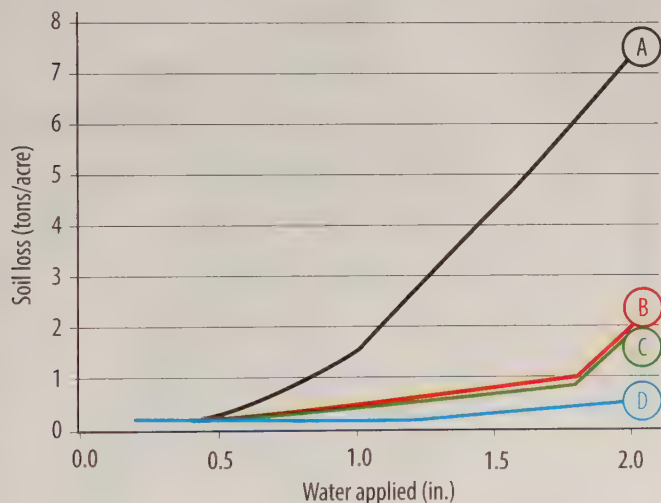
TRUE OR FALSE

20. Current scientific models can be accepted as certain since they very rarely change.
21. The flow of water from the soil through the xylem and out the stomata requires no energy expenditure on the part of the plant.
22. The flow of water from the xylem to the phloem and back again is caused by osmosis, requiring no energy expenditure from the plant.
23. Plant hormones typically work independently of each other.
24. Because of hydrotropism, plant roots can detect water from up to 30 feet away.
25. Long-day plants tend to bloom during the late spring and early summer.
26. Vegetative propagation increases genetic diversity.
27. Plant leaves are incapable of producing new plants through vegetative propagation.
28. Transpiration helps to separate water from pollutants.

CRITICAL THINKING

Use the graph below for Questions 29–34.

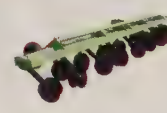
Soil erosion is a major problem for farmers. Erosion removes nutrients from the soil and often washes excess fertilizer and pesticides into nearby streams and rivers where they act as pollutants. Various methods of tilling, including not plowing at all, have been developed. This graph shows the amount of soil erosion associated with the different tilling methods.



A moldboard plow



B disk plow



C chisel plow



D no-till land



29. How much water is applied when the erosion rates suddenly increase for disk and chisel plowing?
30. Why does this spike occur?
31. Why does a similar spike *not* occur with no-till agriculture?
32. If this graph were extended to the right, would such a spike occur for no-till agriculture?
33. A similar increase in the rate of erosion occurs for agriculture using moldboard plows. How much water is applied when this increase occurs?
34. Is erosion affected only by the plowing method? Explain.

Science attempts to analyze how things and people and animals behave; it has no concern whether this behavior is good or bad, is purposeful or not. But religion is precisely the quest for such answers: whether an act is right or wrong, good or bad, and why.

WARREN WEAVER (1894-1978),
MATHEMATICIAN AND SCIENTIST AT
THE ROCKEFELLER FOUNDATION WHO
ADVOCATED FOR SCIENCE EDUCATION AND
INITIATED THE USE OF MACHINE LANGUAGE
TRANSLATION



4 ANIMALS

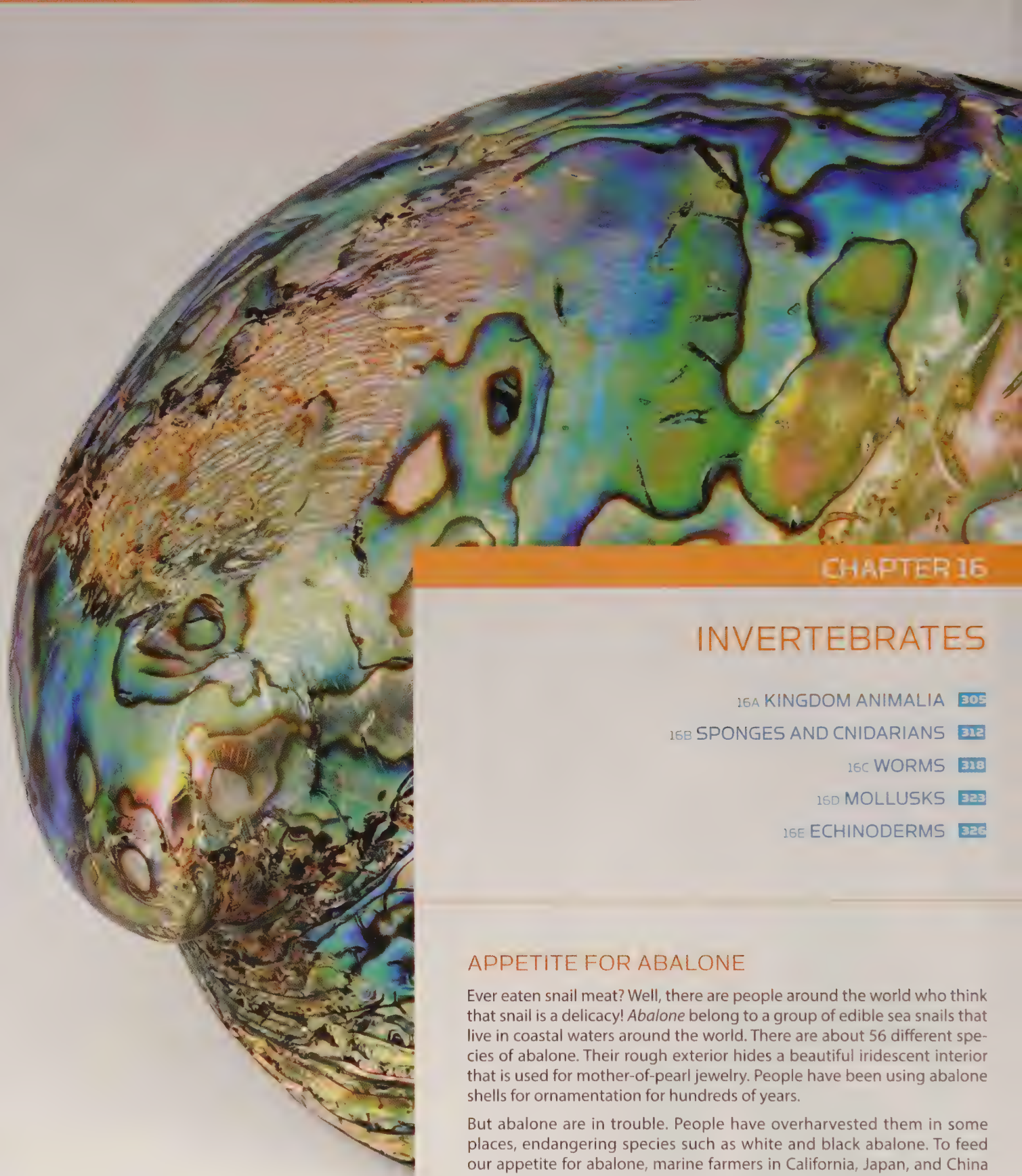
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CHAPTER 16

INVERTEBRATES

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APPETITE FOR ABALONE

Ever eaten snail meat? Well, there are people around the world who think that snail is a delicacy! *Abalone* belong to a group of edible sea snails that live in coastal waters around the world. There are about 56 different species of abalone. Their rough exterior hides a beautiful iridescent interior that is used for mother-of-pearl jewelry. People have been using abalone shells for ornamentation for hundreds of years.

But abalone are in trouble. People have overharvested them in some places, endangering species such as white and black abalone. To feed our appetite for abalone, marine farmers in California, Japan, and China have begun raising them in captivity. How can we use biology to wisely manage animals, especially those that touch the lives of people?

KINGDOM ANIMALIA

What separates animals from other living things?

16.1 ANIMAL ATTRIBUTES

God has filled our earth with animals, and He has commanded us to wisely manage them for His glory. God values animal life (Jon. 4:11), and biology can be a wonderful tool for conserving animal populations, especially ones that provide valuable resources for people. Today people in California are trying to preserve endangered species, like abalone (see Chapter opener), by limiting how they can be caught. Instead of using scuba gear to catch large numbers of abalone (including their young), people there are permitted to fish for abalone using only free-diving techniques, such as snorkeling. Coupled with laws on the number and size of abalone that can be taken, this limits the number of individuals harvested, allowing populations of endangered species to recover since their young are left behind to mature.

Biologists use kingdom Animalia in domain Eukarya to classify all animals. Animals are heterotrophic organisms that are made of many eukaryotic cells. Because their cells have no cell walls, animals must have another means of support. Since they move, they require a structure for their muscles to pull against. For many animals, God has met these two needs by providing them with some kind of skeleton. Some animals, such as mammals and reptiles, have an internal skeleton made of lightweight bones called an **endoskeleton**. Others, such as lobsters and insects, get their support from a stiff, plated outer covering called an **exoskeleton**. Still others, such as jellyfish and starfish, use their watery environment to fill a central cavity inside their bodies to build up pressure. This structure is called a **hydroskeleton**, or a *hydrostatic skeleton*. While the carbohydrate cellulose is the primary chemical providing support in plants, the protein *collagen* is an essential part of the skin, muscles, bones, and connective tissues of animals.

All animals have a **body plan**, the arrangement of physical features that contribute to structure and form. Animals with similar body plans are often grouped and classified together. Different body plans demonstrate various kinds of symmetry that physically balance body parts. Animals demonstrating **bilateral symmetry** can be divided by a plane through their center in one place to form mirror images. Animals with **radial symmetry** have no left and right sides and can be divided by a plane through their center in several places to form mirror images. Some animals have no symmetry—they're said to be *asymmetrical*.

external asymmetry

16A Questions

- » How are animal bodies different yet similar?
- » In general, how are animals classified?
- » How do animals reproduce?
- » How do animals behave in their environments?

endoskeleton: endo- + -skeleton (L. *endo*—within + Gk. *skeletos*—dried body)

exoskeleton: exo- + -skeleton (L. *exo*—outside + Gk. *skeletos*)

hydroskeleton: hydro- + -skeleton (L. *hydro*—water + Gk. *skeletos*)

bilateral symmetry

radial symmetry





Nutrition. All animals are heterotrophs, since they obtain their food for energy and growth from other organisms. Getting nutrition requires taking in food through the process of *ingestion*, breaking down food through the process of *digestion*, and getting rid of waste products through *egestion*. As cells digest proteins, they produce *nitrogenous wastes* that are expelled through *excretion*. Without these processes, an animal wouldn't be able to get needed nutrients and would build up harmful waste products. Such a disruption in homeostasis would eventually kill an animal.



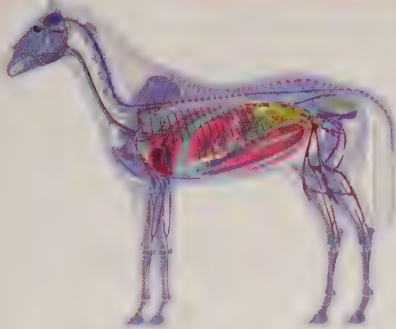
Respiration. Animals need a way to exchange gases with their environment to continue life-sustaining cell processes. They have organs that help them get the oxygen they need for cellular respiration from the environment. Some get oxygen from air, and some from water. Animals exhale carbon dioxide as a waste product.

ANIMAL ATTRIBUTES

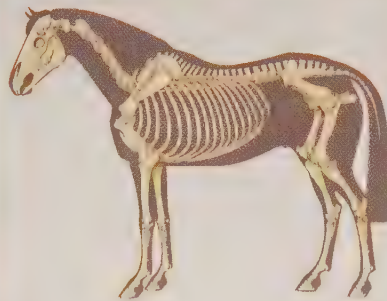
What sets an animal apart from other types of life? All animal cells are eukaryotic, which places animals in the domain Eukarya and distinguishes them from bacteria. Animals are also heterotrophs, getting the nutrients they need from other organisms, unlike the autotrophic plants and algae. Animal cells don't have the cell walls that plants and fungi have. Finally, all animals are multicellular, unlike most prokaryotes, which are primarily unicellular or colonial.



Movement. Animals have some kind of *locomotion*—the ability to move through their environments. Many animals move using *appendages*, limbs that protrude from their bodies. But not all animals move at the same speed. Some animals such as sponges are quite capable of motion as larvae but become **sessile** (fixed in one place) as adults, attaching themselves to objects.



Circulation. Animals transport materials through their bodies to get nutrients to where they're needed. Some animals have blood or a similar fluid that circulates nutrients in vessels or bathes internal organs. Some organisms, like sponges, circulate water through their bodies to transport needed substances.



Support. Most animals have some form of support to hold their weight, with larger animals generally needing more support than smaller ones. This support can be inside or outside of the body, or even separate from the body. The blue whale (*Balaenoptera musculus*) can grow to nearly 200 tons because the ocean water provides additional support for its huge bulk.



Reproduction. All animals reproduce animals after their own kind. Most animals reproduce sexually, requiring haploid gametes from two individuals to form one unique diploid zygote. Many animals also reproduce asexually, and quite a few of them reproduce both ways.

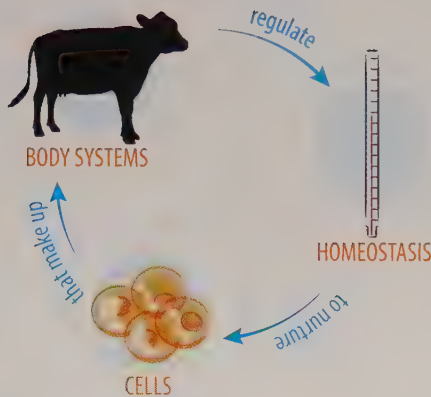
16.2 CLASSIFYING ANIMALS

Kingdom Animalia includes many different phyla, but the animals in these phyla are grouped in different ways. Animals with backbones are called **vertebrates**. All vertebrates are classified in one phylum, phylum Chordata, which includes a few **chordates** without backbones. When you think of animals, you probably think of vertebrates such as mammals, fish, snakes, and birds. But animals that do not have backbones, called **invertebrates**, make up about 97% of all animals and cover about 30 phyla in kingdom Animalia.

Another model of classification that biologists use to group animals is based on the way that they regulate their body temperature to stay at the optimum temperature for homeostasis. An animal's temperature can affect how fast or slow the life-sustaining chemical reactions in the cell take place or even whether they take place at all. Animals must keep their body temperatures sufficiently high for their cellular processes to work fast enough to sustain life but also cool enough so that those processes don't stop working.

Endothermic animals derive much of their body heat from their metabolism, and they often possess insulating body coverings such as blubber, feathers, fur, and hair. They also have complex internal mechanisms that regulate their body temperatures to the right level for life. This is not usually the same temperature as the surrounding environment. When their bodies become too hot or too cold, their bodies activate regulatory mechanisms that involuntarily cause sweating, panting, or shivering to restore the animal's body to the proper temperature.

However, most animals are **ectothermic**. They often have body temperatures much closer to that of the environment. Instead of using internal mechanisms, they use behaviors to establish and maintain their optimum body temperature. A green iguana (*Iguana iguana*) may sun itself on a rock to increase its body temperature or move into the shade to cool off. Honeybees (*Apis mellifera*) vibrate their bodies to generate heat before flight.



16-1

Cells make up body systems, like the respiratory, nervous, and skeletal systems. Systems work together to maintain homeostasis in an organism.

Table 16-1

Germ Layers in Animals

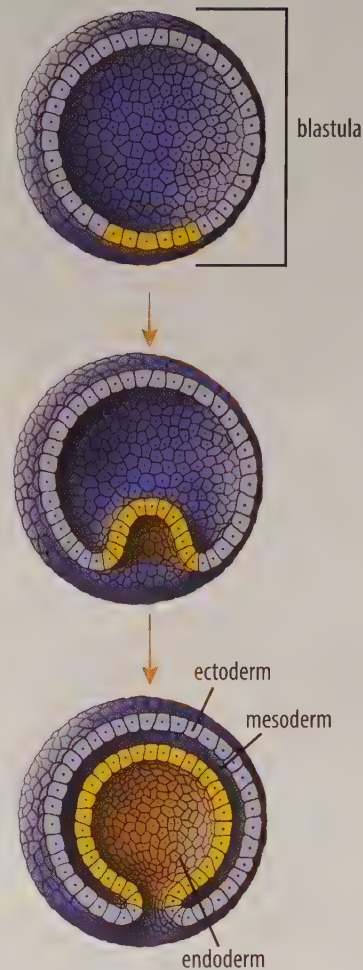
	Sponges	Cnidarians	Segmented Worms
Examples	sea sponges	jellyfish, sea anemone	earthworms
Germ layers	none	two	three
Body symmetry	asymmetrical	radial	bilateral
Cephalization	no	no	yes

Aquatic animals live in environments that don't have big swings in temperature, but land animals in some environments must deal with temperatures during certain times of the year that are hostile to life. Some animals, both endothermic and ectothermic, escape extreme temperatures by entering a state of *torpor* during which their body temperature drops and their life processes slow to a fraction of their normal levels.

16.3 | STRUCTURE IN ANIMALS

Animals are basically tubes, usually exhibiting radial or bilateral symmetry. This body plan begins when an animal is still just a fertilized egg. The zygote undergoes division to form a hollow ball of cells called a **blastula**. The cells in the wall of the blastula begin to move into the inside of the ball through a hole called the *blastopore*. As a result of this inward movement, layers of cells called **germ layers** develop in the embryo. Most animals have germ layers, typically three. The inner layer, the **endoderm**, forms the digestive tract. The **mesoderm**, the middle layer, forms the muscle and circulatory systems along with others. The **ectoderm** forms the outer layer including the outer covering and related systems.

Germ layers influence how an animal's digestive system, circulatory system, and body cavity take shape to enable it to get nourishment, rid itself of wastes, and respond to changes in its environment so that it can maintain homeostasis. Some animals with radial symmetry, such as jellyfish, have two germ layers. Animals with three germ layers often exhibit bilateral symmetry, but some radial animals, such as sea urchins, also have three germ layers. Bilaterally symmetrical animals also tend to have their sensory organs and mouth concentrated at one end. This concentration of sensory and nerve cells is called **cephalization**. This is usually something like an animal's head. In many cases, an **anus**, where the animal expels waste from its food, is located at the other end of the body, away from the head.



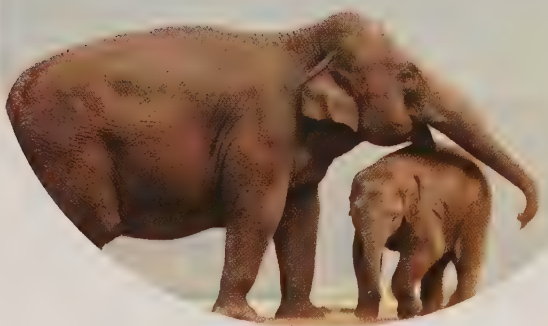
16-2 The blastula folds in on itself to form three germ layers in animals that exhibit bilateral symmetry. The way that the blastula folds determines which end forms the mouth and which end forms the anus. This process is called *gastrulation*.

Mollusks	Echinoderms	Arthropods	Chordates
clams, snails, octopuses, squids	starfish, sand dollars, sea urchins	butterflies, lobsters, spiders	mammals, reptiles, birds, fish
three	three	three	three
bilateral	radial	bilateral	bilateral
yes	no	yes	yes



16-3

These red-eyed tree frog (*Agalychnis callidryas*) eggs fertilized by external fertilization contain embryos that will eventually hatch from their eggs. What kind of species is *A. callidryas*?



viviparous

16.4 | REPRODUCTION IN ANIMALS

Animals, like all living things, reproduce after their kind, a clear reflection of God's created order (Gen. 1:21–22). Most animals reproduce sexually when the sperm from a male fertilizes an egg from the female to produce a zygote. This process can happen either outside or inside the female's body. In a process called **external fertilization**, many fish and other animals that live in water release eggs and sperm into the water, allowing the eggs to be fertilized outside the female's body. Land animals and some aquatic animals fertilize their eggs when sperm travels into the female's body to fertilize the eggs there; this is called **internal fertilization**. The male inserts these sperm into the female's body, or the male deposits the sperm into the environment, and the female later takes it in.

When an animal egg is fertilized, it begins to divide and develop into a multicellular embryo. This process happens in different places in different animals. The embryos of **oviparous** (oh VIH pah rus) species develop outside their mother's body but within the protective shelter of an egg, eventually hatching. Birds and most fish, amphibians, and insects are oviparous. The embryos often use the yolk of the egg for nutrients needed for growth.



oviparous

The embryos of **ovoviviparous** (oh vo vye VIH pah rus) species develop inside their mother's body, without being directly connected to her. Some fish and amphibians develop this way, and there are many variations on this method of reproduction.

Other developing animals draw their nutrients directly from their mother's body. These species of animals are called **viviparous** (vye VIP pah rus). Most mammals and some fish, amphibians, and a few insects develop this way.

If you've ever known a mom expecting a baby, you know that reproduction places a burden on a mother's body. The demand to support another life upsets homeostasis. For all animals, reproduction works against homeostasis in an individual, yet it is a necessary and vital part of being alive and sustaining a population.

16.5 | ANIMALS IN THE ENVIRONMENT

Fall is in the air in New England. Brightly colored maple leaves drift toward the forest floor while squirrels scurry among them, gathering acorns for the winter. A big black bear grazes on a few late blueberries to fatten up before turning into his cave to sleep off the winter. The "Honk! Honk!" of Canada geese migrating south passes overhead while a cardinal on a pine branch fluffs up its feathers to prepare to weather the winter.

God's creative order and care for living things is evident in the way that He has created animals. Geese, squirrels, and black bears respond to their environment, such as by detecting the changing of seasons, according to God's design. Their bodies receive signals from the environment that activate processes and changes to deal with the changing conditions. That's why the bear and cardinal increase their insulation, and snakes and woodchucks prepare to hibernate to survive the bitter cold of winter. The seasonal cycles are an example of how an animal changes what is called its **behavior**—the way that an organism responds to certain environmental conditions. Animals don't just change with the seasons; they change their behaviors every day as the sun begins to set and night comes to the forest. This is called a *circadian rhythm*.

Some animal behaviors are *learned behaviors*; some are not. How do Canada geese even know which way is south? Spiders spin egg sacs in the fall without ever being taught, a built-in response to the environment called **instinct**. But animals must learn certain behaviors. The Canada geese must learn to fly. The black bear and squirrel must learn to forage. Where do they learn these things? Many animals learn these behaviors from their parents.

God's care and love for animals is evident in the way that He provides for their needs and gives them the knowledge and skill to respond to their environments. We can use biology to learn about animals and their behaviors so that we can use them to meet people's needs and take care of God's world.

Animal Culture?

Some animal populations, like dolphins, bees, and ants, have complex interactions with each other and with their environment. Biologists call this an *animal culture*. From a biblical worldview, how is this different from a human culture?

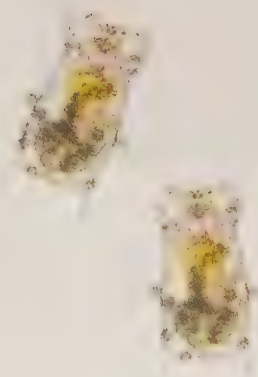
Bi



16A REVIEW QUESTIONS

1. Give an example of an animal with bilateral symmetry not mentioned in the text.
2. Use the characteristics of animals to show that a Holstein cow (*Bos primigenius*) used for milk production on dairy farms is an animal.
3. Rotifers (right) are tiny animals that are only a fraction of a millimeter long. They are usually found in fresh water. Why do you think rotifers are classified as animals and not protozoans?
4. Considering the list of animal attributes on pages 306–7, would you say that man is an animal? Why or why not?

(continued)





16-4

An *Echidna*, or spiny anteater, is an example of a *monotreme*, a mammal that lays eggs rather than giving birth to live young.

5. Create a T-chart graphic organizer (see Appendix B) that compares endothermic and ectothermic animals. Include how their body temperatures compare to their environment and how they regulate their body temperatures.
6. What is the general relationship between animal symmetry and the number of germ layers?
7. What is the connection between the number of germ layers and the presence of cephalization in the animals in Table 16-1 on pages 308–9?
8. What is distinctive about how animals reproduce compared with other organisms?
9. *Echidna* is a genus of mammals from Australia and New Guinea that lays eggs. Identify this group as oviparous, ovoviviparous, or viviparous. Why is this unusual?
10. Identify each of the following as a learned behavior or an instinct.
 - a. A rattlesnake moves to the sun to warm itself.
 - b. A monarch butterfly navigates over Lake Superior toward its winter mating grounds in Mexico.
 - c. A duckling follows its mother and siblings to swim in the local pond.
 - d. A wolf cub joins the pack on its first hunt for food.

16B

SPONGES AND CNIDARIANS

How are sponges and cnidarians animals?

16.6 CLASSIFYING SPONGES

Now that you know about the characteristics of animals, let's consider the largest category of animals—invertebrates. Every phylum in kingdom Animalia contains invertebrates except one. Let's study the different invertebrates in kingdom Animalia on the basis of their germ layers.

Sponges are odd creatures. They are invertebrates with no germ layers and no nervous, digestive, or circulatory systems. They are sessile, attaching themselves to rocks and basically staying in one place most of their lives. They are asymmetric and were actually thought by some of the ancient Greeks to be plants! So why do biologists still consider a sponge to be an animal?

When microscopes came into use in the mid-1800s, we learned that sponges have eukaryotic cells and are multicellular. Though sponges are sessile, they *move their environment through them*. They develop from zygotes to form mature organisms. Along with these factors, sponges are heterotrophic, leading biologists to classify them as animals. Sponges are classified in kingdom Animalia in the phylum Porifera (puh RIF uh ruh) and are sometimes called *poriferans* ("pore bearers"). If you've ever used a natural sponge for bathing, you know that they have lots of holes in them. Sponges can be as tiny as 1 cm

?

16B Questions

- » What is a sponge?
- » How do sponges feed and reproduce?
- » What is a cnidarian?
- » How do cnidarians feed and reproduce?
- » How do sponges and cnidarians contribute to the environment?



16-5

This photo shows three different sponges—the pink-colored stove-pipe sponge (*Aplysina archeri*), the moss-like yellow sponge *Ceratoporella nicholsoni* (bottom left), and the fan-like yellow sponge *Svenzea flava* (right).

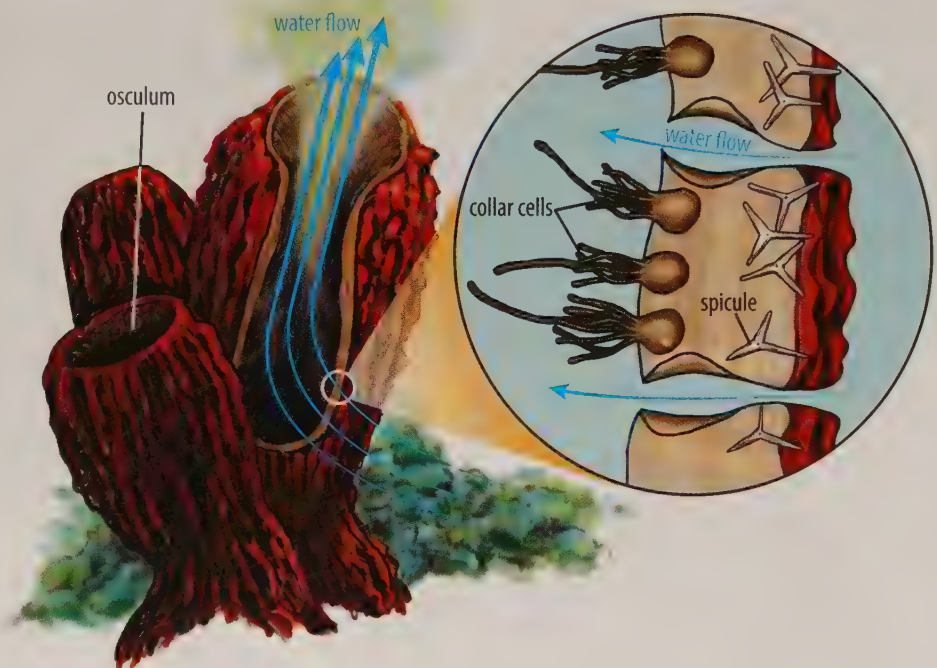
across to as big as 2 m across. There are about 10,000 species of sponges around the world, some marine and some freshwater.

16.7 STRUCTURE AND REPRODUCTION IN SPONGES

SPONGE STRUCTURE

Sponges, like other animals, are basically tubes. But they are a little different in that they have only one open end. This structure is similar to a test tube. The walls of this tube are supported by spikey, stiff needlelike structures called *spicules*. Cells in the sponge that transport nutrients also create these spicules. Some sponges are softer and contain both spicules and a spongier material called *spongin*.

Flagellated cells called *collar cells* that line the inside of the sponge beat vigorously to create a current through the sponge. The water flow through a sponge is similar to the flow of air through a chimney—in the bottom and out the top. Little pores in the sponge take in water from the environment, bringing food and nutrients with it. Collar cells engulf food particles through phagocytosis. These cells partially digest food, sending it to other cells to finish the digestion process. This allows nutrients to spread in a sponge. Waste products are ejected into the current through its *osculum*. When digestion happens inside cells instead of inside a digestive system, it is called **intracellular digestion**.



SPONGE REPRODUCTION

Sponges reproduce both sexually and asexually. They produce offspring asexually through budding, similar to a new branch growing off a tree. They also produce asexually through creating structures called *gemmules* that are released to grow into a clone of the parent sponge. However, sponges reproduce most often through sexual reproduction. Sponges are **hermaphroditic**, having both male and female reproductive organs. They produce both sperm and eggs. They typically release their sperm into the ocean to fertilize the eggs of another sponge. Eggs stay attached to the “mother” sponge until they hatch to release larvae capable of motion. The larvae find places to call home and attach there to mature and live the rest of their lives.

16.8 CLASSIFYING CNIDARIANS

While sponges are stiff, immobile animals, cnidarians are the exact opposite. Their soft, radially symmetric bodies ripple in their watery environment. **Cnidarians** (ny DEHR ee ans) are members of kingdom Animalia classified in phylum Cnidaria. They possess two germ layers. Cnidarians include jellyfish with their bell shapes and painful stings, corals with their hard skeletons, and sea anemones that look like flowers of the sea.

EXPLORING CNIDARIANS

Jellyfish

Jellyfish like this Nomura's jellyfish (*Nemopilema nomurai*) are free swimmers, pulsating their bell for locomotion. Nomura's jellyfish is one of the largest jellyfish, reaching a width of almost 6 feet. Like other jellies, Nomura's jellyfish has tentacles that it uses to sting and capture its food. Believe it or not, people in Asia capture and eat it for food!



Corals

Many of the different colors in this picture represent different kinds of corals. They are sessile, soft animals that build a stone-like coating for protection on top of the coats of past coral polyps. Types of coral include lobe, brain, antler, firecracker, and tongue corals.

Sea Anemones

Like corals, sea anemones are sessile and rely on a hydrostatic skeleton for support. *Unlike* coral, they do not produce a hard coating for protection. Instead, their ability to sting predators gives them some protection.



16.9 STRUCTURE AND REPRODUCTION IN CNIDARIANS

CNIDARIAN STRUCTURE

Cnidarians show much variety in their structures. They have a nervous system that forms a network of nerves called a **nerve net**, but beyond this, they have no true brain. Excretion and respiration are carried out primarily on the cellular level. Each cell extracts its own oxygen from the surrounding water and releases its own nitrogenous wastes and carbon dioxide. All rely on water pressure for support, while the corals excrete calcium carbonate (limestone) to produce exoskeletons for extra protection.

Cnidarians exist in two forms, a polyp form and a medusa form. A **polyp** is a cup-shaped tubular cnidarian with a mouth and tentacles at one end and a sticky **basal disc** for attaching to hard surfaces at the other end. It looks similar to a plant with a suction cup at the bottom instead of roots. The tentacles pull food into its mouth where it enters the *gastrovascular cavity*, a hollow place in the polyp where digestion and food circulation take place. In both cnidarian forms, the gastrovascular cavity has only one open end; a cnidarian does not have an anus.

Other cnidarians have an umbrella-shaped body and swim freely—the **medusa** form. By pumping its body in a way similar to the opening and closing of an umbrella, the medusa glides through the water in a jerky upward motion. Many cnidarians spend part of their lives in both forms, but some cnidarians, such as corals and sea anemones, exist only in the polyp form. Others, including some jellyfish, have only a medusa stage.

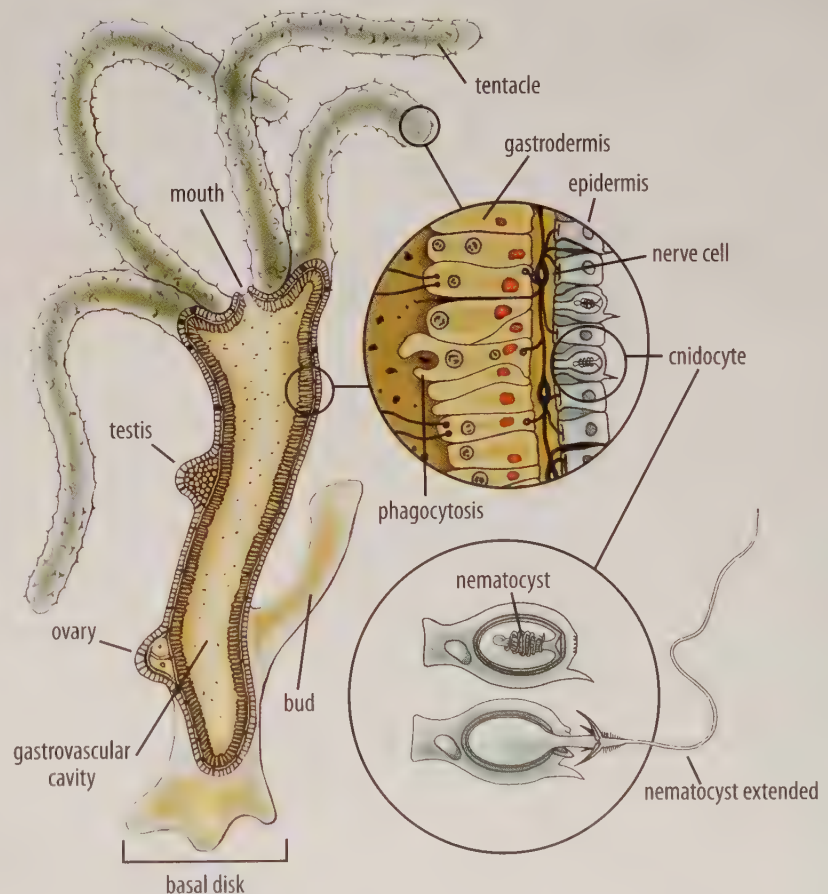
Cnidarians are named for their stinging cells called *cnidocytes*. Both forms of cnidarians have thousands of them on their tentacles, and those of some species are dangerous to humans. The *cnidocyte* holds a coiled tube that acts like a spring attached to a barb. When prey or an unwary swimmer touches the *cnidocyte*'s trigger, the barb launches and discharges a toxin that paralyzes the cnidarian's prey.

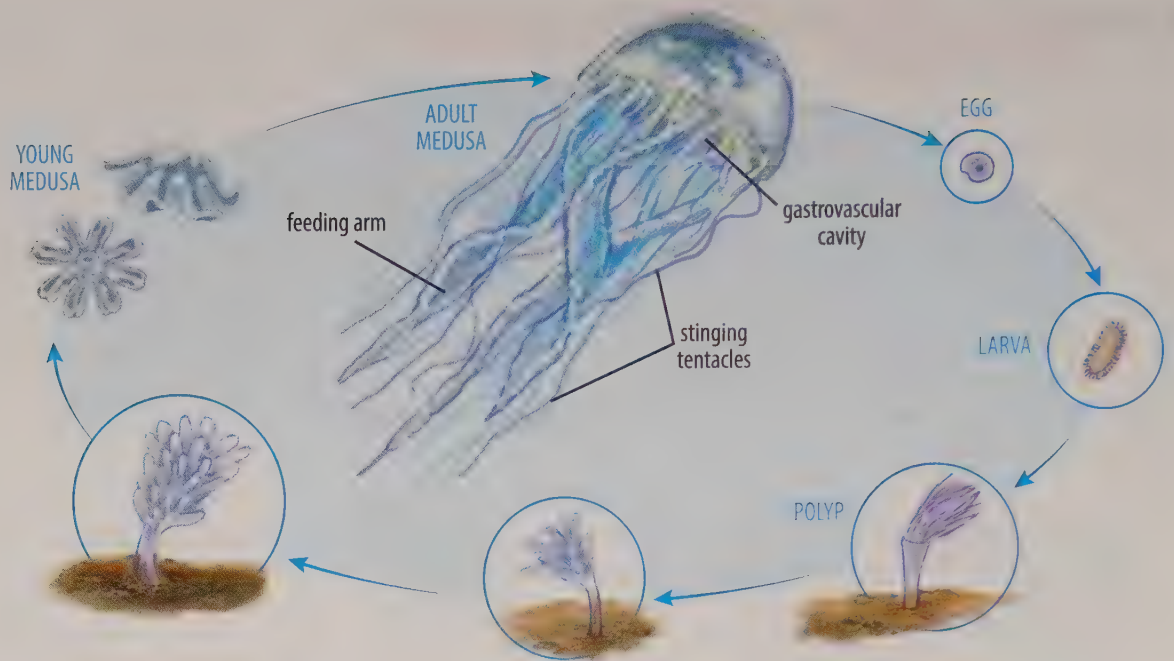
CNIDARIAN REPRODUCTION

Cnidarians, like sponges, reproduce both asexually and sexually. Some reproduce asexually by dividing themselves in half while many cnidarians, especially in the polyp form, also reproduce asexually through budding. In fact, in many coral species, all the polyps that live on a single exoskeleton are genetically identical. They are the result of asexual reproduction.

16-6

A hydra is a good example of a freshwater cnidarian polyp. The nematocyst-containing *cnidocytes* are where cnidarians get their name.





16-7

The jellyfish *Aurelia* has eggs that are fertilized through internal fertilization. The fertilized egg leaves the female's body to become a free-swimming larva. Eventually this larva settles and becomes a polyp that then matures to release medusas.

However, cnidarians reproduce most often through sexual reproduction. Unlike the hermaphroditic sponges, an individual cnidarian is typically either male or female. The male releases sperm into the ocean, which can fertilize ova that a female has also released. The cells of a fertilized zygote multiply until they form a hollow blastula that develops into a larval form. This larval form matures to take on a polyp or medusa form.

16.10 HOW SPONGES AND CNIDARIANS FUNCTION IN THE ENVIRONMENT

Sponges and cnidarians have an effect on their environment as part of the food web. The larval forms of many sponges and cnidarians contribute to plankton, which is the foundation of the marine food chain. Most sponges are filter feeders, eating detritus, though some sponges in the deep ocean are carnivores. These sponges have hooks for grabbing and entangling live prey, such as crustaceans. Cnidarians are usually carnivorous, eating plankton, invertebrates, and sometimes larger prey. They use the cnidocytes on their tentacles to stun and capture larger prey, such as fish. However, they can also eat detritus.

Some sponges and cnidarians are parasitic. Sponges are usually parasites to other moving animals, such as mollusks, breaking down and boring into the shells of clams and barnacles. Cnidarians can be parasites to other moving organisms such as jellyfish and fish. In general, parasitic sponges and cnidarians are sessile and choose free-swimming hosts.

But sponges and cnidarians don't just take from other organisms; sometimes they give too. Sponges form mutualistic symbiotic relationships, such as they do with algae, harboring them in the material

that makes up their spongy walls. The algae produce food through photosynthesis, passing on some of this energy to the sponge. The sponge provides protection and some of the nutrients that the algae needs for photosynthesis.

The best example of symbiosis is a coral reef, a whole ecosystem that relies on cnidarians. Corals also have a mutualistic relationship with algae. In fact, algae somehow seem to be essential to coral's ability to form reefs. Those without the symbiotic algae do not form reefs, and coral on reefs that lose their algae die. Sponges, fish, sea anemones, other corals, jellyfish, and larger animals find food and shelter on the reefs. They are like underwater tropical rainforests that are home to many types of organisms. Many islands are formed by former coral reefs. Coral reefs also protect many beaches from wave erosion.

It should be noted that about 60% of the coral reefs around the world are endangered, and 10% have already been killed. Scientists are still trying to figure out why this is. They theorize that there are a variety of factors at work in each area, including rising sea temperatures and too much fertilizer runoff. These factors cause the corals' symbiotic algae to die. This leads to the corals' deaths, turning them white in a process called *coral bleaching*. Though some of these effects may be natural rather than artificial, we must do our part to keep the water free from pollution. We should avoid dumping wastes in the ocean. We should also protect watersheds, which direct runoff water into the ocean and other bodies of water. By monitoring how we use the earth's resources, we can honor God with their use and protect them for people in the future.

16B REVIEW QUESTIONS

1. How are sponges different from other animals?
2. Why are sponges considered animals even though they are so different from other animals?
3. Do sponges have an exoskeleton, endoskeleton, or hydroskeleton? Explain.
4. How do sponges reproduce?
5. Create a concept definition map for cnidarians. (See Appendix B.)
6. Jellyfish are about 95% water. Suggest what kind of support they use—an exoskeleton, endoskeleton, or hydroskeleton.
7. Male and female sea anemones release eggs and sperm for fertilization. Do they practice internal or external fertilization? Explain.
8. Compare the diets of sponges and cnidarians.
9. Give an example of mutualism involving either sponges or cnidarians.



16C Questions

- » What are worms and how are they classified?
- » What are the differences between flatworms, roundworms, and segmented worms?
- » How do worms feed and reproduce?
- » How can we manage and use worms in the environment?

16C |

WORMS

What are the similarities and differences between the three major groups of worms?

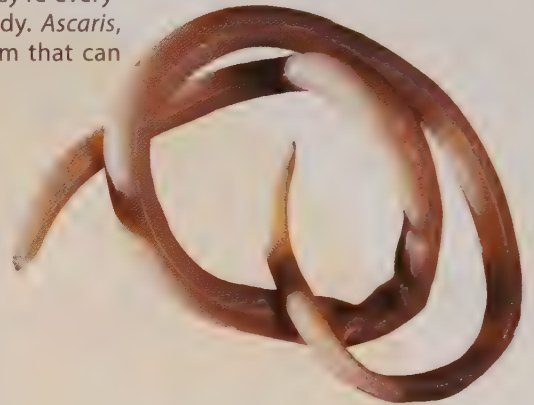
16.11 CLASSIFYING WORMS

Three of the phyla in kingdom Animalia contain the three types of worms—roundworms, flatworms, and segmented worms. Worms are animals with soft, long bodies, three germ layers, and few to no appendages. Explore the various types of worms shown in the images below.

EXPLORING WORMS

Roundworms

Roundworms, also known as *nematodes*, are mostly tiny, round worms less than an inch long, though a few are larger. And they're everywhere—water, soil, even in your body. *Ascaris*, shown here, is a parasitic roundworm that can reach a foot long!



Flatworms

Flatworms look just like what their name suggests. They include tapeworms, flukes, planarians (above), and the colorful marine flatworms. Most flatworms are parasites, but some, like the planarian, are free-living inhabitants of lakes, streams, and moist terrestrial habitats.

Segmented Worms

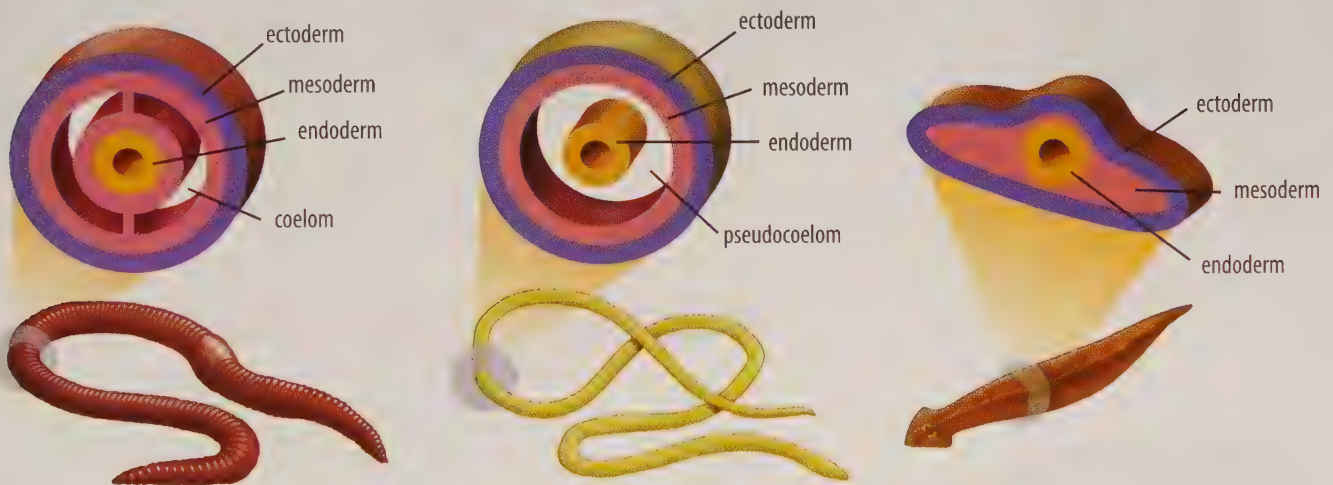
You're probably most familiar with the earthworm, an example of a segmented worm, also called an *annelid*. Segmented worms have a bumpy body, called a *segmented* body plan, similar to a vacuum cleaner hose. They have three germ layers. The Giant Gippsland earthworm (*Megascolides australis*), one of the largest, can grow to be a yard long. Other segmented worms include leeches, clam worms, and feather worms.



16.12 STRUCTURE OF WORMS

All worms exhibit bilateral symmetry, but beyond this, it's hard to make general statements about them since their body plans and lifestyles are so different. As a rule, free-living worms tend to be more complex than parasitic ones, especially internal parasites. Segmented worms and roundworms have a mouth at one end and an anus at the other. Free-living flatworms and some parasitic flatworms have a mouth that leads to its digestive system, while other parasitic worms absorb nutrition directly from their hosts' intestines. Because some worms are parasites and some are free-living, their diets vary. Free-living worms eat things like detritus, fungi, protozoans, and algae. Worms typically use a digestive system to break down their food before it gets into the cells that need it, a strategy called **extracellular digestion**. Their digestive system forms from the endoderm during embryonic development. Tapeworms, however, lack a digestive system and instead absorb already digested nutrients from the intestines of their hosts through their outer layer. All these digestive structures keep a worm alive and maintain homeostasis by allowing it to take in nutrition and expel waste products to its environment.

The ectoderm layer forms the outer layer of the worm, which typically has sensory organs that feed information from the environment to the nervous system made up of two bundles of nerve cells called *ganglia* (s. **ganglion**). This outer layer has several different forms and names depending on the phylum. In flatworms the *tegument* is part of the living cells of the outer layer of the worm, while most segmented worms and roundworms have a nonliving layer called the *cuticle*.



All worms possess a mesoderm in their embryonic form, but only segmented worms have a **closed circulatory system**, one that transports nutrients from food through vessels. Flatworms and roundworms entirely lack a circulatory system because they have no body cavity or *coelom*. Instead, flatworms use diffusion to spread nutrients to the various parts of their bodies, and roundworms transport nutrients with the fluid in their body cavities. Most worms respire through their epidermis, lacking any specialized respiratory organs, although a

16-8

Segmented worms have a body cavity known as a *coelom*. Roundworms have a body cavity called a *pseudocoelom*. Flatworms have a digestive cavity surrounded by the mesoderm and ectoderm, but no body cavity.

few aquatic worms do have gills. All worms have structures to prevent osmosis from disrupting their homeostasis. Some flatworms and segmented worms also remove nitrogenous wastes with the same structures, called *flame cells*. Roundworms rid themselves of these same wastes through structures called *excretory cells* that empty outside the worm's body through excretory pores.

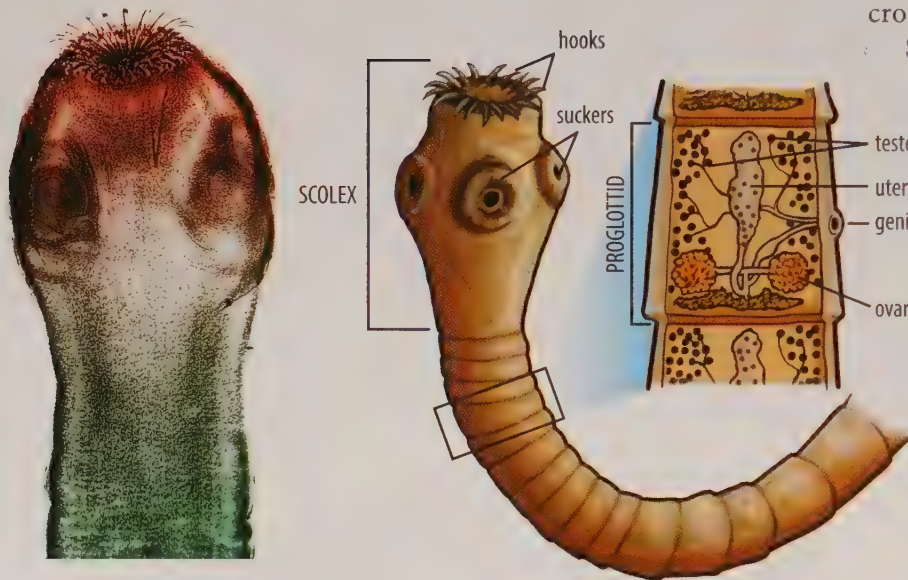
16.13 REPRODUCTION IN WORMS

Like other animals, worms reproduce sexually, although some worms, such as the group of flatworms called the flukes, also reproduce asexually. Flatworms and segmented worms are generally hermaphroditic.

However, this doesn't mean that they don't mate; actually, most hermaphroditic animals will cross-fertilize with other individuals.

Self-fertilization, while sometimes possible and found in some tapeworms, is almost always detrimental to the offspring since it allows genetic problems to accumulate.

After fertilization, some worms (e.g., earthworms) lay eggs in a cocoon that they attach to a plant or rock in their environment. Worms eventually hatch inside the cocoon and then move from it into the outside world. Some species of worms that live in a watery environment have eggs that hatch to release a plankton-like larva called a *trochophore*. Parasitic worms typically release their eggs in the feces of their hosts.

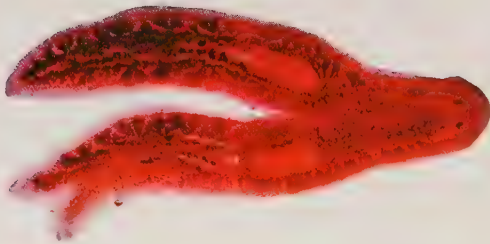


16-9

The parts of a pork tapeworm, a type of flatworm

16.14 HOW WORMS FUNCTION IN THE ENVIRONMENT

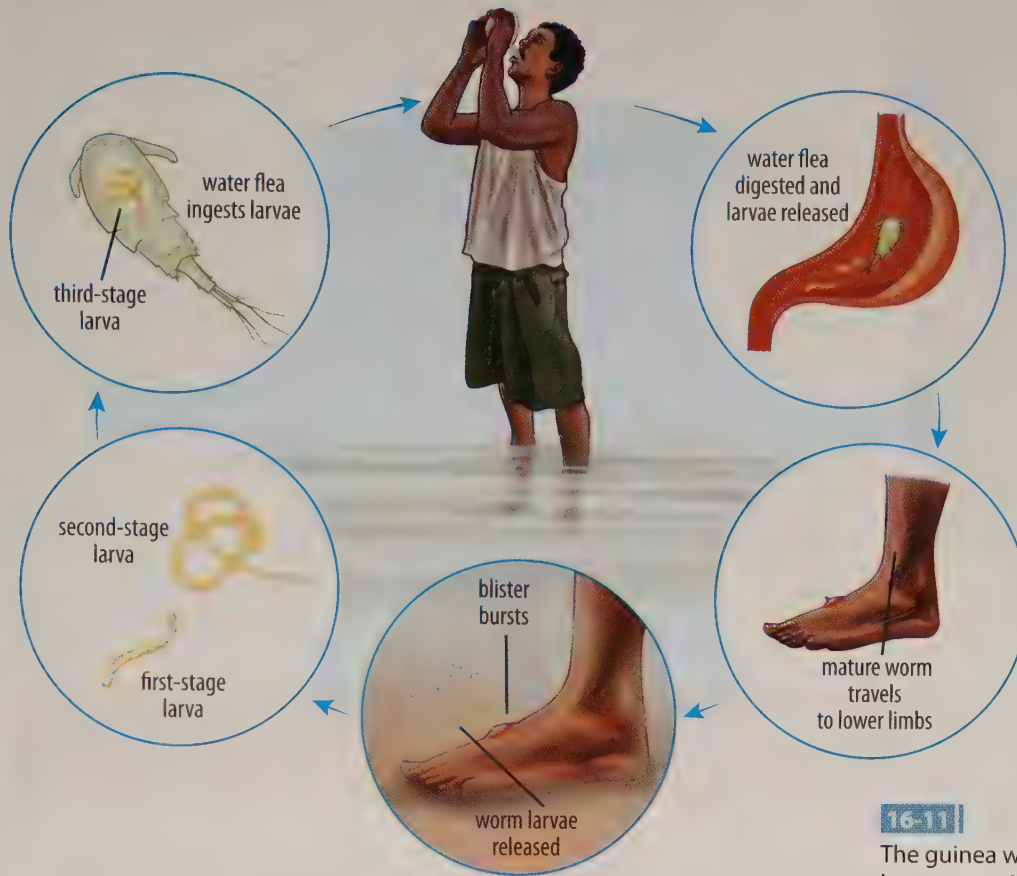
Many worms are parasites, drawing nutrition from their hosts, which could be humans or other animals, such as snails. All three types of worms can be parasitic, though there are fewer parasitic segmented worms than roundworms and flatworms. Parasitic worms have fewer sensory organs and are not as capable of locomotion since they don't have to travel to find food. These parasites have the ability to avoid the host's immune system in order to survive. Many of them have complex lifecycles involving at least two hosts. The adult parasite matures and sexually reproduces in the *definitive host*. After the parasite's eggs pass out of the definitive host, the larvae enter an *intermediate host* and undergo one or more stages of development. The intermediate host is then eaten by the definitive host, completing the parasite's life cycle.



16-10

Planarians have remarkable powers of regeneration. After a certain time, the planarian will pull itself apart, becoming two animals. If one is cut in almost any place, it can regenerate into a new planarian.

GUINEA WORM LIFE CYCLE



16-11

The guinea worm is a roundworm that can infect a human, mating inside its host's body and emerging, usually near the foot, in an extremely painful blister.

Though parasites can cause disease and are usually harmful, doctors are working on using parasitic worms to treat certain diseases. Some experimental procedures deliberately infect ill people, suffering from problems caused by an overactive immune system, with certain types of parasitic worms. The worms seem to decrease the body's immune response, giving relief to the patients. Actually, doctors have been using leeches for medical purposes for centuries. Though most of this use was for the medically useless and often dangerous practice of bleeding, doctors are starting to use leeches on skin graft patients. Leech saliva keeps the blood from clotting, which allows the blood vessels of the two pieces of skin to grow together. The leeches can be raised in sterile environments so that they do not introduce the risk of infection.

Some worms, especially earthworms, fill an important need in the environment as decomposers. Earthworms eat decaying organic matter in the soil, taking in some soil along with the decayed material to help grind it up. This not only sustains the worms but also enriches the soil as the earthworm expels its wastes, called *castings*. Earthworm burrows also allow oxygen and water to filter down into the ground, enabling plants to send their roots down deeper. This burrowing action also mixes organic matter into the soil. A single earthworm can



16-12

Earthworms hatch from an egg-like cocoon.

produce one half pound of rich, fertile soil in one year. When you consider that tens of thousands of earthworms can inhabit one acre of land, you realize what a significant impact one little invertebrate can have on an area's ecology.

16C REVIEW QUESTIONS

1. List five of the general characteristics of worms. (*Hint: Use Table 1 on page 308 to get started.*)
2. How can you tell the difference between flat worms, roundworms, and segmented worms? (See Figure 16-8.)
3. What do worms eat?
4. How do worms reproduce?
5. Are worms like earthworms oviparous, viviparous, or ovoviviparous? Explain.
6. Suggest how we can use worms to help people in ways other than what is mentioned in the text.

Use the case study below to answer Questions 7 and 8.

CASE STUDY: GUINEA WORM

It all starts with a drink of water. People might not know that they have a guinea worm until this 2–3 ft long parasitic worm begins to emerge in a blister that usually forms near the foot a year after infection. The only way to eliminate the worm is to wrap the end of it on a stick and turn it gradually until the worm is extracted, a painful process that may take weeks. As the infected person bathes his foot in a local water supply to relieve the excruciating pain, the guinea worm releases more eggs, potentially beginning a new infection. The good news is that, because of the efforts of health officials, worldwide there remain only a few cases of dracunculiasis, the guinea worm disease.

7. If you were a health official in Africa, how would you help people to avoid and treat dracunculiasis?
8. If you were a government official in Africa, how would you deal with an outbreak of dracunculiasis?

MOLLUSKS

How are mollusks unique as invertebrates?

16.15 CLASSIFYING MOLLUSKS

The submarine sinks to the inky depths of the ocean, attracting the attention of a giant squid which wraps its tentacles around the sub. Captain Nemo sends an electric shock through the ship but fails to dislodge the creature. They decide to rise to the surface to fight the beast in a thunderstorm. Such is the imagined tussle of a submarine with a giant squid in the movie version of *Twenty Thousand Leagues Under the Sea* by Jules Verne.

Squids are members of phylum Mollusca in kingdom Animalia, along with slugs, oysters, octopuses, clams, cuttlefish, nautilus, and snails. These animals are referred to as **mollusks**. They are the second largest phylum in kingdom Animalia.

16D Questions

- » What are mollusks?
- » How do mollusks reproduce?
- » How do mollusks affect their environment?



EXPLORING MOLLUSKS



Bivalves

Clams are part of a category of mollusks that includes oysters, mussels, and scallops, called **bivalves**. The fleshy part that you can see in the image to the left is the **mantle**, a sheath of tissue that wraps around the organs of mollusks. You can also see the two shells, hard, protective coverings created by the mantle. This shell serves as a support for many mollusks. A fleshy, muscular foot helps clams move around.



Gastropods

Though most mollusks live in the ocean, some live on land like this banana slug (*Ariolimax* sp.). The blue dragon sea slug on page 302 is another example. Slugs are found in a category of mollusks called **gastropods**, which also includes snails. Slugs have a foot that is found right below their **visceral mass**, the part of a mollusk's body that contains its heart and digestive organs.



Cephalopods

This flamboyant cuttlefish (*Metasepia pfefferi*, close left) and coconut octopus (*Amphioctopus marginatus*) are both members of the last category of mollusks—**cephalopods**. *Cephalopods* have feet that are divided into sucker-bearing arms, which are used to catch food. Both the cuttlefish and octopus have pigment-bearing cells called **chromatophores** in their skin that allow them to change color for camouflage and communication.

16.16 STRUCTURE AND REPRODUCTION IN MOLLUSKS

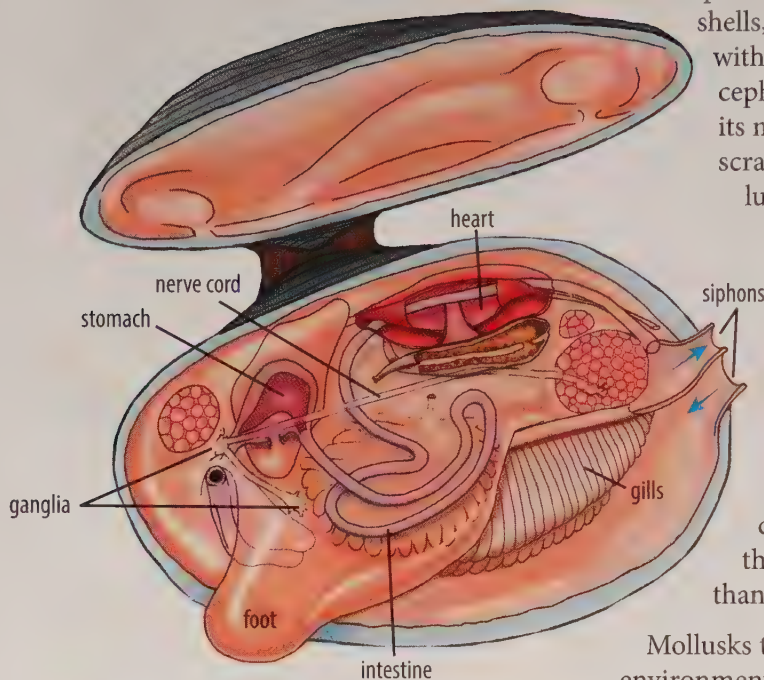
MOLLUSK STRUCTURE

As you can see from the photo gallery in the previous subsection, mollusks are diverse, though they have some common characteristics. Mollusks have three germ layers, most exhibit cephalization and bilateral symmetry, and all have digestive, circulatory, nervous, and respiratory systems.

But the three categories of mollusks—bivalves, gastropods, and cephalopods—are also very different. They can have one shell, two shells, or none at all. They can have one foot or eight arms filled with suckers. Some mollusks, including gastropods and most cephalopods, have both a mouth and a **radula**, an organ near its mouth with many tiny teeth, similar to a cheese grater, for scraping up food and pulling it into its mouth. Some mollusks have a nervous system that consists of ganglia. Some cephalopods stand out among the invertebrates because they are highly intelligent and have a cluster of ganglia that are organized to form a brain similar to those of vertebrates.

Mollusks that live underwater breathe using **gills**, thin-walled structures laced with blood vessels that bring oxygen to the blood. Cephalopods have closed circulatory systems, while bivalves and gastropods have open circulatory systems where blood and other fluids flow through the body cavity to bathe internal organs rather than circulate through vessels.

Mollusks that live in the water also often circulate water from their environment through two tubes, or **siphons**. One tube brings water in, while the other allows water to leave. If the mollusk wants to move quickly to avoid a predator, it jets water out of its siphon. Many cephalopods have the ability to squirt ink to confuse and distract predators.



16.13

Clams have an anatomy that is representative of mollusks. However, the anatomy of cephalopods is different, including a brain and a closed circulatory system.

MOLLUSK REPRODUCTION

Most mollusks reproduce sexually, though they vary in the method. Simpler mollusks reproduce through external fertilization, with some species such as snails being hermaphrodites. More complex mollusks such as cephalopods mate and reproduce through internal fertilization.

In mollusks, fertilization produces eggs that hatch to release larvae. For water-dwelling mollusks, these larvae float as plankton in their watery environment. For simpler mollusks, larvae are trochophores similar to the larvae of earthworms. They change and mature through a process called *metamorphosis*. In cephalopods, the young that hatch from eggs are just smaller versions of their adult form.

16.17 HOW MOLLUSKS FUNCTION IN THE ENVIRONMENT

Though some mollusks live on land, most are aquatic. Mollusks can be carnivores, herbivores, and scavengers in their habitats. They eat algae, detritus, and even each other, with some mollusks like sea snails preying on sea cucumbers. Mollusks play a role in a variety of ecosystems, such as the coral reef community. They find shelter and food in the coral reef community.

People use mollusks to enrich and improve their lives. Some mollusks are edible, such as the abalone mentioned at the beginning of this chapter. Scientists are also studying the regenerative power of mollusks to help create therapies and medications that can help people with specific medical problems. We can use our knowledge of biology to manage the creatures that God has put under our care to help people and bring Him glory.

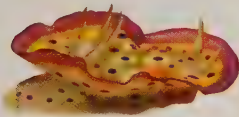


16-14

Scientists are investigating the ink of the neon flying squid (*Ommastrephes bartramii*), which has the ability to suppress the growth of some cancers.

16D REVIEW QUESTIONS

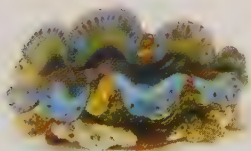
1. Give four of the general characteristics of mollusks.
2. Identify each animal in the photos below as a bivalve, gastropod, or cephalopod. Explain your choice.
 - a. nudibranch (*Goniobranchus kuniei*)



- b. chambered nautilus (*Nautilus pompilius*)



- c. giant clam (*Tridacna gigas*)



3. What does a cephalopod have that every other invertebrate that we have already studied does *not* have? How would this affect its lifestyle?
4. What is different about the type of reproduction of mollusks compared with worms, sponges, and cnidarians?
5. In what kind of ecosystems do mollusks play a key role?

16D Questions

- » What is an echinoderm?
- » How do echinoderms reproduce?
- » How do echinoderms affect their environment?

Echinodermata: Echino- (Gk. *ekhinós*—spiny)
+ -dermata (Gk. *dermata*—skin)

ECHINODERMS

How are echinoderms classified?

16.18 | CLASSIFYING ECHINODERMS

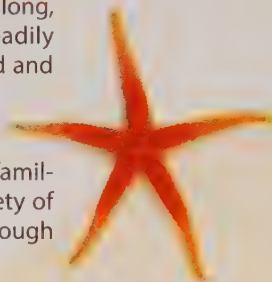
Another phylum of invertebrates in kingdom Animalia is phylum **Echinodermata**. It includes marine animals ranging from the prickly sea urchin to the sea star. These invertebrates can be found in all ocean zones, from the light-filled intertidal zone to the depths of the abyssal zone, though most live in the deep oceans. Animals in this phylum are called **echinoderms** (ee KINE oh derms). They have three germ layers and exhibit radial symmetry. Most also have an endoskeleton made of plates called *ossicles*. Explore the five different classes of echinoderms shown below.

EXPLORING ECHINODERMS

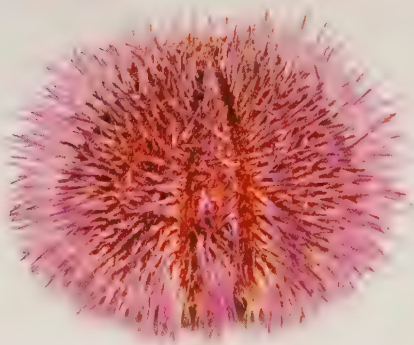


The brittle star looks like a starfish, but it has long, thin arms. It's called "brittle" because it readily discards its arms when attacked or disturbed and easily regenerates them.

Starfish or sea stars are probably the most familiar echinoderm. They can be found in a variety of colors and have various numbers of arms, though most have five.



Sea lilies are echinoderms that are sessile and look more like plants. Many sea lilies, also called *crinoids*, are found as fossils. Crinoids without stalks are called *feather stars*.



Sea urchins are like marine porcupines or hedgehogs. In fact, they were once called *sea hedgehogs*. They have sharp spines that can create painful puncture wounds in predators.

This sea pig (*Scotoplanes*), a genus of sea cucumber, would fit in your hand. You'll probably never hold one, though, because it lives on the ocean floor of the abyssal plain. Its "legs" and the "antennae" on top are actually elongated tube feet. Sea cucumbers are the only class of echinoderms that lack ossicles.



16.19 STRUCTURE AND REPRODUCTION IN ECHINODERMS

ECHINODERM STRUCTURE

One of the identifying features of echinoderms is a **water-vascular system**—a series of canals and tubes used for circulating nutrients, moving, and capturing food. The most obvious feature of this system is hundreds of **tube feet**, knobs or leg-like structures on the bodies of echinoderms. All echinoderms have tube feet. These hollow feet are joined by a water canal that extends to the central part of the echinoderm's body. This water canal system opens to an echinoderm's watery environment through a sieve-like structure called a *madreporite*.

Echinoderms have all of the body systems associated with animals. They breathe through their tube feet, or in some cases through gills, allowing them to take in oxygen from their aquatic environment to maintain homeostasis in their bodies. They have a closed digestive system with a mouth on their lower surface. Their mouth scoops up detritus, algae, and prey. An anus on their upper surface expels waste, again maintaining homeostasis by ridding the body of substances that it can't use. An echinoderm has a nerve net like a cnidarian, and it can sense and respond to its environment even without a head or brain. It also has an open circulatory system.

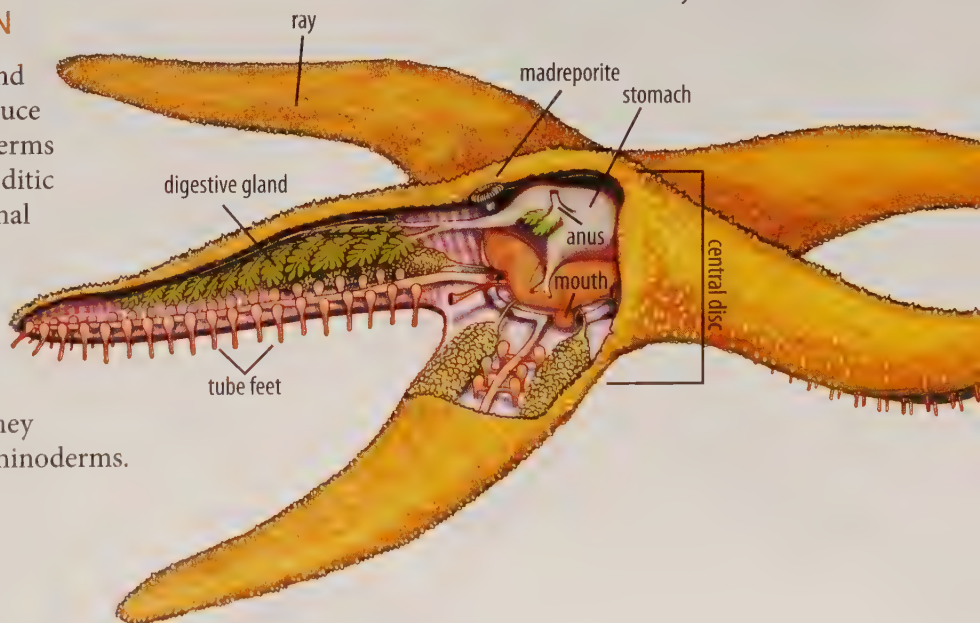
Some echinoderms have amazing powers of regeneration and can regrow a lost limb. They can even completely regenerate from a partial organism made of part of the central body and a limb or two.

ECHINODERM REPRODUCTION

Echinoderms reproduce both asexually and sexually. Most often echinoderms reproduce sexually when male and female echinoderms mate, though there are some hermaphroditic species. Eggs are fertilized through external fertilization, with some echinoderms guarding or *brooding* their fertilized eggs. These eggs hatch to release larvae that exhibit bilateral symmetry and are capable of motion and asexual reproduction. As they mature, they develop the radial symmetry typical of echinoderms.

16-15

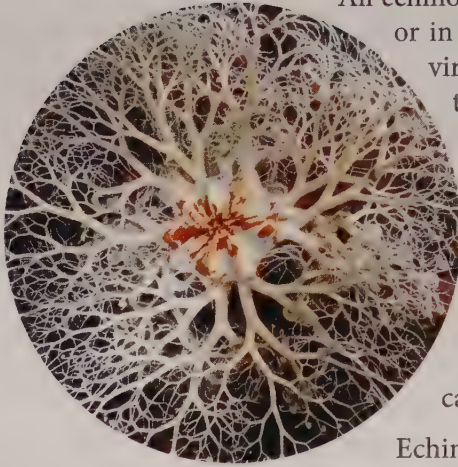
All the canals that you see in this picture are part of a starfish's water-vascular system.



16.20 HOW ECHINODERMS FUNCTION IN THE ENVIRONMENT

16-16

Basket stars feed at night by raising their arms into the form of a basket to trap plankton.



All echinoderms are marine, having no representatives on land or in fresh water. They serve a variety of roles in the environment, acting as algae grazers, scooping up detritus, and even hunting other animals in their ocean environments.

You can find echinoderms in any of the ocean zones. They have a large presence in the dark ocean depths of the hadal and abyssal zones. This area is like an underwater desert—nothing grows because there is no light. Echinoderms serve a useful purpose as scavengers, eating organic matter and carcasses that settle to the ocean depths.

Echinoderms also have a large presence in the other extreme zone of the ocean—the intertidal zone. Starfish and sea urchins flourish amid the bashing waves and fluctuating conditions of tidepools. Some echinoderms find shelter and food in the coral reef community. For example, the crown-of-thorns starfish is one of the few predators that corals have.

Echinoderms are useful to humans too. Sea urchins and sea cucumbers are viewed as a culinary treat in some areas of Asia, and there is a danger of them being overharvested. People are investigating ways to raise them in captivity. The shells of echinoderms are also used by the ton each year as a source of limestone to fertilize farm fields. The stunning and useful diversity and beauty in the world of invertebrates point to a God who is an intelligent, artistic, and caring Creator.



16E REVIEW QUESTIONS

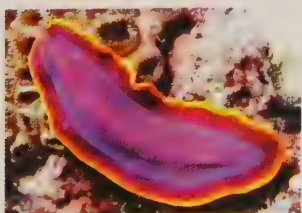
1. What two things about the body of an echinoderm make it different from a mollusk?
2. Compare the number of germ layers and the symmetry of echinoderms and cnidarians.
3. Create a table that compares the five classes of echinoderms, including the following characteristics: locomotion, the presence of ossicles, and the presence of tube feet.
4. Some echinoderms respond to injuries in a way similar to that of planarians. Explain.
5. Mollusks and echinoderms both play a key role in what kind of ecosystems?

REVIEW QUESTIONS

CONCEPT REVIEW

1. List the six characteristics of animals.
2. Use the characteristics of animals to show that a domestic cat (*Felis catus*) is an animal.
3. Use a T-chart (see Appendix B) to compare vertebrates and invertebrates. Include the six characteristics of animal life in your comparison.
4. A peacock butterfly (*Aglais io*) suns itself on a rock to raise its body temperature. Do you think it is an ectothermic or endothermic animal? Explain your choice.
5. Which kind of symmetry does the peacock butterfly demonstrate?
6. Why do you think a sponge has no nervous, circulatory, or digestive system?
7. Give the number of germ layers in each of the following organisms:
 - a. blue dragon sea slug (*Glaucus atlanticus*)
 - b. crown-of-thorns starfish (*Acanthaster planci*)
 - c. lion's mane jellyfish (*Cyanea capillata*)
 - d. marine flatworm
 - e. row pore rope sponge (*Aplysina cauliformis*)
8. Explain the relationship between bilateral symmetry and germ layers.
9. A red kangaroo (*Macropus rufus*) reproduces when the male's sperm fertilizes an egg inside the female's body. Eventually, a young joey the size of a lima bean emerges and migrates up to the pouch where it will nurse and continue to grow. What kind of fertilization and development (oviparous, ovoviviparous, or viviparous) does the red kangaroo exhibit?
10. Why must ovoviviparous and viviparous species always reproduce through internal fertilization?
11. Give an example of how an animal could respond to the environment and change how it interacts with other animals.
12. Name one thing that both the polyp and medusa forms of cnidarians have in common.
13. Why are sponges and cnidarians such an important part of the marine food web?
14. Identify each of the following worms as a flatworm, round worm, or segmented worm. Explain your choice.

a. *Pseudoceros ferrugineus*



b. *Toxascaris leonina*



c. *Spirobranchus giganteus*



Key Terms

endoskeleton	305
exoskeleton	305
hydroskeleton	305
body plan	305
bilateral symmetry	305
radial symmetry	305
sessile	307
vertebrate	308
chordate	308
invertebrate	308
endothermic	308
ectothermic	308
blastula	309
germ layer	309
endoderm	309
mesoderm	309
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cephalization	309
anus	309
external fertilization	310
internal fertilization	310
oviparous	310
ovoviviparous	310
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behavior	311
instinct	311
intracellular digestion	313
hermaphroditic	313
cnidarian	314

(continued)

T

Key Terms (continued)

nerve net	315
polyp	315
medusa	315
extracellular digestion	319
ganglion	319
closed circulatory system	319
mollusk	323
mantle	323
visceral mass	323
radula	324
siphon	324
echinoderm	326
water-vascular system	327
tube feet	327



16-17

A starfish larva

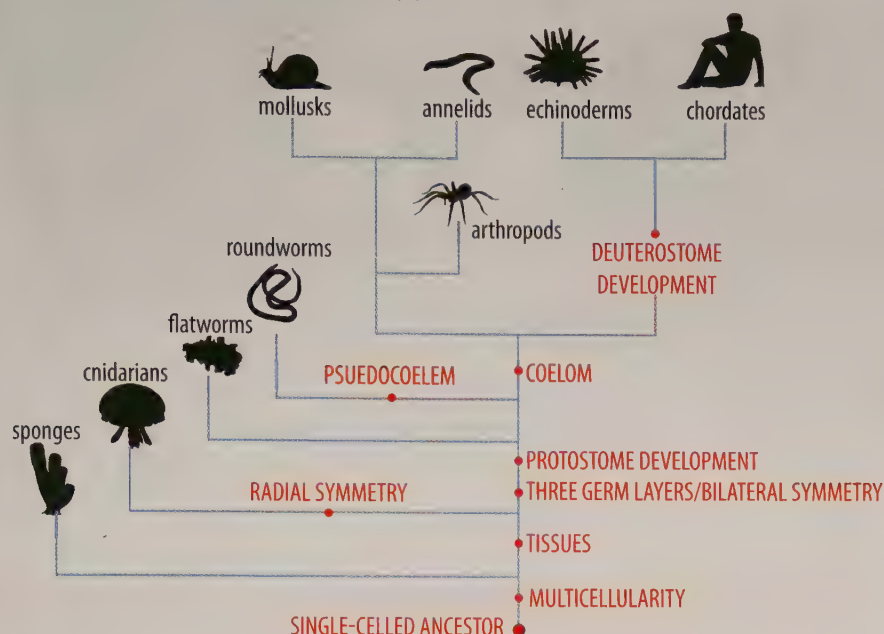
15. Why do segmented worms have digestive, circulatory and nervous systems while sponges don't?
16. Why do many worms *not* need other worms to reproduce?
17. What do we call young earthworms and mollusks?
18. Which two classes of worms contain most of the parasitic worms?
19. How can learning about worms help us to protect people from disease?
20. What is one of the most significant features that make cephalopods different from all the other invertebrates?
21. What ability do some cephalopods have to defend themselves against predators that bivalves and gastropods lack?
22. What do all bivalves have that some gastropods and most cephalopods lack?
23. What feature do sea cucumbers lack that other echinoderms have?
24. Name two things that all echinoderms have.
25. What is different about the body plans of echinoderm larvae and adults?
26. What is the most important role for benthic (bottom-dwelling) echinoderms?
27. List all the groups of invertebrates that you learned about in this chapter that have hermaphroditic species.
28. Invertebrates that have digestive systems use extracellular digestion. Create a T-chart (see Appendix B) with the headings "Intracellular digestion" and "Extracellular digestion." Place, sponges, cnidarians, worms, mollusks and echinoderms in each column on the basis of their method of digestion.
29. Compare the nervous systems of sponges, cnidarians, worms, mollusks, and echinoderms.
30. Compare the circulatory systems of worms with that of sponges, mollusks, and echinoderms.
31. Create a hierarchy chart (see Appendix B) using domain Eukarya and kingdoms Protozoa, Fungi, Chromista, Plantae, and Animalia. Include vertebrates, invertebrates, sponges, cnidarians, mollusks, worms, and echinoderms. Include the different groups of cnidarians, worms, mollusks and echinoderms in your chart.

TRUE OR FALSE

32. All animals demonstrate locomotion at some point in their lives.
33. Most of the animals in the world are vertebrates.
34. All animals have germ layers.
35. Most animals can reproduce sexually.
36. Cnidarians can all inflict stings.
37. Earthworms eat soil.
38. Most mollusks can reproduce asexually.
39. All mollusks have brains.
40. All echinoderms have symmetry and a water-vascular system.

CRITICAL THINKING

Scientists have structured the classifications of invertebrates and vertebrates to link their evolution with their body plans.



Use the cladogram above to answer Questions 41–44.

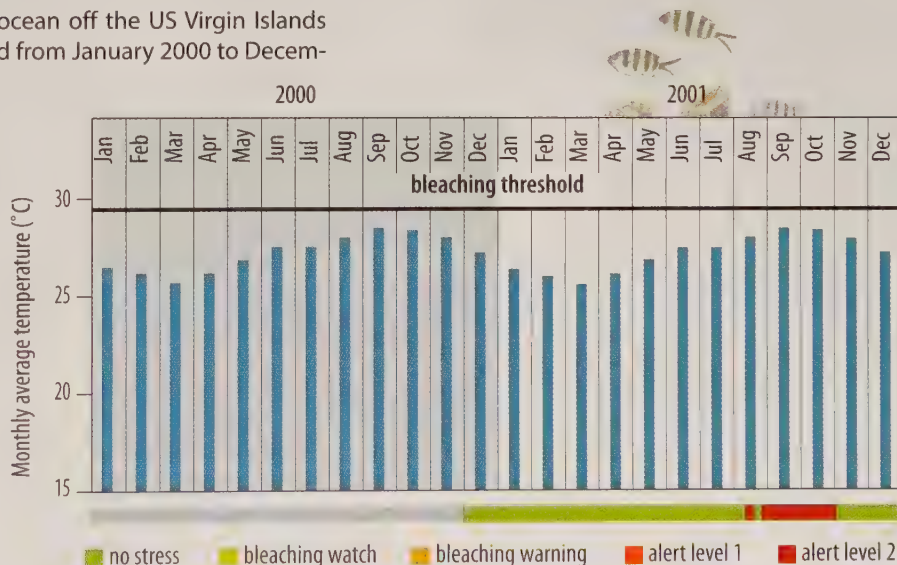
Think about the germ layers as you read these questions. Some of the evolutionary relationships on this chart may surprise you!

41. Why do you think sponges are the lowest on the cladogram?
42. Annelids, arthropods, and mollusks all are on the same branch of the cladogram. Why is this?
43. Why are humans grouped with chordates on this cladogram?
44. Do some research to figure out why evolutionists say that humans, vertebrates, and echinoderms all come from a common ancestor.

Answer Questions 45–49 using the graph below.

The graph shows how the conditions of the ocean off the US Virgin Islands change during the year. This data was collected from January 2000 to December 2001.

45. What time of year do corals experience the least stress?
46. When did the coral reefs near the US Virgin Islands begin to struggle?
47. What do you think is the main concern with coral bleaching (see page 317)?
48. Why is it a problem if corals die?
49. Suggest a course of action to exercise good and wise dominion of coral reefs.





CHAPTER 17

ARTHROPODS

17A ARTHROPOD INTRODUCTION AND CHELICERATES 333

17B CRUSTACEANS 336

17C INSECTS 342



INSECT FORENSICS

The small, annoying insect buzzing around the room right now may just be able to resolve the next murder case. Insects like the green bottle fly (*Lucilia sericata*) are giving forensic scientists the data they need to solve crimes. When a body dies, insects take over to feed and lay eggs. The green bottle fly is one of the first insects to arrive at a corpse, within minutes after death. Scientists know how much time these processes take, so they can use these clues to unravel mysteries and help bring perpetrators of crime to justice.

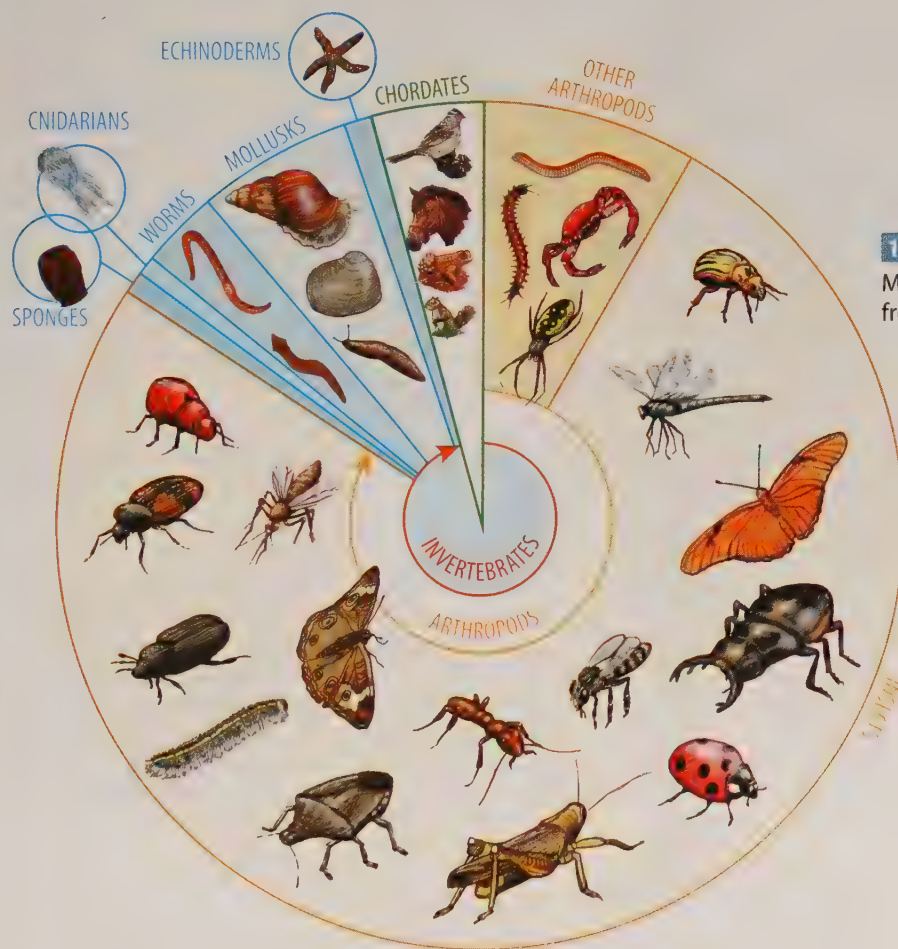
In fourteenth century China, Sung Ts'u, one of the first forensic entomologists, used the green bottle fly to solve a case in which a worker was murdered in a rice field with a sickle. Many people had sickles—who was the culprit? The sickles of all the workers were lined up, and green bottle flies were attracted only to the sickle of the murderer. Case solved!

ARTHROPOD INTRODUCTION AND CHELICERATES

How do spiders compare with other arthropods?

17.1 ARTHROPOD ATTRIBUTES

Arthropods cover our planet. They are members of the largest and most significant phylum in kingdom Animalia—phylum Arthropoda. Insects are the largest group in this phylum. Because insects are so common in our world, they are always available to police and crime scene investigators. Arthropods can give us information to solve murder and abuse cases and even to figure out the causes of aircraft and car accidents (see Chapter opener).



17A Questions

- » What is an arthropod?
- » What is a chelicerate?
- » How do spiders feed and reproduce?
- » What is the role of chelicerates in their environment?

17-1

Most of the organisms in kingdom Animalia are from what group?

Like the other animals you learned about in the last chapter—worms, sponges, cnidarians, mollusks, and echinoderms—all arthropods are invertebrates. They include crustaceans, spiders, scorpions, insects, centipedes, and millipedes. They also include the now-extinct trilobite, which is found fossilized in rock all over the world. Let's look at the characteristics and the three major categories of arthropods—chelicerates, crustaceans, and insects.

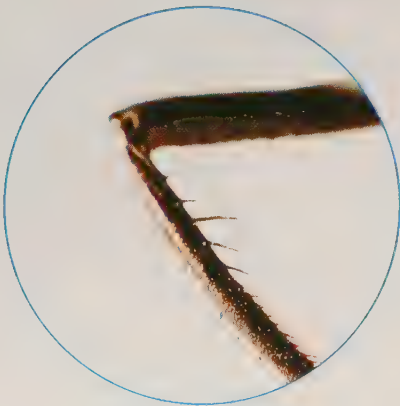
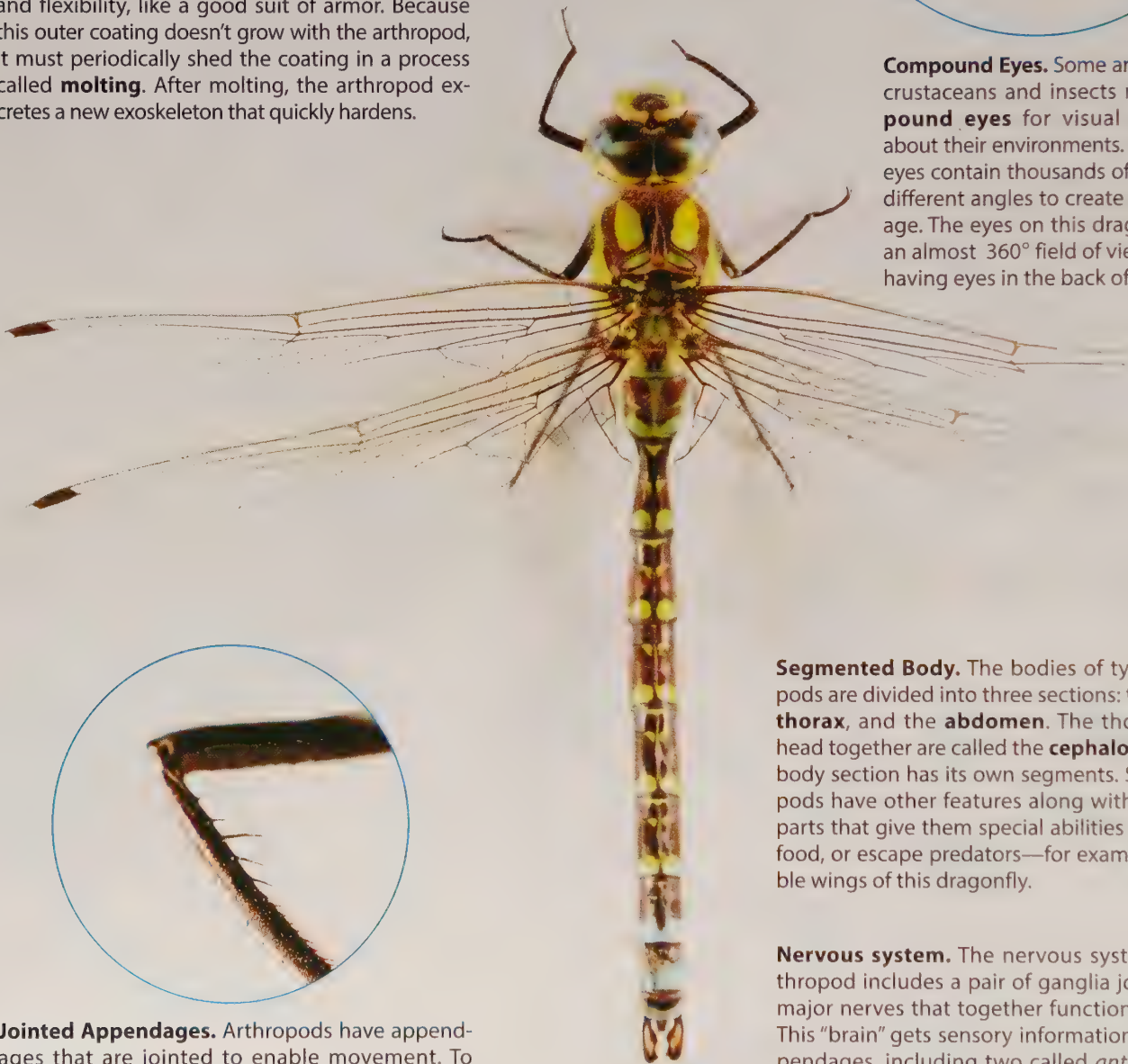
ARTHROPOD ATTRIBUTES

Open Circulatory System. Arthropods have dorsal hearts that pump blood through short veins to deliver blood to the body. The blood then bathes organs in these cavities.

Exoskeletons. Arthropods have stiff exoskeletons that give them support. This structure is made of layers of substances, including one carbohydrate called **chitin**. Chitin gives arthropod bodies strength and flexibility, like a good suit of armor. Because this outer coating doesn't grow with the arthropod, it must periodically shed the coating in a process called **molting**. After molting, the arthropod excretes a new exoskeleton that quickly hardens.



Compound Eyes. Some arthropods like crustaceans and insects rely on **compound eyes** for visual information about their environments. These special eyes contain thousands of lenses set at different angles to create a mosaic image. The eyes on this dragonfly give it an almost 360° field of view. That's like having eyes in the back of your head!



Jointed Appendages. Arthropods have appendages that are jointed to enable movement. To fend off predators, some arthropods have swiveling stinging tails like scorpions, delicate nimble legs like grasshoppers, and ferocious-looking claws like lobsters.

Segmented Body. The bodies of typical arthropods are divided into three sections: the head, the **thorax**, and the **abdomen**. The thorax and the head together are called the **cephalothorax**. Each body section has its own segments. Some arthropods have other features along with these three parts that give them special abilities to move, get food, or escape predators—for example, the double wings of this dragonfly.

Nervous system. The nervous system of an arthropod includes a pair of ganglia joined by two major nerves that together function like a brain. This "brain" gets sensory information from its appendages, including two called **antennae** (s. **antenna**) located in the head region. Antennae give information about taste, smell, and touch, but they can't relay visual information. Insect feet actually have sensory structures that smell and taste (think about that fly on your hamburger).

17.2 CLASSIFYING CHELICERATES

Chelicerates (kih LIS uh rahtes) are arthropods having one or two body sections and clawlike appendages called *chelicerae* (s. **chelicera**) for grabbing and immobilizing prey. Chelicerae work like a pair of tweezers or tongs. Chelicerates include horseshoe crabs and *arachnids*, a class of arthropods that includes spiders, ticks, mites, and scorpions.

EXPLORING CHELICERATES

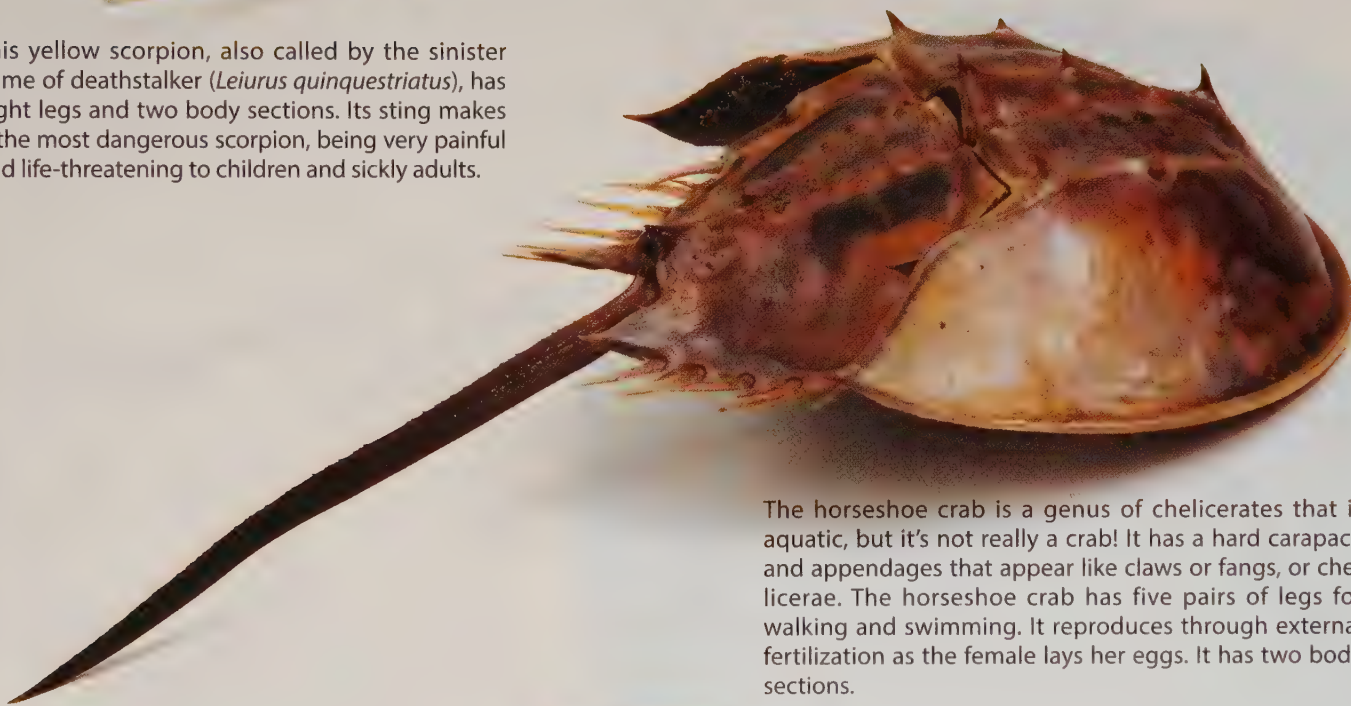


This yellow scorpion, also called by the sinister name of deathstalker (*Leiurus quinquestriatus*), has eight legs and two body sections. Its sting makes it the most dangerous scorpion, being very painful and life-threatening to children and sickly adults.



○ actual size

This red bug (*Trombicula autumnalis*) is a chigger, or mite, that is also an arachnid. Its body sections are fused, so it looks like it has only one body section. This is characteristic of ticks and mites. Red bugs are very tiny, less than half a millimeter, but they can attach to animals and humans just like their tick relatives.



The horseshoe crab is a genus of chelicerates that is aquatic, but it's not really a crab! It has a hard carapace and appendages that appear like claws or fangs, or chelicerae. The horseshoe crab has five pairs of legs for walking and swimming. It reproduces through external fertilization as the female lays her eggs. It has two body sections.

The arachnid you're probably most familiar with is the spider. This colorful peacock spider (*Maratus volans*) displays his vibrant colors for mating. It is very tiny, only 5 mm long; its mating dance can be seen only with the help of a microscope. If he doesn't succeed in attracting a mate, he scampers off quickly—unless he wants to be eaten by disapproving, observing females!



17.3 STRUCTURE AND REPRODUCTION OF CHELICERATES

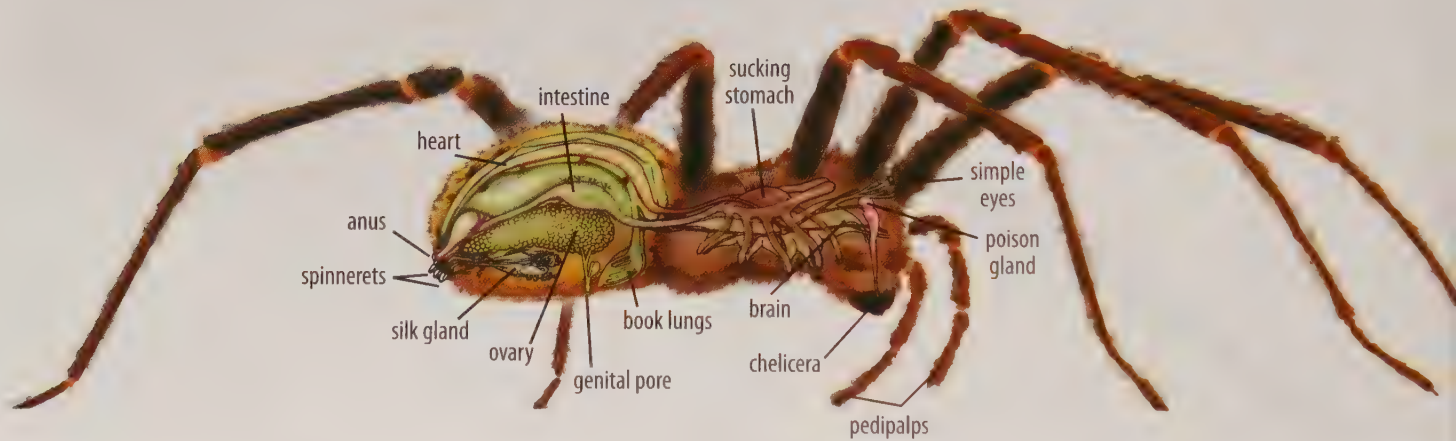
CHELICERATE STRUCTURE

Chelicerates have some common features in addition to their pincer-like chelicerae. Most have four pairs of walking legs and one or two body sections, including a cephalothorax and abdomen. Think about what a spider looks like. In front of the walking legs are **pedipalps**, appendages that chelicerates use to eat, mate, and sense their environment. Chelicerates don't have antennae, unlike other arthropods. They also have two to four eyes, which are usually *simple* eyes with only one lens. How, then, do they get information about their environment? Sensory information is received from their feet and simple eyes.

Since chelicerates are a mix of aquatic animals, such as horseshoe crabs and sea spiders, and land animals, such as scorpions, ticks, and spiders, they have unique features for maintaining homeostasis in their own environments. Just think how different their breathing needs to be. For example, spiders, scorpions and mites have organs called **book lungs** that allow air to enter their bodies. This air goes straight to tissues without passing into the circulatory system. Since *aquatic* chelicerates live in the water, they have *book gills* that help them get oxygen from the water to transport to their tissues.

17-2

Identify some of the common features of chelicerates on this horseshoe crab.



Spiders also have some unique structures. A system called the *Malpighian tubule system* allows the spider to get rid of nitrogen-containing wastes without losing necessary water. Another organ called a **spinneret** spins spider silk from a protein manufactured in the tip of the abdomen. Spiders use this silk for lots of things, including capturing prey for nutrition. Labs full of scientists have not been able to create a material that is as naturally strong as spider silk, and it is manufactured right in the abdomen of spiders.

CHELICERATE REPRODUCTION

Aquatic and terrestrial chelicerates also reproduce differently. Generally, aquatic chelicerates such as sea spiders and horseshoe crabs reproduce sexually through external fertilization, while terrestrial chelicerates undergo internal fertilization. Some chelicerates, such as scorpions, spiders, and sea spiders, brood their eggs until they hatch to release young.

174 CHELICERATES IN THE ENVIRONMENT

Chelicerates play various roles in the environment—they are parasites, predators, and prey. Ticks and mites are parasitic, with some being vectors for diseases such as Lyme's disease and Rocky Mountain spotted fever.

But not all chelicerates are bad news. Since many are insect predators, they also help keep insect populations under control. For example, some smaller scorpions eat the dust mites and moth larvae that eat clothes. Spiders spin cobwebs and orb webs to catch insects.

Chelicerates are part of the food web in their roles as both predator and prey. For example, horseshoe crab eggs are an easy food source for shore birds. Insects even eat spiders! The tarantula hawk captures a single tarantula, stings and paralyzes it, and lays a single egg, which then hatches, releasing a larva that slowly eats the spider alive.

Chelicerates could save your life. Scientists have been “milk-ing” horseshoe crabs for their blue blood, which has amazing antibacterial properties, forming clots around even very small amounts of bacteria that could be lethal for humans. After horseshoe crabs are “milked,” they can be released back into the wild to regenerate their blood supply. Scientists are using this blood to test for the presence of bacteria in medicines and on medical equipment. Scientific work is being done to use horseshoe crab blood to detect viral and fungal infections and even treat cancers.



17-3

The tarantula hawk, a type of wasp, has one of the most painful insect stings in the world. In the photo above, a wasp incapacitates a tarantula so that she can use the tarantula as a food source for her larva.



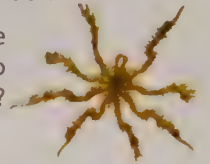
17-4

Horseshoe crab blood is blue because it contains a chemical called *hemocyanin* instead of the hemoglobin that makes blood red. It is used in the *LAL test*, which indicates the presence of even extremely small amounts of bacteria in about 45 minutes. Horseshoe crab blood costs over \$10,000 per quart!



17A REVIEW QUESTIONS

1. Demonstrate that the cicada (*Homoptera*) shown in the margin is an arthropod using at least three characteristics of arthropods that you can observe in the photo.
2. Does the photo indicate that the cicada lives in water or on land? Explain.
3. Draw a hierarchy chart using the following terms: arachnids, arthropods, horseshoe crab, invertebrates, mite, spider, scorpion, and tick.
4. What one characteristic does every chelicerate have?
5. Name one attribute of arthropods that spiders lack.
6. Name one attribute of spiders that other arthropods lack.
7. The sea spider (shown right) is an aquatic chelicerate that is not actually a spider. Would it be more likely to reproduce through internal or external fertilization? Explain.
8. The organism that permanently lives at the highest elevation on Earth is a spider—the Himalayan jumping spider (*Euophrys omnisuperstes*). It eats insects that are occasionally carried to these elevations by mountain breezes. Where is this spider in the food chain for its habitat?
9. Before scientists used horseshoe crab blood for the LAL test, they used rabbits to test vaccines for contamination by bacteria. Live rabbits were injected with the vaccine and observed for days. Much like humans, they have a sensitivity to these bacteria. Horseshoe crab blood is about 100 times more sensitive. Give reasons why using horseshoe crab blood is a better way to help people and wisely use animals.
10. Suggest a way that we could improve the LAL test that would reduce our reliance on horseshoe crabs, especially since they are so useful for other things and are so important to marine ecology.



17B Questions

- » How is a crustacean different from other arthropods?
- » How do crustaceans feed and reproduce?
- » How do crustaceans affect their environment?

17B

CRUSTACEANS

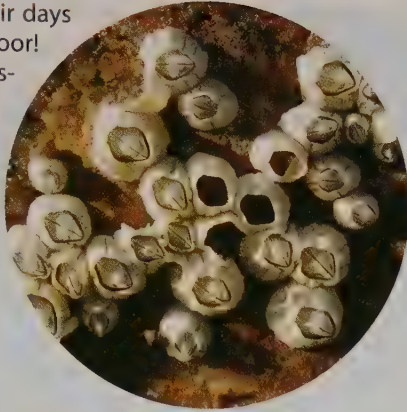
What traits do crustaceans share?

17.5 CLASSIFYING CRUSTACEANS

Crustaceans are a large group of arthropods, second in the number of species only to insects. Most crustaceans spend the majority of their time in water, although some spend a good bit of time on land. Crustaceans are as abundant in the oceans as insects on land. Because they are usually aquatic, many share some key features, including a cephalothorax covered by a single exoskeletal plate called a **carapace** (KEHR uh pase). Crustaceans have two or three body sections. The abdomens of many are covered by a series of plates. Pairs of flipper-like appendages called **swimmerets** extend from the abdomen.

EXPLORING CRUSTACEANS

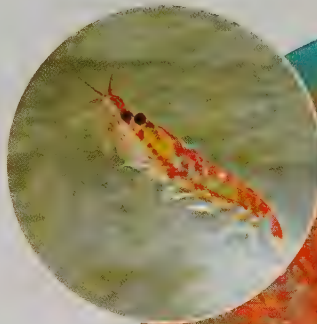
Not all crustaceans spend their days galloping across the ocean floor! These barnacles are mostly sessile, though they have free-swimming larvae. They have one body section. They inhabit places with lots of tidal action, feeding on food particles that float in ocean water.



This Japanese spider crab (*Macrocheira kaempferi*) is the largest known arthropod at a whopping 15 feet wide! The spider crab and most other crustaceans are aquatic. Large arthropods tend to be aquatic since they lack the muscle power to move their heavy exoskeletons on land.



Some crustaceans, like this white river crayfish (*Procambarus actus*), live in fresh water, along with some species of shrimp. Crayfish are very similar to lobsters in their structure and function.



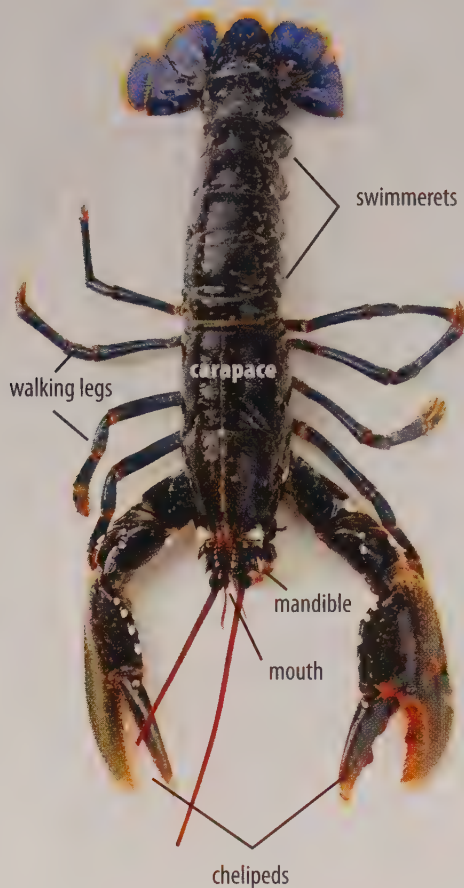
17.6 STRUCTURE AND REPRODUCTION OF CRUSTACEANS

CRUSTACEAN STRUCTURE

Crustaceans have body parts that help them function in their environment, whether it be salty or fresh water. Many crustaceans like crabs can venture out of the water onto land for shelter or to hunt for food. Their appendages help them do this. Most crustaceans have appendages that branch into two parts, unlike the other arthropods that have non-branching appendages. Five pairs of **walking legs** allow them to maneuver on land and in the water. The first three pairs often exhibit claws called **chelipeds**. Crustaceans use their chelipeds to fend off predators, spar with other crustaceans, capture prey, and groom themselves.

When hunting for prey, crustaceans collect sensory information from their environment with their compound eyes. They also use their two sets of antennae, appendages on their heads, to feed sensory information to their nervous system. Many crustaceans are also equipped with

Krill are shrimp-like crustaceans with two body sections. They make up a huge percentage of the biomass in the oceans. Krill forms a key link in the marine food chain between phytoplankton and larger forms of life. Marine life near Antarctica couldn't survive without Antarctic krill (*Euphausia superba*), which appears in pink, opaque clouds when millions hatch.



chromatophores like some mollusks, enabling them to change color in order to blend into their surroundings or to communicate. Once they capture prey, some crustaceans use **mandibles**, appendages near their mouths, to crush their food. They have a digestive system with both a mouth and anus. Crustaceans have an open circulatory system to spread nutrition to their body for maintaining life processes. Larger crustaceans use gills to breathe in their aquatic environment. Even crabs that venture onto land must often return to the water to wet their gills. Air can diffuse into the water on the gills so that they can extract oxygen from the water. Smaller crustaceans breathe through their skin.

CRUSTACEAN REPRODUCTION

Crustaceans can't reproduce asexually, but they can regenerate their limbs when one is lost in a battle with a predator. Crustaceans usually reproduce sexually when males mate with the females, who store sperm in their bodies until they lay eggs. Fertilization happens externally as the eggs pass out of the female's body past the place where the sperm is stored. Some aquatic crustaceans can also exhibit internal fertilization, though it is more common with terrestrial crustaceans such as crabs.

177 CRUSTACEANS IN THE ENVIRONMENT

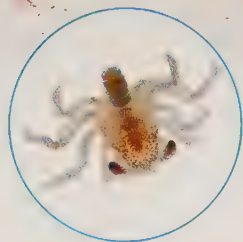
Since crustaceans are so common in the marine environment, they have the greatest effect on this biome. Crustaceans are *ecosystem engineers*, organisms that shape their environment in ways that often make it a better place for other organisms to live. The changes that ecosystem engineers make usually result in increasing the species richness of a community. We've seen other ecosystem engineers like the African termite, giant kelp, and corals. So what do crustaceans do to make the marine environment better for other organisms?

Many crustaceans are filter feeders and dine on detritus, returning nutrients to their environments and keeping the water free of waste products. Crayfish serve this purpose in fresh water. Other crustaceans keep the ocean floor clean, scavenging dead carcasses like fallen whales that sink slowly into the abyssal zones. Scavenging crustaceans include lobsters, prawns, shrimp, and isopods (a marine version of pillbugs, also called roly-polies).

Krill are ecosystem engineers not because of what they eat but because they get eaten! This tiny crustacean is a giant in the marine community. Krill make up the largest biomass of any animal in the ocean. They eat plankton, sometimes scraping algae off sea ice in polar regions. Larger organisms such as whales, squid, fish, and seabirds eat the krill when they gather in large groups called *swarms*. In fact, animals that eat krill migrate with their babies to the Antarctic to feast when krill swarms form as millions of krill hatch from their eggs. Because of their strategic place on the food chain, krill are called a *key-stone species*.

17-5

This Christmas Island red crab (*Gecarcoidea natalis*) mother broods her fertilized eggs on the underside of her body until they hatch later to release larvae (bottom).



17B REVIEW QUESTIONS

1. Why can aquatic arthropods grow larger than terrestrial arthropods?
2. Suggest one way that you could tell a crustacean apart from other arthropods.
3. It's dinnertime for a common lobster (*Homarus gammarus*), and it's not being eaten—it's eating! It climbs out of its cave, dragging along its large claws as the waters grow dark, so that it can feast on sea urchins, mollusks, and starfish. Suggest how it captures and eats its prey.
4. Terrestrial crabs such as the blue land crab (*Cardisoma guanhumi*) don't use external fertilization. Why not?
5. The blue mud shrimp (*Upogebia pugettensis*) lives in the intertidal region in Oregon. Its feeding on detritus alters the chemistry of its habitat. Because of its influence on its habitat, what is this kind of species called?
6. Suggest what would happen in the Antarctic if Antarctic krill experienced a drastic decline in population.



17C INSECTS

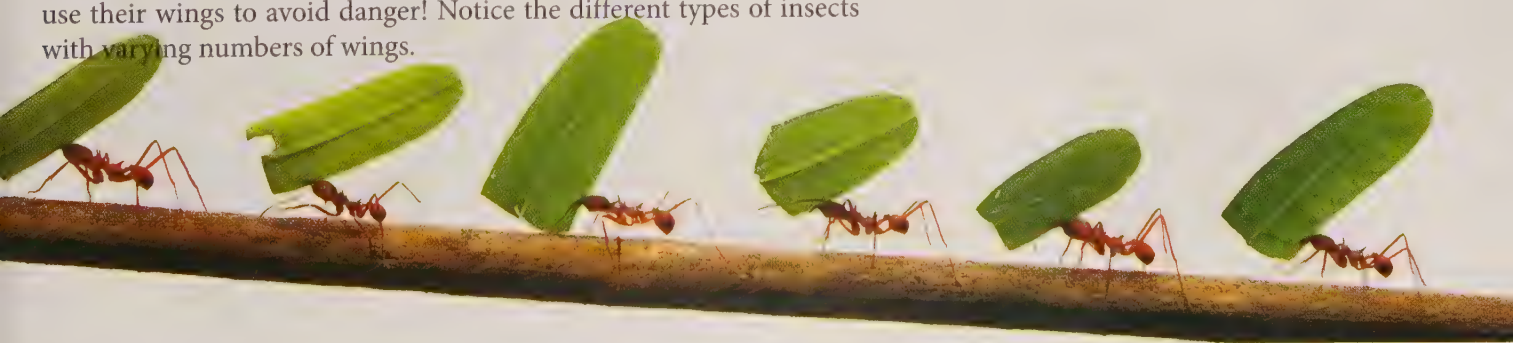
How do insects live and function in the environment?

17.8 CLASSIFYING INSECTS

Insects are all over the place! They are the most abundant animals in the world. They are a part of the largest and most significant class in phylum Arthropoda—class Insecta.

So how could you tell an insect from a chelicerate or a crustacean? One easy way would be to look at the number of body sections. Insects have three body parts, while chelicerates and crustaceans have two or even only one body part. You could also look at the number of legs. Insects have six legs, while chelicerates often have eight and many crustaceans have ten. Insect legs don't branch like crustacean appendages do. Also, insects have one pair of antennae, while chelicerates have none and crustaceans have two pairs. Insects have one pair of compound eyes, compared with chelicerates and crustaceans that may or may not have compound eyes.

There's another thing that almost all insects have—wings. In fact, many of the orders of insects include the suffix *-ptera*, meaning “wings.” Insects use their wings to fly, finding prey and mates. If you've ever chased around a fly or mosquito, you also know that they use their wings to avoid danger! Notice the different types of insects with varying numbers of wings.



17C Questions

- » What is an insect?
- » How do insects feed and reproduce?
- » How can insects be controlled but still be useful to people and the environment?

?

WINGS AND THINGS

No Wings

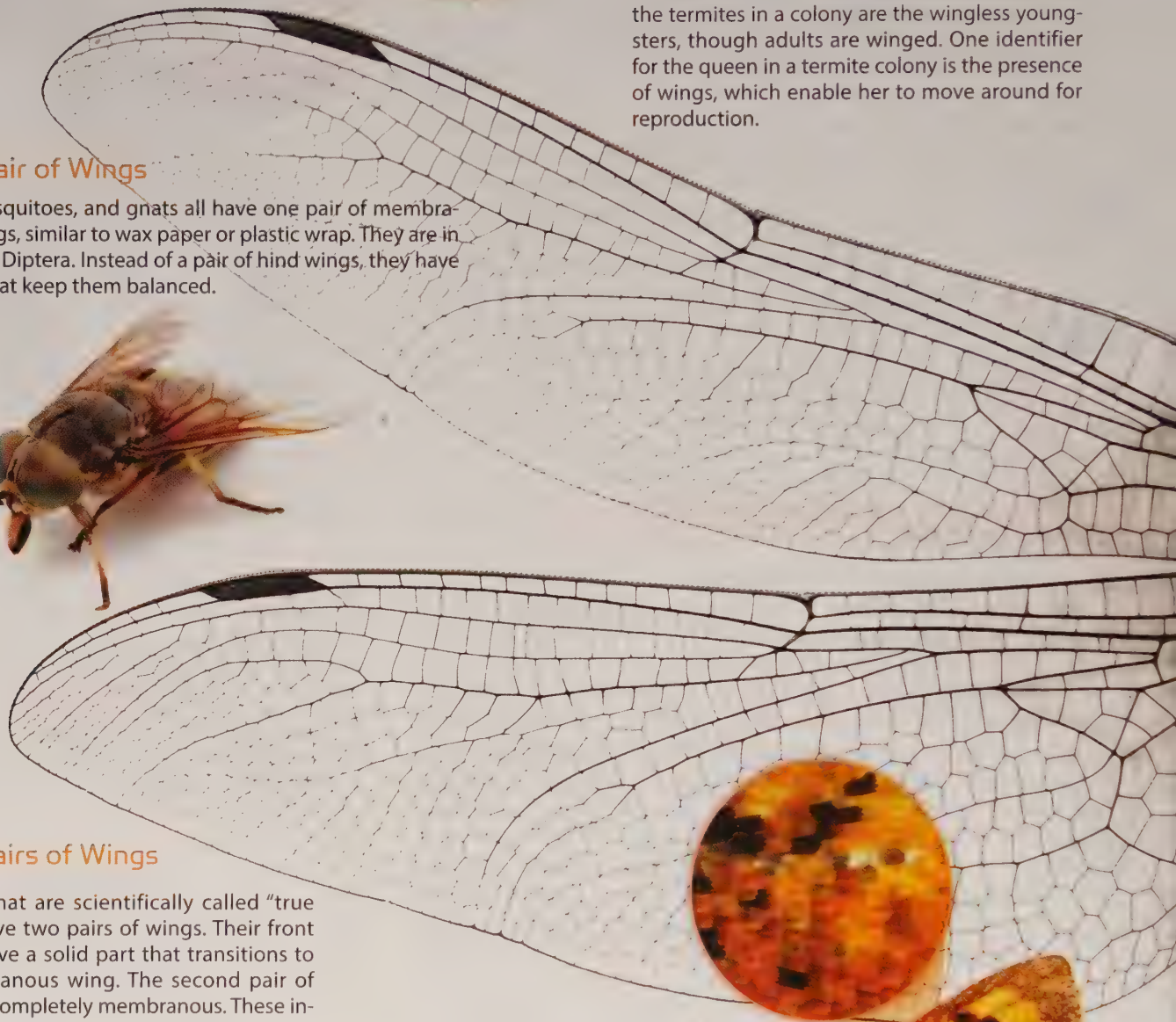
You're most likely to run into a silverfish when digging through boxes in your attic since they like to eat the cellulose in paper and clothing. They are one of the few wingless insects in the order Thysanura.



All termites are in the order Isoptera. Most of the termites in a colony are the wingless youngsters, though adults are winged. One identifier for the queen in a termite colony is the presence of wings, which enable her to move around for reproduction.

One Pair of Wings

Flies, mosquitoes, and gnats all have one pair of membranous wings, similar to wax paper or plastic wrap. They are in the order Diptera. Instead of a pair of hind wings, they have organs that keep them balanced.



Two Pairs of Wings

Insects that are scientifically called "true bugs" have two pairs of wings. Their front wings have a solid part that transitions to a membranous wing. The second pair of wings is completely membranous. These insects are in the order Hemiptera. This group includes stink bugs like the one below.



Some scientists estimate that 10% of the organisms on Earth are in the second-largest order of insects, Lepidoptera. This group contains butterflies and moths, organisms that have bodies and wings covered with scales. Two pairs of stunning wings make these insects some of the showiest in the insect world.

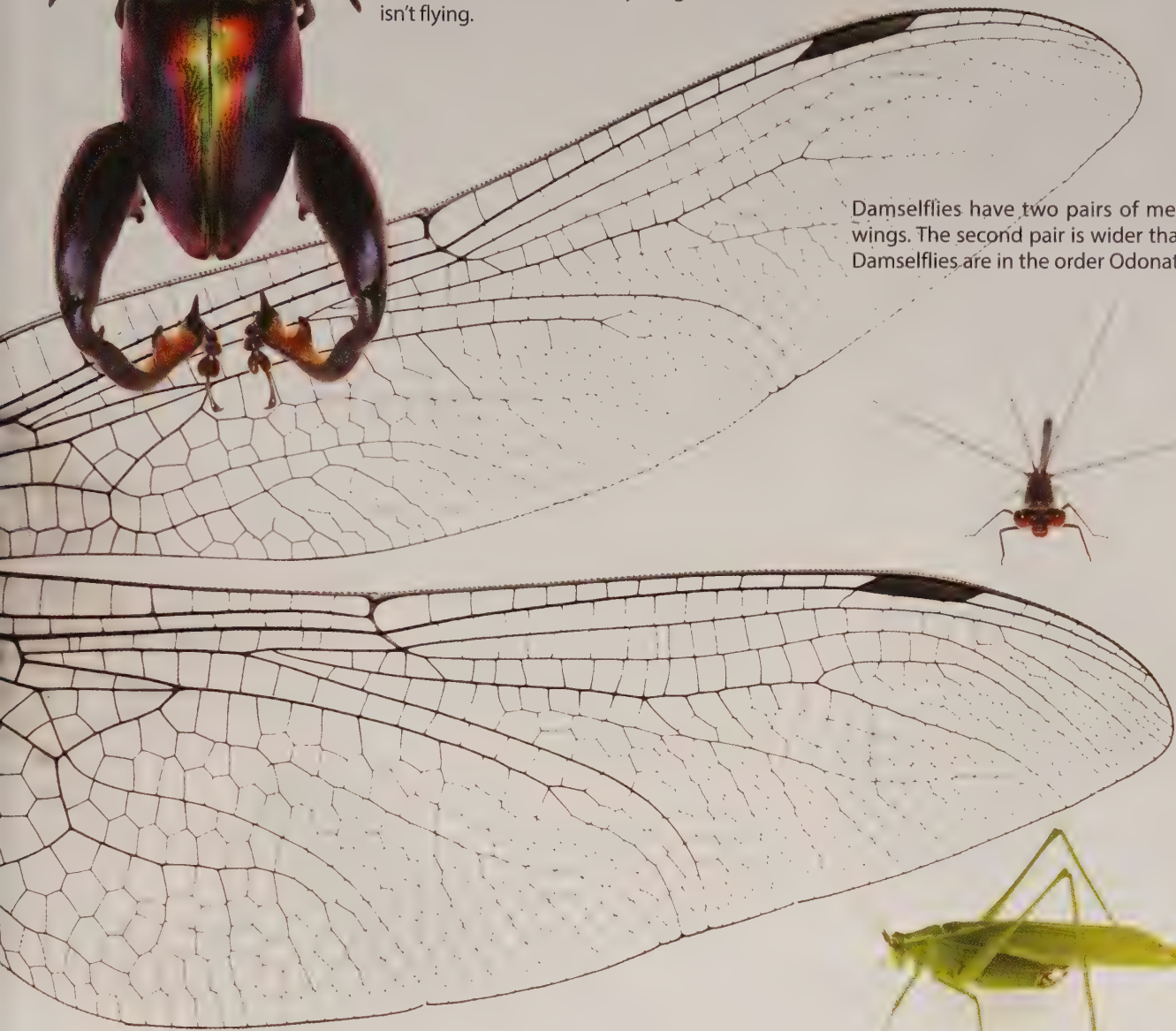


Two Pairs of Wings

The order of insects that has the most species (300,000+) is Coleoptera. This group includes weevils and beetles like the frog beetle (*Sagra buqueti*, left). One pair of stiff, horny wings, which are *not* used during flight, protects a pair of membranous wings, as you can see on the flying beetle to the right. The membranous wings fold up and are sheathed beneath the horny wings when the beetle isn't flying.



Damselflies have two pairs of membranous wings. The second pair is wider than the first. Damselflies are in the order Odonata.



Bees, ants, and wasps have two pairs of membranous wings, much like dragonflies do. Uniquely, though, the first pair of wings is hooked to the second pair. These three insects are grouped together in the third largest order of insects, Hymenoptera.



Grasshoppers, crickets, and cockroaches all have two pairs of straight wings, like the northern bush katydid (*Scudderia septentrionalis*) below. These straight wings accompany legs that give these insects super jumping ability. The front pair of wings is more leathery, and the back pair is membranous. The leathery wings cover the membranous wings when the insect is resting, as in the case of the beetle's horny wings. These insects can use their legs and wings to produce sounds in their own form of an insect orchestra, a process called *stridulation*. And grasshoppers can hear what they play with a chamber in their abdomens called a *tympanum*. Grasshoppers, crickets, and cockroaches are in the order Orthoptera.

17.9 STRUCTURE OF INSECTS

PIERCING MOUTH
(MOSQUITO)



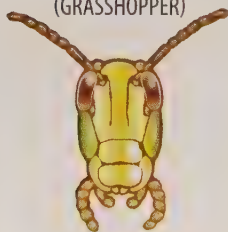
SPONGING MOUTH
(FLY)



SIPHONING MOUTH
(BUTTERFLY)



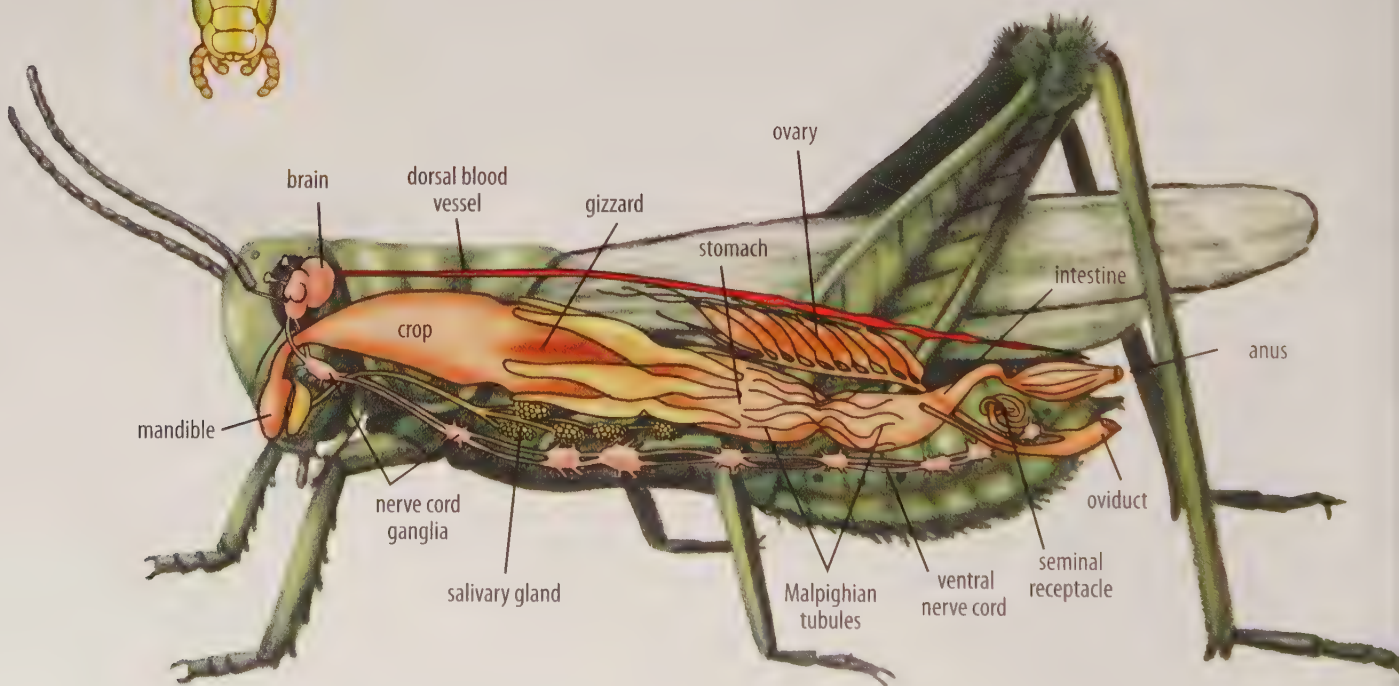
CHEWING MOUTH
(GRASSHOPPER)



To maintain homeostasis and carry out their life functions, insects need certain body parts. The first order of business is getting nutrition. We've seen that their wings help them move to capture prey, find a mate, gather nectar, and avoid predators. Some insects come with stingers to help them capture prey. Other insects like butterflies and bees have special appendages to help them gather nectar. Grasshoppers have mouthparts that help them gather vegetation. Mosquitoes have mouthparts that pierce through a host's skin to feed on its fluids.

Once an insect has obtained food, it needs to break it down. An insect has various kinds of mouthparts appropriate for its diet. It has something like lips and a mandible similar to crustaceans for grinding up food. It generates saliva just like you do to help break down food. Ground-up food passes through its digestive system, including the foregut with its gizzard, the stomach in the midgut, and the intestine in the hindgut. This system allows the insect to absorb nutrients from its food and eliminate solid waste products through the anus. An open circulatory system allows the insect to get rid of nitrogen-containing wastes in the blood through a bundle of thin tubes between the midgut and hindgut called **Malpighian tubules**.

Insects also need to breathe. The respiratory system for an insect is made of tubes called *tracheae* (s. **trachea**) that branch throughout the animal. Some spiders also have tracheae that connect to their book lungs. These tracheae open to the outside through a series of small pores on the sides of the insect called **spiracles**. Some spiders have these features that work with the book lungs. The combination of structures in an insect's body helps it sustain its life systems to get nutrition, eliminate wastes, and breathe.



SAILOR BUG

Crustaceans are the arthropods of the sea, and insects are the arthropods of the land, right? Don't tell that to the ocean strider (*Halobates sericeus*), a member of the true bug family and one of the very few marine insects. But though he lives on the ocean, he doesn't swim; he walks on water! Ocean striders (similar to the freshwater strider on the right) eat plankton off the surface of the ocean. They have little air-trapping hairs that act as life jackets to keep them afloat. They better look out though! Sea birds are constantly trying to scoop them up from the air, while crustaceans are trying to grab them from below the surface.

Ocean striders are getting an unexpected lift from the Great Pacific Garbage Patch, an area of tiny artificial particles suspended in the water column trapped in a circular current in the North Pacific Ocean. Some experts estimate the patch to be the size of Texas. Much of the garbage has been broken down into very small pieces after being continually bashed by wave action. The particles are creating an unnatural rivalry between crustaceans and insects, but they provide a handy place for ocean striders to lay their eggs on the open sea. Thanks to the garbage patch, ocean striders are thriving.



Economists are concerned that the biodiversity of the ocean could be affected by all this artificial material in the ocean. And in another twist, scientists are finding that the ocean strider acts as a storage vehicle for heavy metals, such as cadmium, present in the ocean. This could give scientists some clues about how pollution and toxic metals spread in the oceans and what we can do to keep our waters and insects pollutant free.

17.10 | REPRODUCTION OF INSECTS

Insects get information about their environment from their antennae and their compound eyes. When insects are ready to mate, females produce and release chemicals called **pheromones** to attract and find a mate. They also use pheromones to communicate with other members of the population about danger or to give directions to a food source.

Sexual reproduction in insects takes place through internal fertilization. The male deposits sperm, which are stored by the female. As the female lays eggs, they are fertilized. The last body section of the female's abdomen forms a pointed extension called the *ovipositor* that is used to deposit the fertilized eggs.

METAMORPHOSIS

Each insect begins as a tiny fertilized egg. It goes through a series of stages called **metamorphosis** (met uh MOHR fuh sis) in which it changes and grows. Other animals, such as sponges, crustaceans, and amphibians, also go through this process. A few insect species do not go through metamorphosis, but most follow one of two major processes of metamorphosis—*incomplete metamorphosis* and *complete metamorphosis*. Grasshoppers, cicadas, and true bugs go through incomplete metamorphosis. Almost 90% of all insects undergo complete metamorphosis.



17-6 |

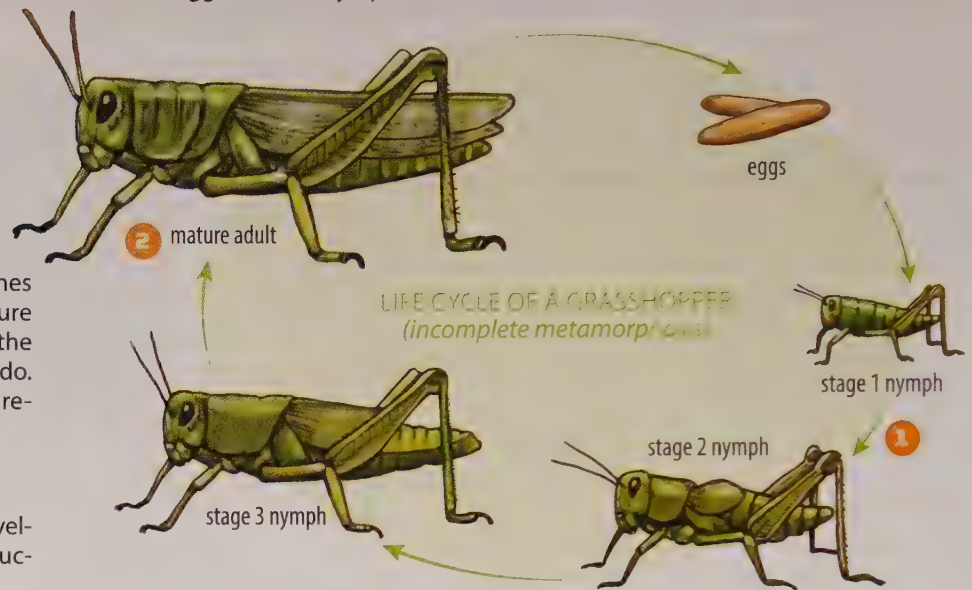
Insects can also use pheromones to signal other individuals to form a cluster called an *aggregation*. Here insects are clustering around food. It's the insect equivalent of calling, "It's dinnertime!" Aggregation can also be used to muster mass attack against a predator.

INCOMPLETE METAMORPHOSIS

Incomplete metamorphosis is the process in which an insect hatches from an egg to form a nymph, which matures into an adult.

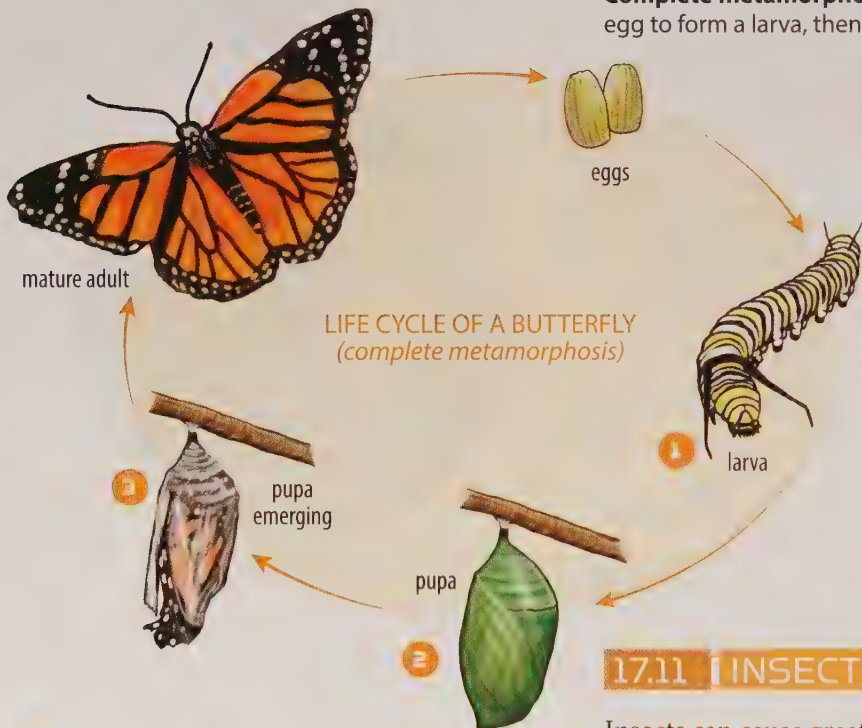
1 The **nymph**, an immature form, hatches from the egg and looks like a miniature form of the adult. It eats and lives in the same places that adults of its species do. However, it lacks wings and external reproductive structures.

2 As the nymph grows and molts, it develops both wings and reproductive structures to become an adult.



COMPLETE METAMORPHOSIS

Complete metamorphosis is the process in which an insect hatches from an egg to form a larva, then a pupa, and finally an adult.



1 The larva is a segmented, wormlike stage. Fly larvae are called *maggots*, beetle larvae are called *grubs*, mosquito larvae are called *wrigglers*, and butterfly and moth larvae are called *caterpillars*. The larva's most important activity is to eat a lot!

2 After eating and molting, the larva becomes a **pupa** as it forms a case around itself. The pupa of a butterfly is called a *chrysalis*. On the other hand, moths form *cocoons*. The cocoons of certain moths are used to make silk. Don't be fooled—the larva is busy inside its cocoon! Its body structure and organs are completely re-formed during the pupa stage.

3 Eventually the chrysalis opens, and a fully grown, fully developed adult emerges.

17.11 INSECTS IN THE ENVIRONMENT

Insects can cause great harm yet also bring great help to their environments. For example, mosquitos and fleas can be parasitic and become vectors for diseases, such as dengue fever and malaria. Some insects, such as locusts, can greatly affect agriculture, reducing a field of crops to bare twigs, but are also prey to other insects, and so we see a kind of balance in the ecosystem. Even humans eat insects, though some are inedible. Insects are a vital part of the food web in almost every biome, providing food for a wide variety of animals.



17-7

Locusts swarm, especially in desert areas. When they destroy the crops, the locals do the only reasonable thing: they eat the locusts!

Insects serve a vital role to both plants and humans as pollinators. Without them, farmers would have to pollinate all their crops by hand in order to get a harvest. Pollinators like bees, moths, and butterflies allow plants to reproduce and spread.

Insects interact with each other in complex ways. Some ants, bees, and all termites form populations that are almost like a society. There are queens in these populations and roles for different insects in a colony, such as nursery workers, foragers, guards, and those that discard the colony's trash. Older generations of individuals train younger generations to do specific jobs, such as taking care of larvae. Scouts mark food sources with pheromones so that other workers in the colony can find them. Some ants even capture ants from other colonies and force them to work as slaves. As you learned in Chapter 13, some termites have underground farms, raising fungi for food.

Because of the incredible number of arthropods, especially insects, on Earth, their impact on the biosphere is almost immeasurable. Insects account for a large percentage of the biomass on land. They have shaped the course of history, led to the development of culture and art, given us medicines, and inspired us with ideas for technological design. As we saw early in the chapter, insects have even given us clues for fighting crime and bringing justice. As we work to understand, manage, and use insects and their fellow arthropods, we can make the world a better place for people. God meets our needs through His provision for all His creatures, even the tiny insects.



17C REVIEW QUESTIONS

1. Give three ways that you can identify the walking stick (*Phasmatodea*) shown in the margin as an insect.
2. How does an insect use its wings to maintain homeostasis?
3. How do an insect's mouthpart shapes relate to their function?
4. How does an insect breathe?
5. How does an insect find a mate?
6. Does an insect reproduce sexually or asexually? Explain.
7. How does an insect change over its life?
8. What are some ways that we can control insects without using pesticides that could be harmful to the environment?



REVIEW QUESTIONS

T Key Terms	
arthropod	333
chitin	334
molting	334
compound eye	334
thorax	334
abdomen	334
cephalothorax	334
antenna	334
chelicera	335
pedipalp	336
book lung	336
spinneret	336
carapace	338
swimmeret	338
walking leg	339
cheliped	339
mandible	340
Malpighian tubule	344
trachea	344
spiracle	344
pheromone	345
metamorphosis	345
incomplete metamorphosis	346
nymph	346
complete metamorphosis	346
pupa	346

CONCEPT REVIEW

1. Since an arthropod doesn't have a backbone, what provides its support?
2. What do all chelicerates have in common?
3. Create a table with three columns for chelicerates, crustaceans, and insects. Indicate the number of body sections, legs, wings, and antennae for each of these groups of arthropods.
4. Compare the environments in which chelicerates, crustaceans, and insects live.
5. Give one example of how chelicerates, crustaceans, or insects communicate with each other.
6. Compare the ways that chelicerates, crustaceans, and insects breathe.
7. Write a sentence that relates how arthropods breathe in their environments to maintain homeostasis.
8. Identify each of the following arthropods as a chelicerate, crustacean, or insect.

a.



b.



c.



a. bed bug (*Cimex lectularius*)

b. amphipod (*Gammarus pulex*)

c. cellar spider (*Pholcus phalangioides*)

9. What is similar about the way chelicerates, crustaceans, and insects eat?
10. What is similar about the way chelicerates, crustaceans and insects reproduce?
11. From what you've learned so far about invertebrates, write a general rule that describes how marine and terrestrial animals fertilize their eggs.
12. What are the three main roles chelicerates play in the environment?
13. Why are crustaceans on the ocean floor so crucial to their environment?
14. How does an insect eliminate wastes and keep its body free of toxins?
15. What is the difference between the nymph and adult stages of a cicada?
16. What stage is present in complete metamorphosis that is lacking in incomplete metamorphosis? What happens during this stage?
17. How do insects interact with each other in the environment?

TRUE OR FALSE

18. Arthropods are invertebrates.
19. Horseshoe crabs are crustaceans.
20. There are no freshwater crustaceans.
21. Crustaceans can demonstrate regeneration similar to planarians and echinoderms.
22. All insects have three body sections.

23. Most insects undergo complete metamorphosis.
24. Insects are the only animals that go through metamorphosis.

CRITICAL THINKING

25. The suffix *-pod* in biology means “foot.” Crustaceans are referred to as decapods, chelicerates as octopods, and insects as hexapods. Centipedes and millipedes are in a group of arthropods called *myriapods*. Why are they referred to this way?
26. Tardigrades (right), or water bears, are microscopic animals that have body sections and eight legs and live in the water. They are some of the hardiest organisms on Earth, able to survive in deep space, in extreme temperatures, and under high doses of ionizing radiation. Why aren't they classified as arachnids?
27. Give an example of an ecosystem engineer not mentioned in the text.
28. Why do most people use pesticides to control insect populations?
29. Why don't people in underdeveloped countries use many pesticides?
30. Why should we be careful with pesticides?



17-8

Tardigrades are also called moss piglets, shown above many times magnified on moss.

CASE STUDY: COLONY COLLAPSE DISORDER

Honeybee workers are dying around the world—leaving behind queens, hives full of food, and bee nurseries. In 1947 there were 5.9 million managed honeybee colonies in the United States. In 2005, there were less than half that, at 2.4 million. And about 30% of US honeybee colonies died in the winter of 2012–13 alone.

This bee epidemic is causing major problems in places like China, where apple farmers often must pollinate their trees by

hand. Experts estimate that pollination in the United States is worth almost \$15 billion a year!

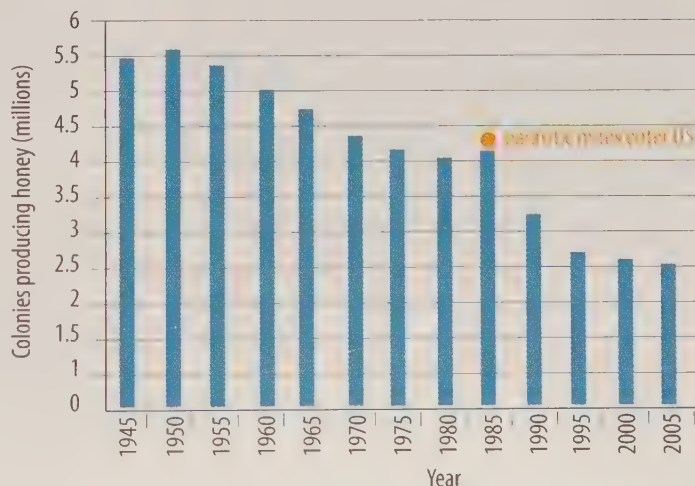
But what is causing this phenomenon, called *colony collapse disorder*? Scientists don't know for sure, but some suggest that disease or even a change in the way we take care of honeybees could be killing them.

Use the case study above to answer Questions 31–36.

31. According to the graph, when was the number of honey-producing colonies the highest?
32. In 1982 a parasitic mite was introduced into the United States. What do you notice about the number of honey-producing bee colonies after that date?
33. Can we conclude that colony collapse disorder is caused by these mites? Explain.
34. Suggest three factors that could affect the health of honeybee colonies in America beyond what the case study box mentions.
35. Bee colonies have experienced times of growth and loss in the past. What kind of information could historical data give us to solve the problem of colony collapse disorder?
36. Suggest one way to begin to solve the problem of colony collapse disorder.

The Big Picture on Bees

Do you think it should matter to Christians that honeybee colonies are collapsing in the United States? Why or why not?





CHAPTER 18

ECTOTHERMIC VERTEBRATES

18A CHORDATE INTRODUCTION AND FISH 351

18B AMPHIBIANS 356

REPTILES 363

DON'T FEED THE DRAGONS

As evening falls on Komodo Island, Indonesia, a long, lithe shape moves in the shadow of the stilt houses. It's a 9 ft, 150 lb Komodo dragon (*Varanus komodoensis*). In recent years, the dragons have come more frequently to the villages. In an effort to preserve these lizards, the Indonesian government declared the islands where they live a national park. The people living within the boundaries of the park make money from tourists, but they have been required to abandon their traditional ways of life. Hunting native Timor deer (*Rusa timorensis*) is now banned so that the dragons can use them for food. The islanders' dogs have been removed, and the local tradition of occasionally tying goats on the edges of their villages for the dragons is no longer allowed. Some of the locals believe that the conservationists who run the park for the Indonesian government have tipped the balance between humans and dragons in the dragons' favor.

CHORDATE INTRODUCTION AND FISH

How do fish live and function?

18.1 ATTRIBUTES OF CHORDATES

Do you have a pet? Chances are it's a vertebrate! Dogs, cats, gerbils, fish, snakes—all of these are vertebrates. Perhaps because of their physical similarities to humans, these kinds of animals are most commonly kept as pets and are often at the center of environmental debates similar to the Komodo dragon situation in Indonesia.

Just as in the rest of science, decisions about when and how to set aside resources to preserve a species are guided by models. A biblical model of ecology operates under two constraints, both outlined in the Creation Mandate. Man is created in the image of God and is to exercise dominion over the other creatures, so humans are distinct from the other creatures and have a greater inherent worth. However, man's dominion is over *God's* creation, and as custodians, humans do not have the right to abuse the creation. These two ideas—man's right to rule over nature and his responsibility to rule well—should guide all ecological decisions.

Part of wisely managing vertebrates is understanding them, and so scientists group chordates and look at the characteristics they have in common. Vertebrates form a subphylum in phylum Chordata. Although the three subphyla of **chordates** have little in common, they all share four characteristics during at least some stage of their lives. Many chordates possess all these characteristics only as embryos.

1

Chordates have a dorsal tubular **nerve cord**. In vertebrates, this is the familiar spinal cord that forms the central nervous system with the brain.

2

Chordates have a dorsal **notochord** at some time during their life. This tough, flexible rod provides protection and support. In most vertebrates, vertebrae of the backbone grow to replace the notochord.

18A Questions

- » What is a fish?
- » How are groups of fish different from each other?
- » How do fish breathe?
- » How do fish function and reproduce?

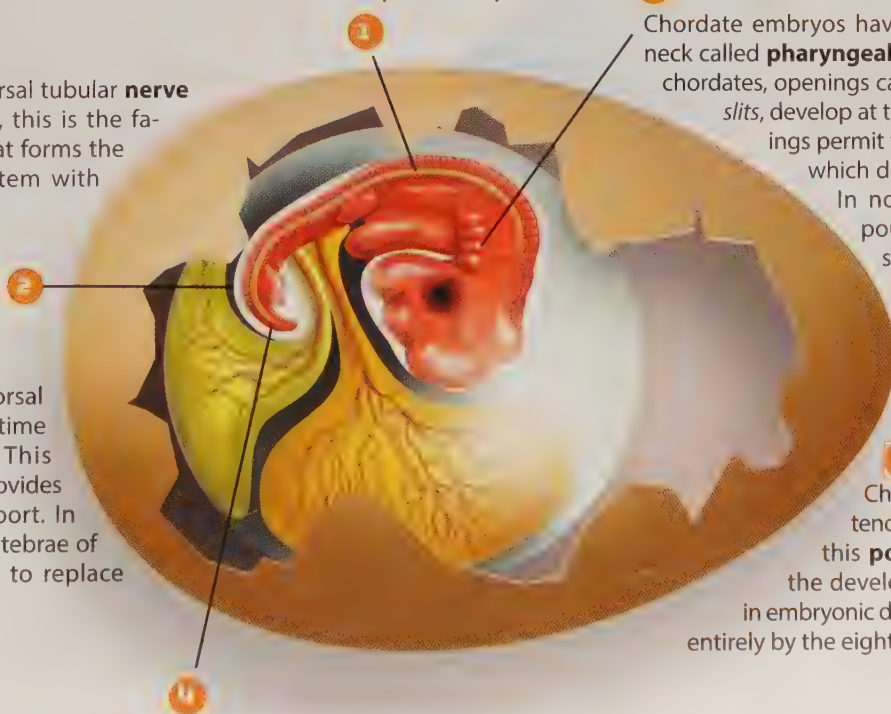


3

Chordate embryos have folds of skin along the neck called **pharyngeal pouches**. In most aquatic chordates, openings called **pharyngeal slits**, or **gill slits**, develop at these pouches. These openings permit water to flow over the gills, which develop inside the pouches. In nonaquatic chordates, the pouches never open but instead develop into structures of the lower face, neck, and upper chest.

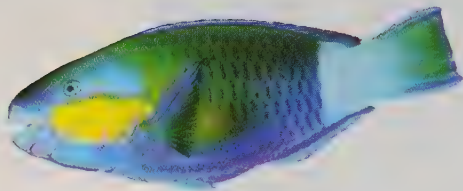
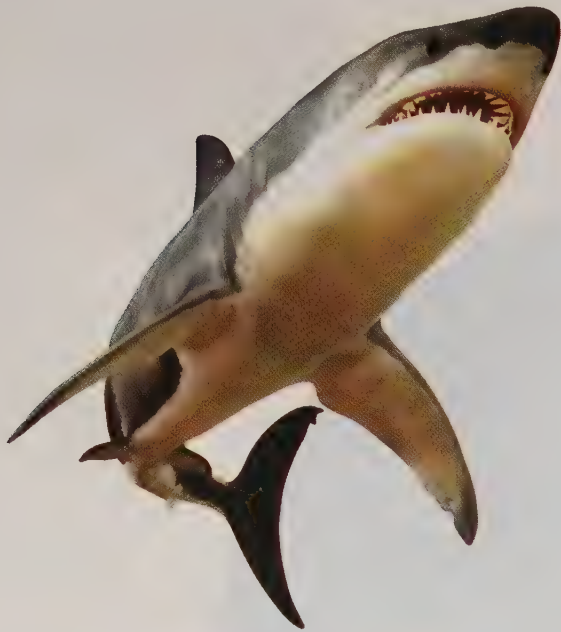
4

Chordates have a tail that extends past the anus. In humans this **post-anal tail** is formed by the developing spinal column early in embryonic development but disappears entirely by the eighth week of development.



Vertebrates are divided into five groups: fish, amphibians, reptiles, birds, and mammals. In this chapter, we will study the ectothermic vertebrates—fish, amphibians, and reptiles—so grouped because they generally must regulate their body temperature by their behavior rather than by their internal metabolism. While it might seem that ectothermic vertebrates would be limited to living where the temperature is perfect for life, God designed them to live in all kinds of environments. Ectothermic vertebrates live in a variety of habitats—from the dark waters of ocean trenches to the sunbaked sands of the desert and the frozen tundra of the Arctic Circle. Let's explore the three groups of ectothermic vertebrates.

The majority of **cartilaginous fishes**, those having skeletons entirely made of cartilage, are placed in the class Chondrichthyes. Cartilaginous fishes include some of the most graceful and some of the most notorious fish of the sea, including the Atlantic manta ray (*Manta birostris*) and the great white shark (*Carcharodon carcharias*, shown below). Like all fish, they possess fins, but their fins are covered with the same type of skin as the rest of their bodies.

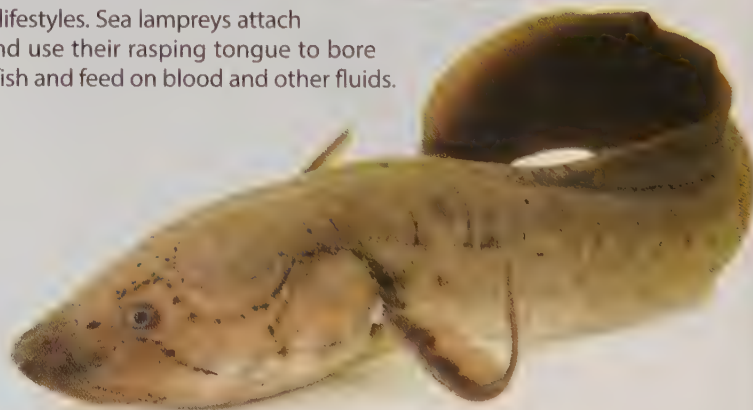


18.2 CLASSIFYING FISH

Fish, as a rule, are strictly aquatic. Their gills dry out in air and they quickly suffocate if removed from the water. Other generalizations are difficult partly because fish are a negative group, meaning that if a vertebrate is *not* a bird, mammal, reptile, or amphibian, it is considered a fish. As a result, fish classification is complicated, with some taxonomists classifying fish into three classes and some spreading them over as many as six. However, it is commonly accepted that fish can be divided into three general groups.

EXPLORING FISH

Jawless fishes lack many of the characteristics of vertebrates; hagfish (class Myxini, shown right) even lack vertebrae. While hagfish generally feed on dead and dying fish and are known for the copious amounts of slime they produce as a defensive measure, the adults of some lampreys (class Cephalaspidomorphi) are notorious for their parasitic lifestyles. Sea lampreys attach to fish and use their rasping tongue to bore into the fish and feed on blood and other fluids.

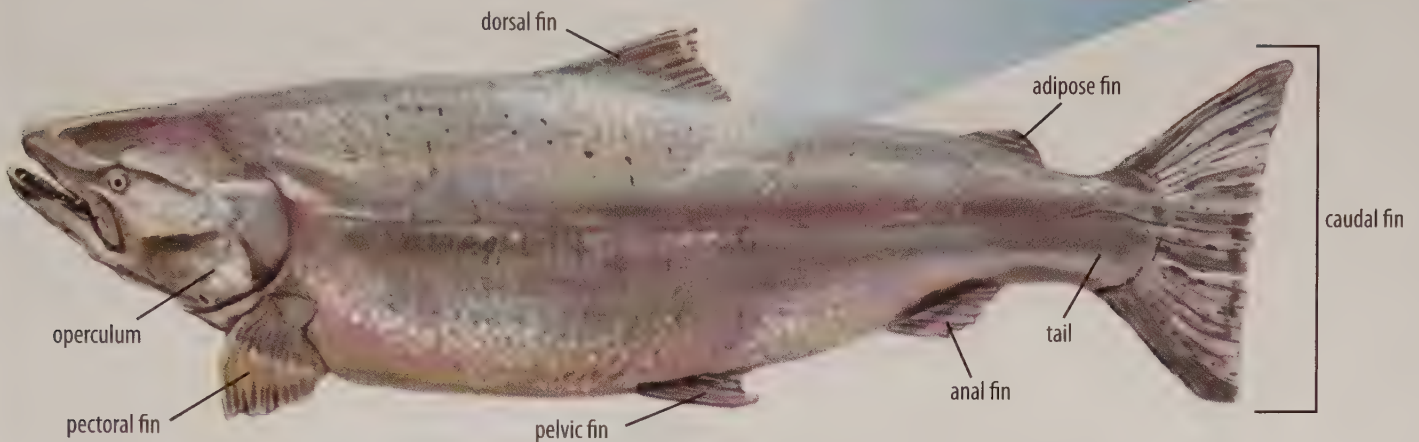


Most **bony fishes** are placed in the class Actinopterygii, the ray-finned fishes. The spines and soft rays that support their membranous fins give them both their common and scientific names. Since they make up over 95% of all fish species, most of our discussion of fish will concern them. The other class of bony fishes are the lobe-finned fishes in the class Sarcopterygii, including the lungfishes (shown right).

18.3 FISH STRUCTURE

All animals face the challenge of maintaining homeostasis in order to survive. For fish, this process is complicated by their extracting dissolved oxygen from the water and living in water that is more salty or less salty than their bodies. Their organ systems work together to maintain their homeostasis and allow them to thrive in their watery world.

The most distinguishing external feature of a fish is its fins. Fins are mainly used to steer, maintain stability, and move in an aquatic environment. Modified fins can serve other functions as well.



Most fish are covered with **scales** that give them some protection and help them move through the water. There are several types of scales, and sometimes the type of scale can help to identify a fish. Fish scales are produced by the dermis layer of their skin and are made of several substances that vary somewhat with the type of fish. In most fish species, the scales overlap each other, reducing drag from the water. Some species are born with roughly the same number of scales that they will have as adults, so their scales must grow as the fish grows. Others grow additional scales as their bodies grow. Bony fishes also secrete a layer of mucus over their scales that waterproofs them, further reduces drag, and helps protect them from parasites. Along the center of each side of most fishes is a thin dark line called the *lateral line* composed of sensory organs that detect vibrations in the water. The upper sides of many fish species are darker than their lower sides. This *countershading* camouflages the fish by preventing its being silhouetted by the sunlight filtering down through the water.

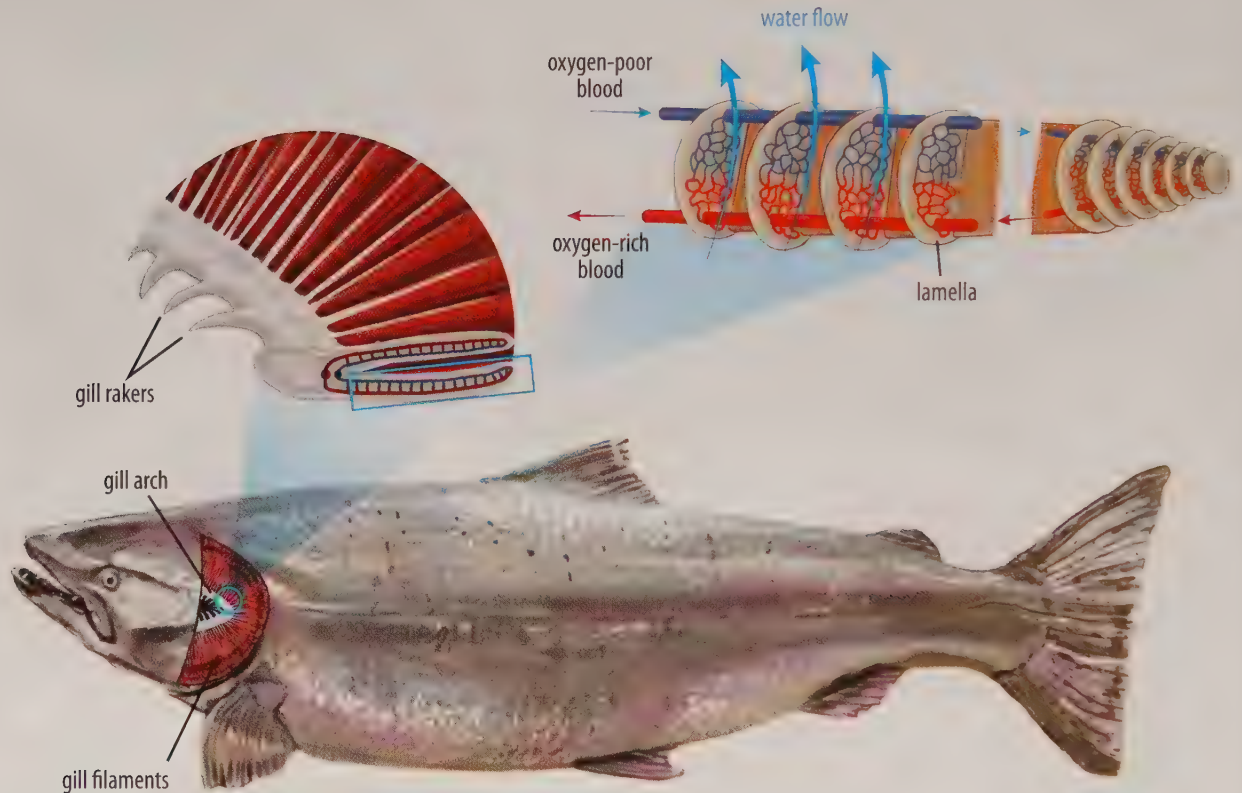
Like all vertebrates, fish have a closed circulatory system. The two-chambered heart has one *atrium* and one *ventricle*. It pumps the blood through the gills where gas exchange takes place, and then the blood moves throughout the rest of the body before returning to the heart. As the blood passes through the kidneys, nitrogenous wastes are removed and typically released into the surrounding water as ammonia.



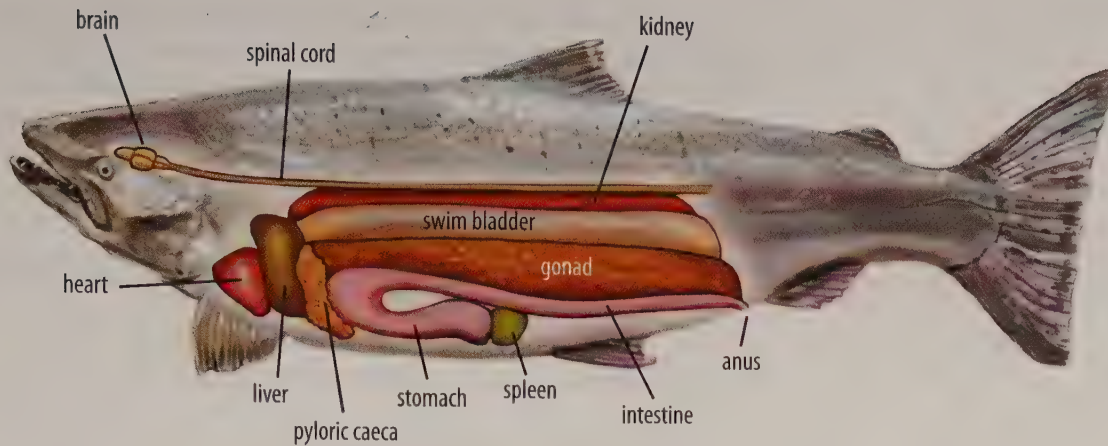
18-1

The dark upper side and white underside of this manta ray (*Manta birostris*) are an example of countershading. The fish blends in with its surroundings whether it is being viewed from above or below.

At the back of its head, a bony fish has a structure called an **operculum**, which covers its gills. After filling its mouth with water, a fish can open its operculum and pump water over its gills and out the opening. The gill filaments with their many blood vessels release carbon dioxide to the water through diffusion and take in dissolved oxygen. The water then passes out of the fish's body through the gap created as the operculum opens, taking the carbon dioxide with it. Most cartilaginous fishes have a series of gill slits instead of an operculum. Instead of pumping water over their gills, they must constantly move to keep water flowing over their gills, a process called *ram ventilation*.



Because fish breathe through gills, the biggest challenge to their maintaining homeostasis is regulating the proper balance of water and salt inside their bodies, a process known as *osmoregulation*. Gills must be permeable to allow gases to diffuse into and out of the blood, but that same permeability also allows water to diffuse into or out of the blood stream. Saltwater bony fishes live in a hypertonic environment, so ironically they are in danger of dehydration as water tends to leave their bodies through their gills by osmosis. To replace this lost water, bony fishes have to drink, but the only water available is salty. Salt enters the bloodstream and travels to the gills where specialized cells pump the excess salt into the water flowing over the gills. Cartilaginous fishes, on the other hand, turn their nitrogenous wastes into *urea* and allow large amounts to build up in their tissues. This makes them effectively isotonic to the salt water around them, so they avoid the danger of dehydration altogether.



Freshwater fish live in a hypotonic environment, so water moves by osmosis into their bodies through their gills. However, their kidneys remove excess water from their bloodstreams and release very dilute urine. Furthermore, like saltwater fish, freshwater fish also have gills with specialized salt-pump cells. But in freshwater fish, these cells pump salt into the body, helping to maintain a proper level of salt in the fish's system.

Fish, like all vertebrates, face the issue of staying afloat in the water. Many bony fishes have a **swim bladder** that fills with gases from the bloodstream or digestive tract. This allows the fish to increase or decrease the amount of gas in the swim bladder as it swims deeper or higher in the water, changing the fish's overall density to maintain *neutral buoyancy*. Because it is located on the dorsal side, it also helps stabilize the fish. However, not all fish species possess a swim bladder. Many bottom-dwelling fishes lack one, and cartilaginous fishes rely on their large, oily livers to maintain buoyancy. Additionally, some cartilaginous fishes have fins that provide lift like an airplane's wings as they swim through the water.

Both cartilaginous and bony fishes have jaws, and many have teeth to capture their food. Once food enters the mouth of a bony fish, a second set of jaws in its throat called *pharyngeal jaws* chews it and moves it down the esophagus into the stomach to be digested. (Cartilaginous fishes lack this second set of jaws.) From the stomach, the digested food is absorbed in the intestine, while waste is released through the anus.

18.4 FISH REPRODUCTION

In a group as large and varied as fish, reproduction strategies are just as varied. Many bony fishes reproduce by **spawning**. Females lay eggs that the males then fertilize with sperm. Some fish species, such as the Atlantic salmon (*Salmo salar*), will travel many miles to spawn in the same waters where their parents did. Many oviparous cartilaginous fishes exhibit *internal fertilization*, laying their eggs in an egg case commonly called a *mermaid's purse*. Still other fishes are ovoviviparous, and a few are even viviparous.



18-2 Sockeye salmon (*Oncorhynchus nerka*) turn bright red when they are preparing to spawn.

A few species of fish can reproduce asexually. The most common method is *parthenogenesis*, in which a female produces young from an unfertilized egg. Most of these fish species, including the bonnethead shark (*Sphyrna tiburo*), typically reproduce sexually, and females reproduce asexually only when unable to mate with a male.

185 FISH IN THE ENVIRONMENT

As the overwhelming majority of vertebrates in the aquatic biomes, fish fill many different niches. Some, such as the Achilles surgeonfish (*Acanthurus achilles*), are peaceful herbivores, grazing on the plants and algae in the water. Many of these fishes help keep in check algae populations that would otherwise overwhelm coral reefs. Others, like the rainbow trout (*Oncorhynchus mykiss*), feed primarily on aquatic invertebrates. Still others such as the bull shark (*Carcharhinus leucas*) are on the top of the food chain, having few to no enemies and are suspected of attacks on humans. Ironically the very largest fish, the whale shark (*Rhincodon typus*, below), eats only plankton and is so peaceful that divers have been known to ride them without provoking them.



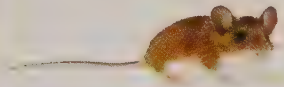
Approximately 71% of the earth is covered by water, so a great part of the Creation Mandate involves learning to properly manage aquatic resources. Many people fish for a living, and many others for pleasure, yet the National Oceanic and Atmospheric Administration (NOAA) estimates that mankind has explored less than 5% of the waters of the ocean. At the same time, many fish populations, including the formerly abundant cod of the Grand Banks of Newfoundland, have drastically declined due to overfishing.

Part of being a good steward is finding ways to manage the fish populations to provide mankind's needs without destroying them for future generations. This involves a combination of limiting catches, seeking new areas to fish, growing fish in ponds (fish farming, or *aquaculture*), and eliminating some practices altogether. For instance, many shark species have greatly declined, at least partly, because of a practice called *finning*—a shark is caught and its dorsal fin is removed to make an Asian delicacy known as shark fin soup. The shark is then

thrown back into the water where, unable to swim, it soon suffocates or is killed by predators. Taking dominion of the earth does not excuse this type of waste. Biblical dominion requires maintaining sustainable levels of shark fishing and using as many parts of the fish as possible, including the fins.

18A REVIEW QUESTIONS

1. What are the four characteristic physical features of all chordates?
2. At what stage of life do most chordates have all four chordate characteristics? Explain.
3. Hagfish and lampreys are grouped together because they lack what head structure found in other fish?
4. Which of these three animals demonstrates countershading? Explain.



5. You dissect a fish with jaws and a large oily liver but no swim bladder. What type of fish is it? Explain.
6. Describe ram ventilation.
7. Salmon live in the ocean but return to fresh water to spawn. What process has to change its normal function to allow the salmon to make this journey and maintain homeostasis? Explain.
8. Is it wrong to make shark fin soup? Explain.
9. Coelacanths (genus *Latimeria*), deep-water fish of the Indian Ocean, were known to exist only in the fossil record. Evolutionists viewed them as part of a lineage that gave rise to land animals. Then in 1938 the scientific world was shocked to learn that a coelacanth had been caught off the coast of South Africa, alive and well! What does the coelacanth show us about the nature of science?



AMPHIBIANS

How do amphibians live and function in their environment?

18.6 CLASSIFYING AMPHIBIANS

Unlike the essentially aquatic fish, many members of the class Amphibia live part of their lives on land and part in water. The most aquatic ones, such as the hellbender salamander (*Cryptobranchus alleganiensis*), spend their entire lives in water. The most terrestrial **amphibians**, like the invasive cane toad (*Rhinella marina*), live most of their adult lives on land except during the mating season when they return to water to lay eggs. Because most amphibians—along with most reptiles, birds, and mammals—have four limbs, they are known collectively as **tetrapods**, a group that includes all vertebrates other than fish. Amphibians are divided into three orders, shown in the photo gallery below.

EXPLORING AMPHIBIANS



By far the largest order of amphibians is Anura, the **frogs**. Frogs often live in and near water, but they also inhabit drier areas, though generally not the desert. Some species have special suction pads on their feet that allow them to live in trees. However, most frogs must eventually return to water to breed and lay eggs.



Members of the order Gymnophiona, often called **caecilians**, are legless, generally burrowing creatures. They resemble large earthworms, but they have the characteristics of vertebrates including vertebrae, a closed circulatory system, and jaws.



Salamanders make up the order Caudata. Like almost all amphibians, they hatch from eggs in water as larva that typically breathe with gills. They go through metamorphosis as they transition to a terrestrial or semiaquatic life, but there are many variations on this general lifestyle.

18B Questions

- » What is an amphibian?
- » How does an amphibian function and reproduce?
- » According to a biblical worldview, what should we do to preserve amphibians?

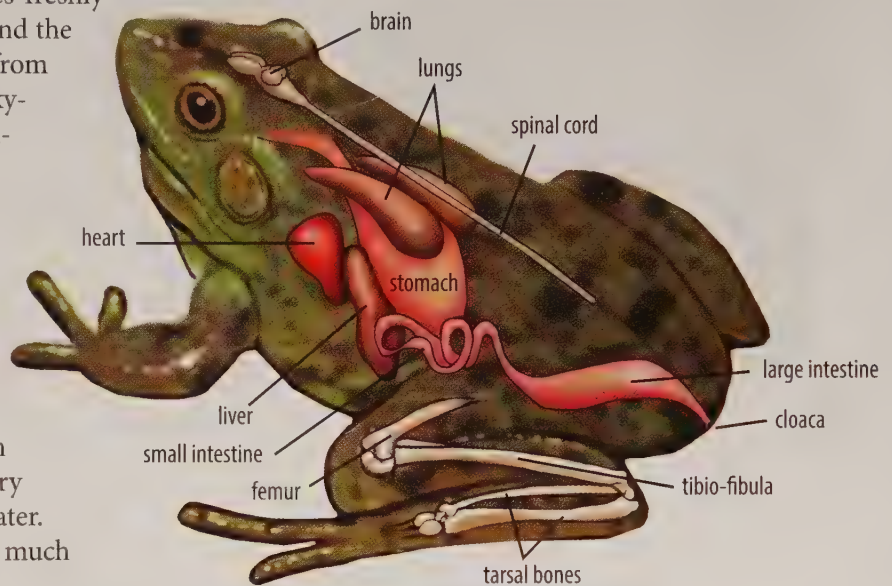
18.7 | AMPHIBIAN STRUCTURE

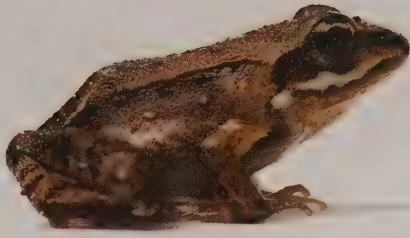
The most obvious feature of all amphibians is their thin, moist, highly permeable skin. In many amphibians, the skin is thin enough to function in respiration. Most amphibians do possess lungs, but they are small, and much of their respiration occurs through the skin, especially when the animal is underwater. As the blood flows through the vessels of the skin or lungs, carbon dioxide diffuses out and oxygen diffuses into the blood to be carried back to the animal's heart and then on to the rest of its body. Since moist skin is a much more effective respiratory organ than dry skin, amphibians secrete mucus when they are on land, giving their skin its moist look. Amphibians lack a diaphragm, so they use the lower part of their mouths to pump air into their lungs. You can easily observe this *buccal pumping* when looking at a living frog.

Amphibians have a three-chambered heart with two atria and only one ventricle. One atrium receives freshly oxygenated blood from the lungs and skin, and the other atrium receives deoxygenated blood from the veins. While the two atria pump both oxygenated and deoxygenated blood into the single ventricle, they contract at different times, so the two types of blood mix very little. The deoxygenated blood is pumped to the lungs and skin to be oxygenated, and the oxygenated blood is pumped to the body. As the blood circulates, it picks up nitrogenous waste from the body's cells and carries it to the kidneys to be removed and released as urine. Because water easily passes through amphibians' skin, their kidneys produce a very dilute urine when the animals are in the water. While amphibians are on land, they produce much less urine, allowing them to reduce water loss.

Amphibian larvae are generally herbivorous, but adults are carnivorous, generally eating anything that will fit into their mouths. After passing down the esophagus, the food is digested in the stomach before moving into the small intestine where nutrients are absorbed into the bloodstream. What cannot be digested passes through the large intestine and out through the **cloaca**. Both the digestive tract and the urogenital tract end in the cloaca, so solid wastes, urine, and eggs and sperm all pass out of the body through it.

Like all tetrapods, an amphibian's nervous system can be divided into two parts. The **central nervous system** is composed of the brain and spinal cord, enclosed and protected by the skull and vertebrae. From the central nervous system, all the nerves forming the **peripheral nervous system** run through the animal's body, allowing the brain to direct the muscles and sensory organs to send messages to its brain. As a hiker walks along a lake, a frog hears him and jumps into the water to hide—that simple action involved hundreds of nerve cells all working together with the frog's muscles and other organs.





18-3

The wood frogs of Alaska produce a substance in their blood that acts as antifreeze, preventing ice crystals from forming in their tissues while they sleep through the winter.



18-4

Amplexus is characteristic of amphibian mating.

Because amphibians are ectothermic, they are not able to adjust their body temperatures internally when the weather becomes too hot or too cold. Their moist skin can easily dry out, making them even more vulnerable to temperature extremes. As a result, many amphibians hide away and enter a torpor state to avoid summer heat or winter cold. The animal's systems reduce activity to a minimum with very low metabolism and respiratory levels. Frogs that live in hot places often **estivate** in the mud at the bottom of lakes. Others, such as the wood frog (*Lithobates sylvaticus*), live in regions where they must deal with winter cold. Wood frogs survive by **hibernating** in the ground.

18.8 AMPHIBIAN REPRODUCTION

As the days in spring lengthen and temperatures increase, male frogs gather at creeks, ponds, and marshes and burst into their mating choruses. Each species has its own mating call, and females are attracted to the call of the males of their own species. When a pair mates, the male typically grasps the female from on top and behind, a position known as **amplexus**. Most anurans exhibit external fertilization, so this position allows the male to fertilize the eggs as the female lays them. Mating typically occurs in or near water where the eggs are laid; the water can range from a permanent lake to a temporary stream to a pocket of water held in the leaves of a plant. Salamanders, on the other hand, find each other by scent, and some perform courtship rituals before amplexus and mating. Unlike frogs, salamanders exhibit internal fertilization, with some species laying eggs and others bearing live young.



When the eggs hatch, the larvae often look very different from their parents, especially in the case of frogs. Amphibian larva typically are aquatic and often have external gills. Frog larvae lack legs and swim with their large muscular tails. Salamander larvae do possess legs in addition to finned tails. The time from hatching to completing metamorphosis varies according to species. Spring peepers (*Pseudacris crucifer*) emerge as adult frogs only a few weeks after hatching, while American bullfrogs (*Lithobates catesbeianus*) may take over a year to complete metamorphosis in the colder parts of their range.

The amount of parental care amphibians provide their young varies. Some amphibian species leave their eggs as soon as they are laid, some take pains to hide their eggs before leaving, and others actively guard their eggs or even their young. Some amphibians exhibit unusual or even bizarre forms of parental care. The male common midwife toad (*Alytes obstetricans*) carries the eggs of his mate on his back until they are ready to hatch. Just before the larvae emerge, the male enters water and allows the tadpoles to swim away. The eggs of the common Surinam toad (*Pipa pipa*) become imbedded in the skin of the female's back during mating (see photo on the right). The eggs hatch, and the tadpoles metamorphose into young frogs before they leave. The female horned marsupial frog (*Gastrotheca cornuta*) takes this strategy one step further and houses the eggs and larvae in a pouch on her back. When the young frogs have completed metamorphosis, they emerge to begin life on their own.



18.9 AMPHIBIANS IN THE ENVIRONMENT

Beginning in the 1980s, scientists began noticing that frogs were dying all over the world. For a while, these mysterious amphibian deaths baffled them. Then they discovered that the fungus *Batrachochytrium dendrobatidis* had begun to infect the frogs and kill them. This fungus, called the *chytrid fungus*, is now common in frog habitats throughout much of the world. Scientists estimate that as many as 30% of the amphibians in the world have been affected, hitting endangered species of frogs especially hard. But some frogs appear to be immune to the fungus because they carry the bacterium *Janthinobacterium lividum*, which produces an antifungal agent. Researchers are working on a way to introduce *J. lividum* to other frog populations to help them resist the fungus. Could fungus-resistant frogs be the key to curing their fellow amphibians?

Scientists continue to study the chytrid fungus, searching for possible ways to stop its destruction of amphibians. Since this research will likely cost a great deal of time and money, as Christians we must wrestle with the question of value. Is it worth spending large amounts of resources to save frogs?

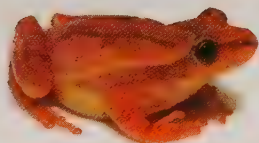


The answer to that question is not always simple. It is possible to be so concerned about the frogs that we hinder human well-being. Humans are more important than frogs, and we should always keep that priority straight. But taking care of the frogs can provide great value to humans and their habitats as well.

Because their lifestyles often encompass both aquatic and terrestrial habitats, amphibians are an important part of both the food chain and their ecosystems. Tadpoles provide food for many fish, and the adult amphibians greatly reduce the number of insects and other small invertebrates. Since many of their prey species carry diseases and are otherwise a pest to humans, amphibians can be greatly beneficial.

When God gave mankind dominion over the earth in Genesis 1:28, He gave him the responsibility to care for and rule over the animals of the world. Working to find a way to save amphibians from the deadly effects of the chytrid fungus fits within that responsibility as long as it does not threaten the welfare of humans.

18B REVIEW QUESTIONS



1. Why are caecilians not a typical tetrapod?
2. In what amphibian order would the spring peeper (*Pseudacris crucifer*), a common frog of eastern North America, be placed?
3. In most animals, a three-chambered heart that allows blood from the lungs to mix with blood from the body systems would be very inefficient. Why does it work well for amphibians?
4. What body system keeps an amphibian from becoming overhydrated in water and dehydrated on land? Explain.
5. Why would you not expect salamanders to make loud calls in the spring like frogs do?
6. Is a bullfrog more likely to lay its eggs in a permanent or a temporary body of water? Explain.
7. Should humans invest resources into trying to cure amphibian populations of the chytrid fungus? Explain.

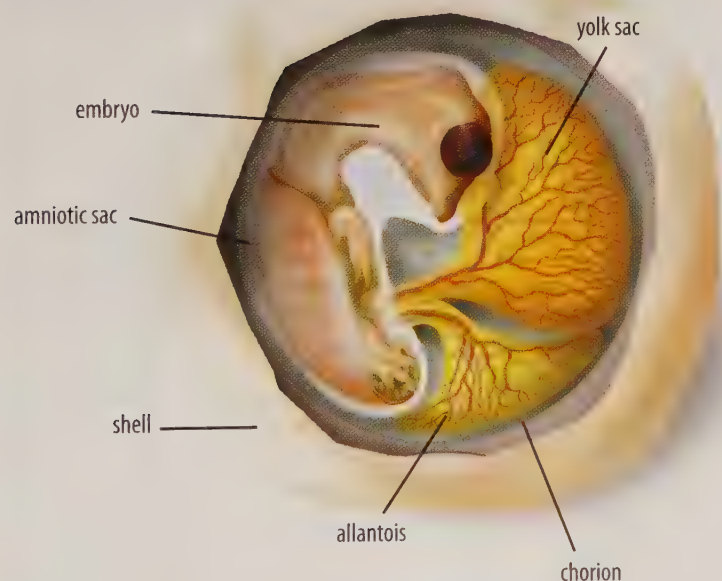
REPTILES

How do reptiles live and function in their environment?

18.10 | CLASSIFYING REPTILES

Hot, dry desert sand. Wet, salty ocean sand. You're not going to find amphibians in either of these places, but you can find reptiles there. Amphibians' moist, permeable skin generally makes them unsuited for life in the desert or the ocean. A reptile's scaly skin, however, allows it to live in both environments. Torpid turtles, lithe lizards, slithering snakes, colossal crocodilians, and three-eyed tuataras—reptiles possess a wide variety of forms, colors, and lifestyles. But all reptiles have scaly skin and are ectothermic. Their young do not go through a metamorphic stage but instead look like smaller versions of their parents.

Reptiles, along with birds and mammals, are **amniotes**, vertebrates whose unborn young are surrounded by an *amnion*. This membrane holds the fluid that protects and cushions the embryo. All *amniotic* eggs also contain a *yolk sac* that holds the yolk that nourishes the embryo. As the yolk is used, it is absorbed into the embryo's body. Metabolic wastes are stored in the *allantois*, and the embryo and other structures are surrounded by the *chorion*. In oviparous species, the entire egg is surrounded by a shell that further protects the embryo. Living reptiles are divided into four orders—turtles, lizards and snakes, crocodilians, and tuataras.



18C Questions

- » What are the different orders of reptiles?
- » How does a reptile function and reproduce?
- » According to a biblical worldview, how should protecting endangered species be balanced with the well-being of humans?



EXPLORING REPTILES

Turtles, in order Testudines, are protected by a hard shell formed by bony plates fused to their ribs and vertebrae along their backs and to their ribs underneath. On top of the plates, the shell adds an additional layer of protection by being covered by large scale-like **scutes** made of **keratin**, a protein found in the external structures of amniotes. Horns, nails, hair, scales, and claws are all made of keratin. Turtles range in size from the three-inch speckled cape tortoise (*Homopus signatus*) of South Africa to the eight-foot leatherback sea turtle (*Dermochelys coriacea*).

The unrivaled giants of the reptile world in terms of weight and ferocity are the **crocodilians** in the order Crocodylia. The largest of these massive creatures, the saltwater crocodile (*Crocodylus porosus*) of Australia and Southeast Asia, can reach 20 feet long and weigh over a ton. Crocodiles in the family Crocodylidae are generally distinguished from alligators of the family Alligatoridae by their narrower bodies and snouts, by their more aggressive dispositions, and by the fact that one of their lower teeth on each side of their mouths fits into a groove on the outside of their upper jaws.

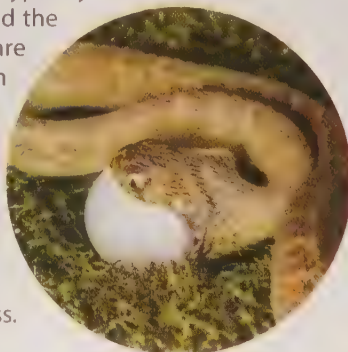
The two living species in Rhynchocephalia are **tuataras**. They inhabit islands north and south of North Island, New Zealand. Tuatara often share burrows with seabirds such as the fairy prion (*Pachyptila turtur*). While early observers thought of the tuatara as protectors of the nesting birds, their relationship seems to be more complex than that, ranging from commensalism to predation.

In contrast to the crocodile, all of an alligator's lower teeth fit inside its mouth.

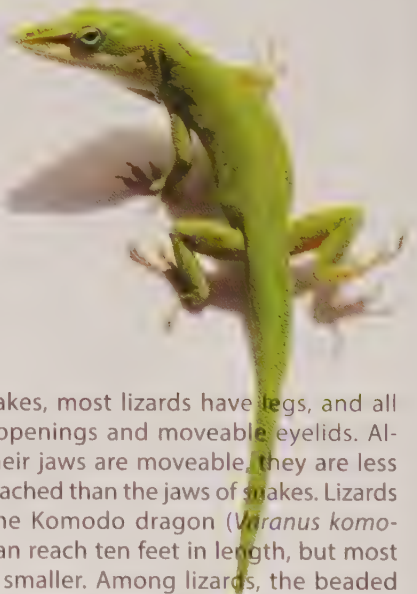


The lesser known but very large gharials of the family Gavialidae have the narrowest snouts of all crocodilians and primarily eat fish. The most distinguishing feature of the gharials is the bulbous growth on the end of the mature male's snout called a *ghara*. Its exact function is unknown.

Most living reptiles are in the order Squamata, typically divided into the lizards in suborder Sauria and the snakes in suborder Serpentes. **Squamates** are distinguished by their loosely attached jaws. In snakes this attachment is so loose that they can swallow prey much larger than their own heads. Snakes can be very long, with the reticulated python (*Broghammerus reticulatus*) surpassing twenty feet in length. People often fear snakes because some are infamously venomous, but 90% of species are nonvenomous, and most are perfectly harmless.

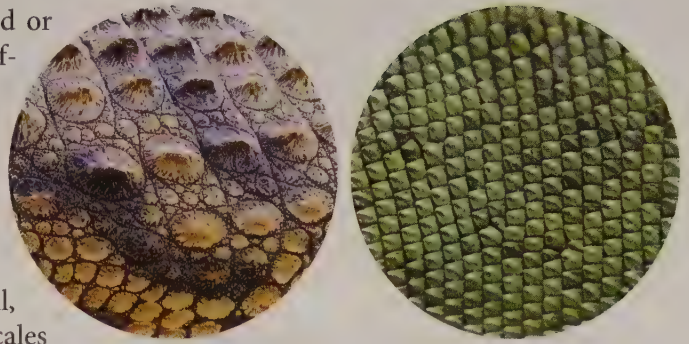


Unlike snakes, most lizards have legs, and all have ear openings and moveable eyelids. Although their jaws are moveable, they are less loosely attached than the jaws of snakes. Lizards such as the Komodo dragon (*Varanus komodoensis*) can reach ten feet in length, but most are much smaller. Among lizards, the bearded lizard (*Heloderma horridum*) and the Gila monster (*Heloderma suspectum*) are known to be venomous along with the komodo dragon.



18.11 REPTILE STRUCTURE

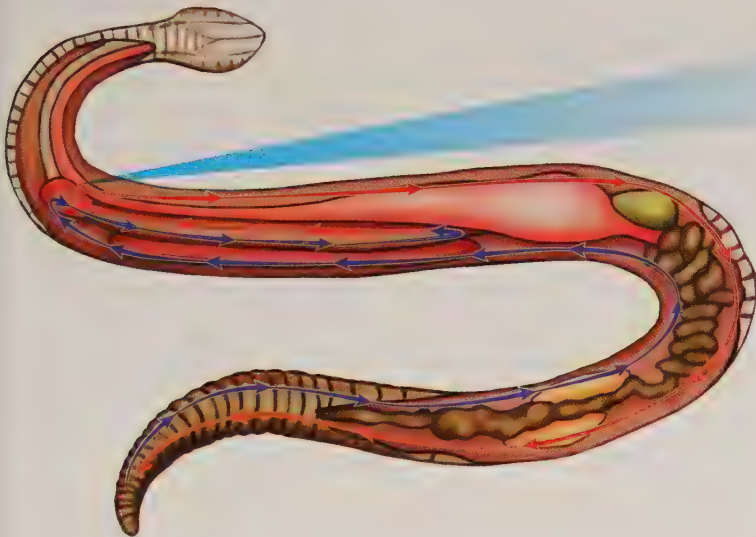
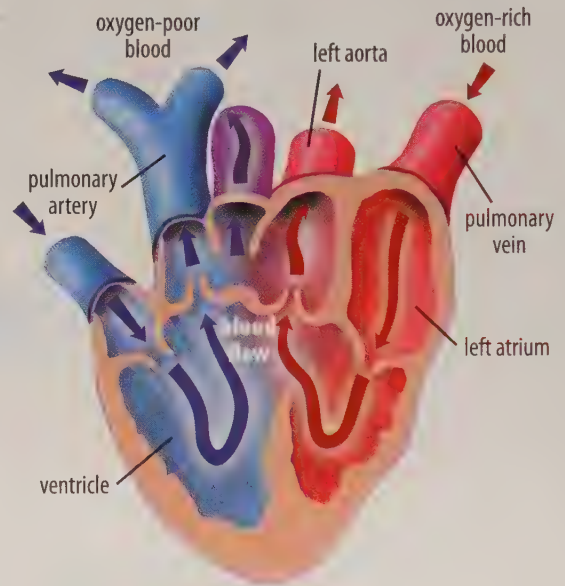
Like all animals, the reptile's organ systems work together to maintain the animal's homeostasis. Since reptiles often live in arid or aquatic environments, they need a way to keep water from diffusing through their skin in either direction. Reptiles are covered with an armor of scales or scutes. While these structures look similar and are both made of keratin, scales are produced by the epidermis while scutes are produced by the dermis. Squamates and tuatara have scales while crocodilians have scutes. Turtles typically have scutes on their shells and scales on the rest of their bodies. While the difference may seem small, it determines how the reptile replaces its skin. Animals with scales grow a new epidermis under the old and then shed the old one, either gradually in pieces like turtles or all at once like snakes. Animals with scutes simply add layers of keratin to the inner layer of their scutes as the outer layers are worn away. So you will never find a shed turtle shell or alligator skin.



18-5

Observe up close the scutes on a Nile crocodile (*Crocodylus niloticus*, left) and the scales on a chameleon (right).

Like amphibians, most reptiles have a three-chambered heart, but the ventricle has a wall called a **septum** that partially divides it. Although the deoxygenated blood from the body and the oxygenated blood from the lungs could potentially mix in the ventricle, the blood from the two atria generally remains separate due to the flow patterns within the chamber. Crocodilians are unusual among reptiles in having completely divided ventricles, making them the only ectothermic animals with a four-chambered heart.



As the blood flows through the lungs, carbon dioxide from the body's cells diffuses from the blood into the lungs, and oxygen diffuses from the lungs into the blood to be carried to the body's cells. Unlike amphibians, which pump air into their lungs, reptiles contract their rib muscles to allow their lungs to expand. When they increase the volume of their lungs, the air pressure in the lungs decreases, drawing in air. However, unlike mammals, reptiles lack a diaphragm and must employ various other means to expand their lungs. The lungs are the only major respiratory organ in most reptiles, although turtles and sea snakes have supplementary methods of respiration.

Reptiles generally have more complex brains than amphibians and fish. Most reptiles see quite well and are believed to be able to perceive color better than many mammals. However, their sense of hearing is poor, though some have the ability for vocal communication. Some reptiles, such as snakes and tuatara, lack external ears entirely and so can hear sounds only within a very limited range of frequencies.

Squamates are infamous for flicking their tongues. They sample the air, bringing scent particles back into their mouths to be processed by the **Jacobson's organ**, a sensory organ in the roof of the mouth. This extra sensory organ, found in many animals, more than makes up for squamates' rather poor sense of smell. Additionally, certain venomous snakes such as the timber rattlesnake (*Crotalus horridus*) are called **pit vipers** because of the heat-sensing pit located on each side of their heads between the eye and nostril. While turtles and crocodilians lack these types of specialized organs, they do have a relatively good sense of smell.

Pit vipers, like all snakes, are carnivorous, as most reptiles tend to be. Exceptions do exist among turtles and lizards. Not all reptiles possess teeth, and the teeth of those that have them are less suited for chewing than for grabbing and holding prey or, in the case of venomous snakes, for injecting venom into their prey. As a result, much of a reptile's food is swallowed whole or in large chunks. Salivary glands aid in swallowing, and digestion occurs primarily in the stomach. From there, the reptile's food moves to its small intestine where nutrients are absorbed. Wastes pass through the large intestine and into the cloaca to be expelled.

The reptilian excretory system varies according to the habitat of the species. Aquatic species generally do not need to worry about conserving water, so they typically release diluted ammonia. However, the bodies of terrestrial species must conserve water, and even a small amount of ammonia is highly toxic. So terrestrial reptiles typically excrete nitrogenous wastes as uric acid, which is almost insoluble in water. This allows reptiles to remove the nitrogenous wastes in a harmless, nearly solid form with very little water loss. Marine species such as the green sea turtle (*Chelonia mydas*) and the marine iguana (*Amblyrhynchus cristatus*) of the Galapagos Islands must deal with the buildup of salt in their systems. Reptile kidneys do not remove enough salt from their blood to prevent the salt concentration from reaching toxic levels; a **salt gland** near each eye removes excess salt and excretes it as a concentrated salt solution.



18-6

Pit vipers use their pits to detect the heat of their endothermic prey. It is believed that some can detect a temperature change of only a fraction of a degree.



18-7

Salt glands in this marine iguana's nostrils allow it to eat salty marine algae by filtering the salt from the blood and releasing it through the nostrils.

18.12 REPTILE REPRODUCTION

Reptiles have a variety of reproductive strategies. All turtles, crocodilians, tuatara, and some lizards and snakes lay eggs, but many lizards and snakes bear live young. However, all reptiles exhibit internal fertilization since the oviparous species have eggs surrounded by a calcium-based shell that makes external fertilization impossible. With the exception of turtle eggs, the amount of calcium in reptile eggs is generally lower than in bird eggs, so most reptile eggs have a leathery feel.

The populations of a few lizards and at least one species of snake, the brahminy blindsnake (*Ramphotyphlops braminus*), are entirely female, and as a result they reproduce asexually through parthenogenesis. Often these species are triploid and entirely female, so they cannot reproduce sexually. Increasingly, captive females in other reptile species, including Komodo dragons, have laid eggs that hatch without any genetic input from a male. Some scientists think that this is a normal method of reproduction when the females cannot find a suitable mate. However others believe that this is merely a rare instance of incomplete meiosis that mimics parthenogenesis.

Reptiles generally bestow little parental care on their young. The female will often lay her eggs in a hole, cover them, and then leave. The primary exception to this rule is the crocodilians. Female crocodilians guard their nests from predators, and when the young hatch, the female breaks open the nest to allow them to escape. Females of some species care for their young for a year or more.

In crocodilians, tuatara, many turtles, and some lizards, the temperature of the nest determines the sex of the young. In some species, lower temperatures result in a large number of females while higher temperatures produce primarily males. In other species, the opposite is true. In still other species, the effect of temperature on sex is even more complex with high and low temperatures resulting in females and an in-between temperature producing males. The temperature of the eggs affects the production of hormones that determine the sex of the hatchling. However, the sex of young snakes along with some young turtles and lizards is determined by sex chromosomes.



18-8

Crocodilians exhibit a level of maternal care unusual among reptiles. This mother is carrying her baby in her mouth, not eating it.

18.13 REPTILES IN THE ENVIRONMENT

Some reptiles are at the top of the food chain. Crocodilians and the largest snakes, such as the green anaconda (*Eunectes murinus*), have few predators, such as large cats, as adults. However, even these reptiles are vulnerable before they mature. Young reptiles and adults of smaller species often fall prey to predators, including other reptiles. Birds and mammals also take a heavy toll. Tuatara on isolated small islands have historically been safe from predators. On islands where rats have been introduced and become established, the tuatara have declined and even died out entirely due to rats preying on tuatara eggs.



18-9

The green tree python (*Morelia viridis*) is much smaller than many other pythons with the largest green tree pythons being less than 2 m long.

On several of these islands, conservationists have exterminated the rats and reintroduced the tuatara, which seem to do very well in the absence of the invasive rodents.

Other conservation attempts have not always gone so well. The villagers on Komodo Island have attributed increased attacks by dragons on humans to the efforts of a conservation group (see Chapter opener). The islanders feel that conservationists have not been sympathetic to their plight. At one time, the conservation organization was prepared to spend five million dollars in the national park but had yet to follow up on its promise to build dragon-proof fences around the villages, a project that would have cost a mere \$20,000. The standard of living of the people of Komodo Island is an issue that must be factored into any decisions about the area. People, not giant lizards, bear the image of God. At the same time, conserving an endangered species is a worthy goal and one that fits within the scope of the Creation Mandate.

THOSE TERRIBLE LIZARDS

Move over, *Tyrannosaurus rex*! Meet the titanosaur *Dreadnoughtus*. This enormous plant-eater probably lived up to its name and feared very little, but would it have feared humans? We often imagine dinosaurs as extremely ferocious, especially the carnivorous ones, but today even extremely large carnivorous mammals such as the grizzly bear will tend to avoid a confrontation with humans if given the choice. This fits with God's promise to Noah that animals would fear His image bearers (Gen. 9:2), so it seems logical that dinosaurs would share this innate fear.

The term *dinosaur* (literally, "monstrous lizard") was coined by English paleontologist and biologist Sir Richard Owen in 1842, about the time of the first fossil finds of large reptiles. Although the term is normally used to describe the extremely large, presumably extinct reptiles, most species were about the size of horses, and some were as small as chickens. Technically, the term applies only to the land-dwelling reptiles that walked with their legs beneath them.

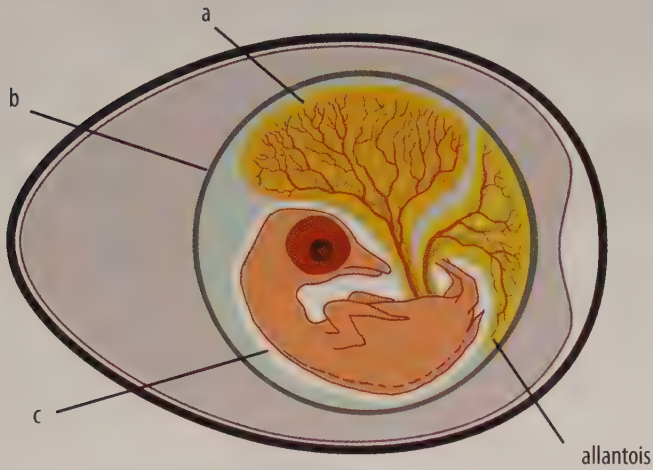
The biblical account of Creation says that God made the land animals on the sixth day, the same day that He made Adam and Eve. Therefore, dinosaurs and men must have lived together. Evolutionists believe that dinosaurs died out 65 million years ago and over 50 million years before humans and chimpanzees diverged. For an evolutionist, humans and dinosaurs never lived together.



As a result of these different models, creationists and evolutionists tend to interpret data differently. However, even holding the correct model does not guarantee that a scientist will always correctly *interpret* the evidence. Many creationists long believed that fossilized tracks near Texas's Paluxy River showed dinosaur and human tracks together. Evolutionists rejected this interpretation because it did not fit their model. As creationists have continued to study the prints, most have come to agree that these fossils show only dinosaur tracks. When the truth of the Bible is not in question, creationists should always be willing to humbly reexamine their interpretation of scientific evidence.

18C REVIEW QUESTIONS

1. Correctly identify the three membranes in an amniotic egg marked in the diagram.



2. Which reptilian order contains species without legs?
3. Create a T-graph showing which of the orders of reptiles have scales and which have scutes.
4. Members of which reptilian order have armored scutes and regularly prey on large mammals such as deer?
5. What circulatory structure is more complete in crocodilians than in other reptiles? Explain.
6. Which structure of egg-laying amniotes makes external fertilization impossible? Explain.
7. If crocodilians could survive near the Arctic Circle, what aspect of sex determination would prevent a population from being established?
8. Is the life of one person more important than the survival of an entire species? Explain.
9. Besides giving humans authority over the created order, how else does the Creation Mandate affect man's relationship with the earth?



18-10

Let's see, blue scarf or pink?

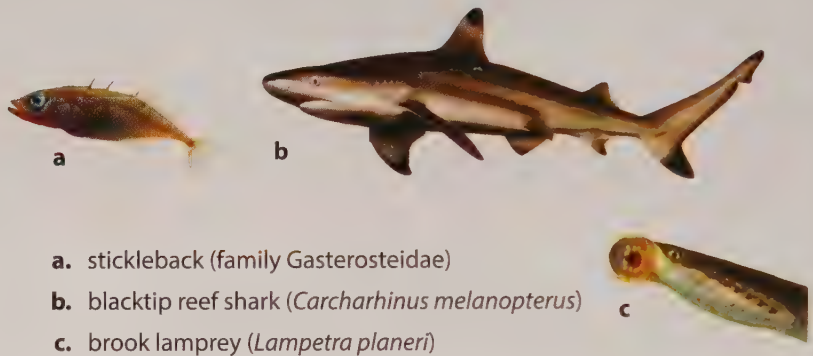
REVIEW QUESTIONS

T	Key Terms	
	chordate	351
	nerve cord	351
	notochord	351
	pharyngeal pouch	351
	post-anal tail	351
	cartilaginous fish	352
	jawless fish	352
	bony fish	352
	scale	353
	operculum	354
	swim bladder	355
	spawning	355
	amphibian	358
	tetrapod	358
	caecilian	358
	frog	358
	salamander	358
	cloaca	359
	central nervous system	359
	peripheral nervous system	359

(continued)

CONCEPT REVIEW

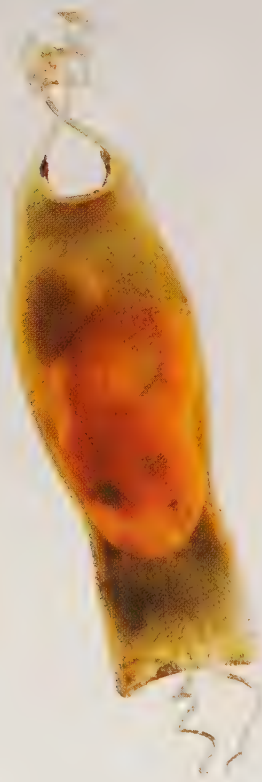
1. What four characteristic physical features distinguish chordates from other animals?
2. Which class of fish is not really a vertebrate? Explain.
3. Compare cartilaginous fishes with bony fishes using a T-chart. Include the jaws, gill structure, skeletons, fins, and organs used for buoyancy in your comparison.
4. Identify each fish as jawless, bony, or cartilaginous. Answers will be used only once.



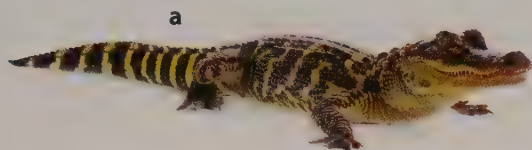
5. Explain the difference between the gill structures of bony fishes and cartilaginous fishes.
6. What is the function of the lateral line?
7. What type of reproduction and fertilization would a fish that produces a mermaid's purse exhibit?
8. How might shark fins be collected for shark fin soup in a responsible manner?
9. Which order of the amphibians lacks the basic characteristic of a tetrapod? Explain.
10. How do amphibians survive periods of intense heat or cold?
11. How does an amphibian's diet change during metamorphosis?
12. What three structures function as respiratory organs during some time in a typical amphibian's life? Explain.
13. If a deaf female frog and a deaf female salamander were both searching for a mate, would either be able to find one? Explain.
14. How might bacteria be the answer to the amphibian die-off caused by the chytrid fungus?
15. Which groups of vertebrates are not amniotes?

18-11

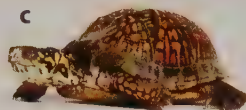
This mermaid's purse is holding the developing embryo of a cartilaginous fish.



16. Place each animal in the correct reptilian order.



- a. Nile crocodile (*Crocodylus niloticus*)
b. eastern racer (*Coluber constrictor*)
c. box turtle (*Terrapene carolina*)



17. Name three differences between a legless lizard and a snake.
18. Create a hierarchy chart showing the levels of classification of the ectothermic vertebrates. Include the following terms: jawless fishes, reptiles, Chordata, bony fishes, amphibians, salamanders, frogs, turtles, cartilaginous fishes, squamates, caecilians, vertebrates, crocodilians, and tuatara.
19. What is the primary difference between reptilian scales and scutes?
20. How is an amphibian's method of filling its lungs different from the way that a reptile does it?
21. What two sense organs does a timber rattlesnake have that a crocodile does not have?
22. What is unusual about the parental care that crocodilians exhibit compared with other reptiles?
23. How might an unusually warm summer affect the sex of the snakes that hatch during that time? Explain.
24. When is a large reptile most likely to fall prey to a predator?

Key Terms (continued)

estivate	360
hibernate	360
amplexus	360
amniote	363
turtle	364
scute	364
keratin	364
tuatara	364
crocodilian	364
squamate	364
septum	365
Jacobson's organ	366
pit viper	366
salt gland	366

TRUE OR FALSE

25. Ectothermic vertebrates can live in a variety of habitats including those that are very hot and very cold.
26. Bony fishes are classified into orders according to the structure of their gills.
27. The liver in cartilaginous fishes serves the same function as the swim bladder in bony fishes.
28. Spawning is a method of external fertilization.
29. Overfishing is an issue that must be dealt with as part of a biblical view of managing our fish resources.
30. All vertebrates are tetrapods.
31. Amphibians release their wastes and eggs through the same opening.
32. The Surinam toad exhibits internal fertilization.
33. Christians should oppose anything that environmentalists support.
34. Squamata is the largest order in class Reptilia.
35. Terrestrial reptiles typically excrete their nitrogenous wastes as ammonia.
36. Triploid hybrid reptiles must reproduce asexually.

CRITICAL THINKING

Use the Case Study below to answer Questions 37–39.

CASE STUDY: INDICATOR SPECIES

When scientists survey the health of an ecosystem, they can't sample all the organisms in the ecosystem, since one community can contain thousands of individual species. Instead, scientists employ *indicator species*. These organisms are chosen because their abundance is tied to the health of the whole ecosystem, so they can often give early warning if the ecosystem is not doing well. In addition, indicator species can also help ecologists locate the boundary between one ecosystem and another.



18-12

King cobras are the longest venomous snakes, growing up to 5.5 m long.

37. Butterflyfish like the blue-cheeked butterflyfish (*Chaetodon semilarvatus*) feed on coral polyps. Why would this make them a good indicator species?
38. Would a species that lives in a wide variety of habitats make a good indicator species? Explain.
39. What are some potential problems that could arise when choosing an indicator species?
40. Some evolutionists see the two-chambered heart of fish, the three-chambered hearts of amphibians, and the three- and four-chambered hearts of reptiles as an example of evolutionary development. Refute this idea by considering how the different heart designs function with the animals' respiratory systems.
41. A terrestrial ectothermic animal often basks in the sun to raise its body's temperature. At what time of a summer day in the desert is a lizard likely to bask?
42. Many male vertebrates fight over females. Venomous snakes such as the king cobra (*Ophiophagus hannah*) are easily capable of killing each other during such combats, so instead they engage in wrestling. The snake that pins its opponent's head to the ground, usually the larger one, wins. How does this behavior help ensure the survival of the species?
43. Write a short paragraph that explains the privileges and responsibilities of human beings in relation to animals.



CHAPTER 19

ENDOTHERMIC VERTEBRATES

BIRDS

MAMMALS

THE MISFIT

Africa. Zebras and giraffes gather at a waterhole. But beneath their feet, another mammal lives out its existence without ever seeing the light of the sun—the naked mole-rat (see page 383). Despite its hideous appearance, scientists love this rodent. It even won the 2013 Vertebrate of the Year award. It's the only known ectothermic mammal, and it forms social groups similar to colonies of termites, each one complete with a queen and several kings. Scientists found that the naked mole-rat has the ability to survive on little oxygen, fight the effects of aging, and ward off cancer. Scrambling to sequence its genome, scientists are hoping to unlock the secrets of one of the healthiest animals on Earth. Researching the naked mole-rat could lead to medical breakthroughs, but the research is laced with evolutionary thinking. Does that matter? How should someone with a biblical worldview respond to this research?



BIRDS



19A Questions

- » What is a bird?
- » How does a bird function and reproduce?
- » How are birds able to fly?
- » How are birds designed to live in different environments?
- » How do birds interact with other birds and the environment?

Raptors. Raptors like the red-tailed hawk (*Buteo jamaicensis*, below right) are carnivorous birds equipped with hooked beaks and strong grasping talons. Raptors are some of the largest birds and can carry half their own body weight while flying. Although they fly primarily by gliding on rising currents of warm air, they often take their prey in a high-speed dive. A peregrine falcon (*Falco peregrinus*) can dive at speeds in excess of 300 km/h.

How do birds live and function in their environment?

191 ENDOTHERMIC VERTEBRATES

All known birds and mammals (other than the naked mole-rat) are endothermic. Instead of relying on behaviors such as basking to maintain their body temperatures as ectotherms do, endotherms use heat energy produced during cellular respiration to keep their bodies at the right temperature. They often have complex internal regulation systems that keep them from becoming too hot or too cold. Because they rely on metabolic energy, endothermic vertebrates often need to eat much more than ectothermic vertebrates. Their bodies also contain layers of fat or special structures that insulate them from heat loss. Birds have feathers, while most mammals grow hair.

MASTERS OF FLIGHT



Shorebirds. Birds like this spotted sandpiper (*Actitis macularius*, right) spend most of their lives near water but rarely swim. They search for food along the shore in the company of other shorebirds, such as the sanderling (*Calidris alba*). As many birders can attest, distinguishing the various species is a major challenge.



Seabirds. The herring gull (*Larus argentatus*, above) and similar birds spend much of their lives at the ocean. Most of them nest on land and fly over the beach and water looking for food, but a few, such as the wandering albatross (*Diomedea exulans*), spend much of their lives either flying over the ocean or riding its waves, coming to land primarily to breed and nest.

Wading Birds. The great egret (*Ardea alba*, right) and many other birds in this group are equipped with long legs for wading through the water. Many of them have sharp bills for spearing fish, though some, like the roseate spoonbill (*Platalea ajaja*), have sieve-like bills for straining out the crustaceans and small vertebrates they eat.



19.2 CLASSIFYING BIRDS

The **feathers** of birds are their most distinguishing feature. No other living animal has feathers. Without them, birds would not be able to fly. Although they have only two legs, they have four limbs including their wings, so they are considered tetrapods.

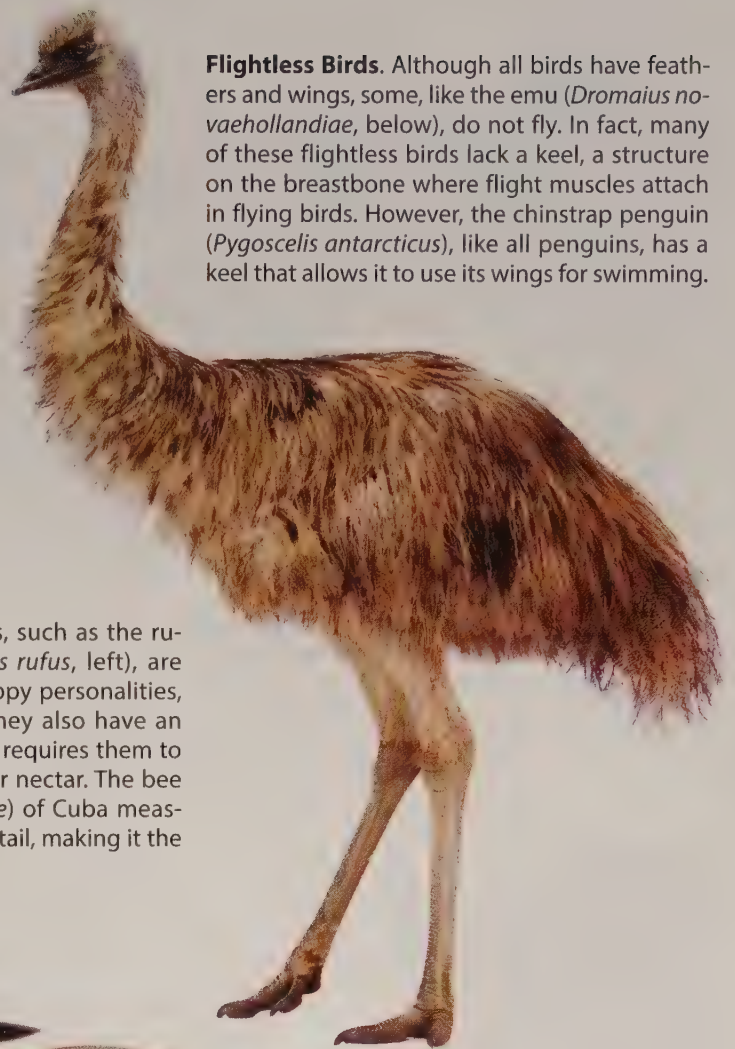
Unlike fish, amphibians, and reptiles, which can each be easily divided into three or four large groups, birds are classified into more than thirty different orders. However, it is possible to loosely group them according to habitat, behavior, and appearance.



Hummingbirds. Hummingbirds, such as the rufous hummingbird (*Selasphorus rufus*, left), are famous for their small size, scrappy personalities, and buzzing, hovering flight. They also have an extremely high metabolism that requires them to feed almost constantly on flower nectar. The bee hummingbird (*Mellisuga helenae*) of Cuba measures less than 6 cm from beak to tail, making it the smallest bird known.



Game Birds. Game birds, such as ruffed grouse (*Bonasa umbellus*, below), quails, and doves, are a rather loose group of birds, commonly hunted for sport and food. Some species, including the ring-necked pheasant (*Phasianus colchicus*), have been introduced throughout the world outside their native Asia.



Flightless Birds. Although all birds have feathers and wings, some, like the emu (*Dromaius novaehollandiae*, below), do not fly. In fact, many of these flightless birds lack a keel, a structure on the breastbone where flight muscles attach in flying birds. However, the chinstrap penguin (*Pygoscelis antarcticus*), like all penguins, has a keel that allows it to use its wings for swimming.

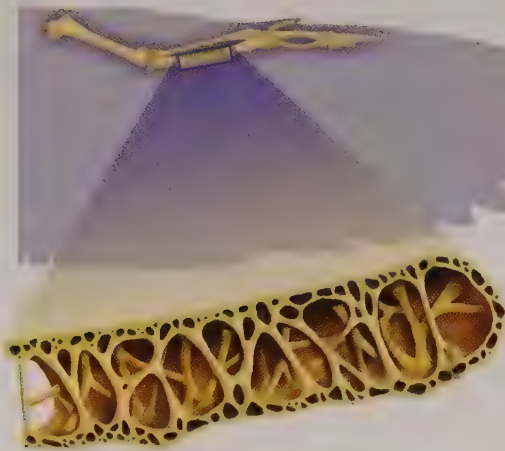


Waterfowl. The hooded merganser (*Lophodytes cucullatus*, left), like all ducks, is designed for water. Its webbed feet are much more suited for swimming than for walking, and its oily feathers and low-density bones make it naturally buoyant. However, even the largest waterfowl, such as the trumpeter swan (*Cygnus buccinator*), are also very capable flyers.

Perching Birds. Perching birds, such as the indigo bunting (*Passerina cyanea*, right), are some of the most beloved birds due to their songs, their sometimes very bright colors, and their willingness to live near human habitation. A perching bird's feet automatically lock while perching until the bird releases them, so an eastern bluebird (*Sialia sialis*), for example, can sleep on a branch without falling off.



19.3 AVIAN STRUCTURE



19-1

Internal support structures inside a bird's bones make its skeleton lightweight and strong.

Flying is not easy. As many engineers and designers have found over the years, flight requires much more than just wings. A bird takes wing because all of its systems work together to achieve flight. In the early sixteenth century, Leonardo da Vinci studied the flight of birds and bats in order to design machines that he thought might enable humans to fly. Four hundred years later, Wilbur and Orville Wright studied the flight of birds and realized that several of the common beliefs about flight were wrong. As a result of this insight, the Wright brothers accomplished the first powered human flight.

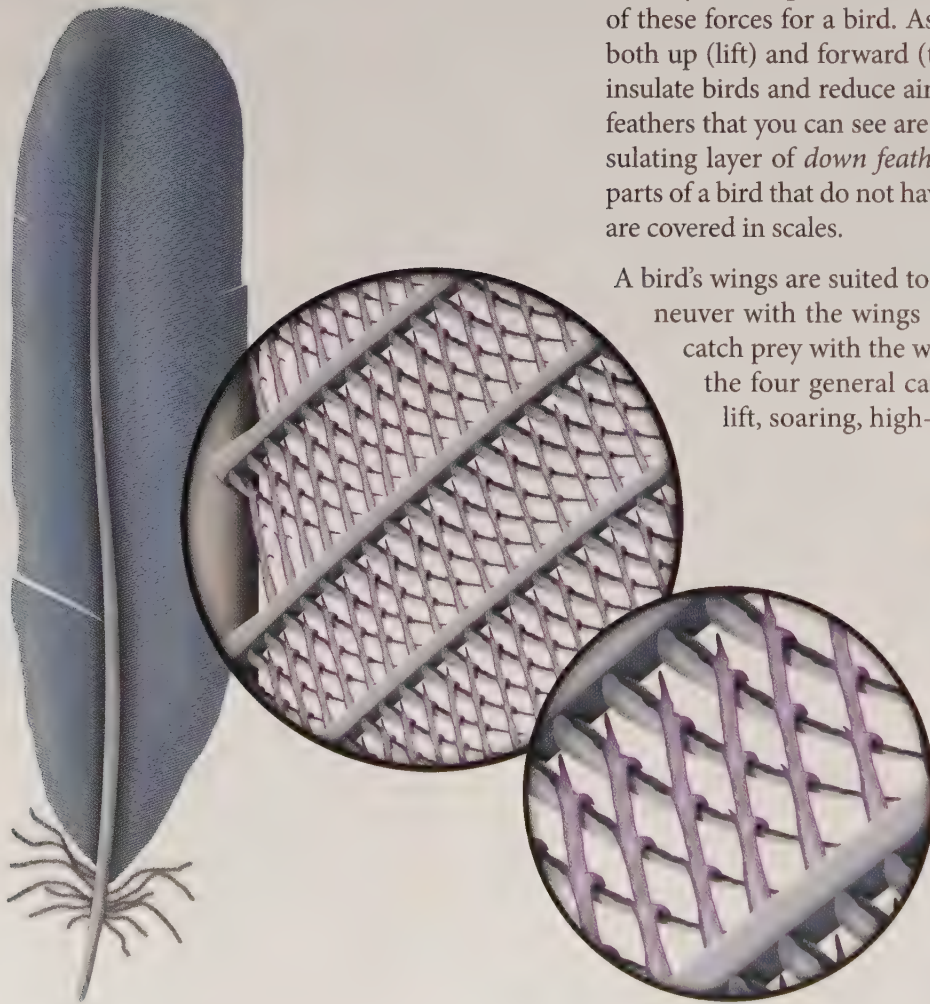
Flying requires structural support that is both lightweight and strong. A lack of either characteristic spells doom to flight, but God has given birds special skeletons that meet their needs. The most obvious difference between the avian skeleton and other vertebrate skeletons is the presence of a **keel**, a large flat structure on a bird's breastbone that provides a place for the wing muscles to attach. Many of a bird's bones, including most of its vertebrae, are also fused to give the skeleton needed rigidity. They are hollow, yet strong. In fact, the skeletons of many birds are so light that they weigh less than the bird's feathers.

In addition to a lightweight, rigid skeleton, flight requires lift and thrust to carry birds upward and forward, and feathered wings provide both of these forces for a bird. As a bird flaps its wings, the wings propel it both up (lift) and forward (thrust). Additionally, feathers cushion and insulate birds and reduce air resistance as they fly through the air. The feathers that you can see are *contour feathers*, but birds also have an insulating layer of *down feathers* next to their skin. Generally, the only parts of a bird that do not have feathers are its lower legs and feet, which are covered in scales.

A bird's wings are suited to its lifestyle. A woodpecker could not maneuver with the wings of an albatross, and a falcon could never catch prey with the wings of a grouse. Generally, wings fall into the four general categories shown on the facing page: high-lift, soaring, high-speed, and elliptical.

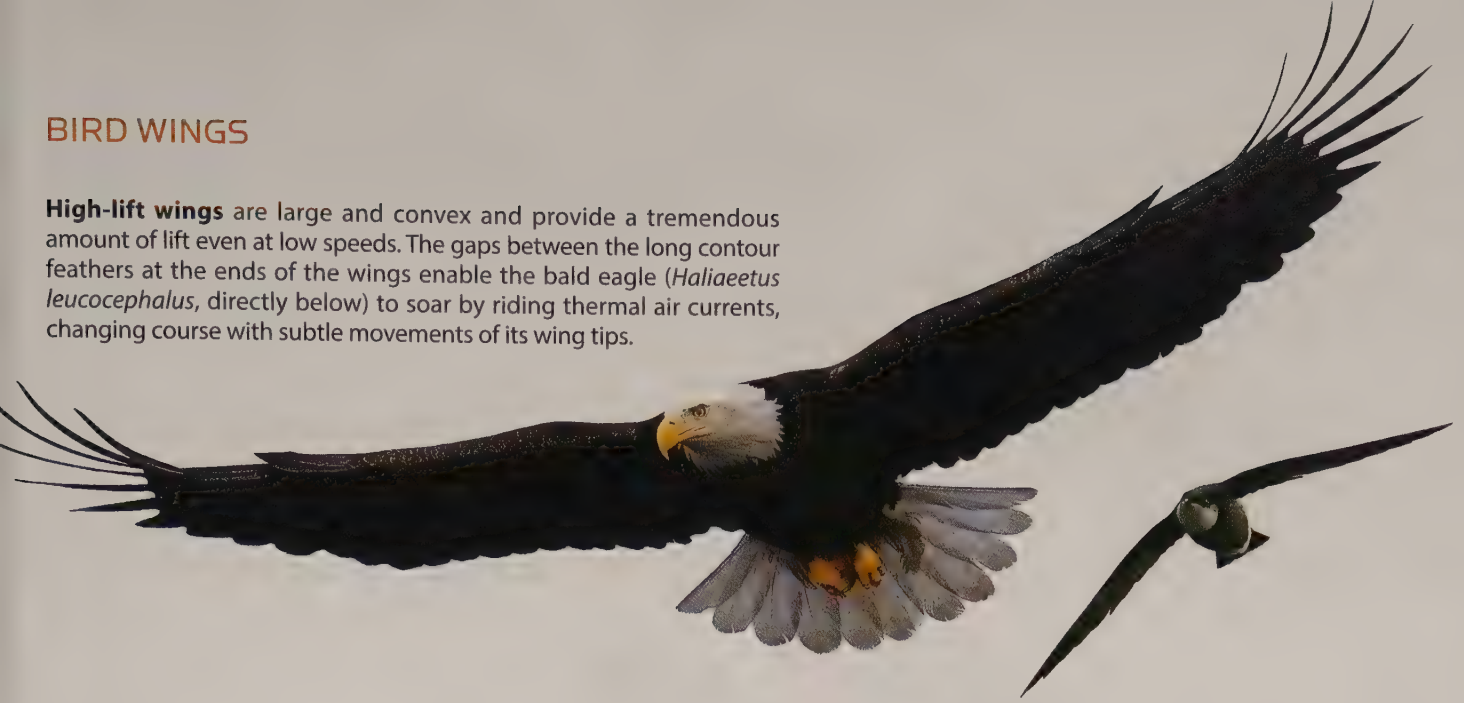
19-2

A feather grows from a follicle deep in the skin and is made of a central shaft and a flat vane consisting of hundreds of rows of barbs. Each barb carries multiple pairs of barbules that overlap and connect with barbules on other barbs by means of tiny hooks. These hold all the barbs together as part of the vane of the feather.

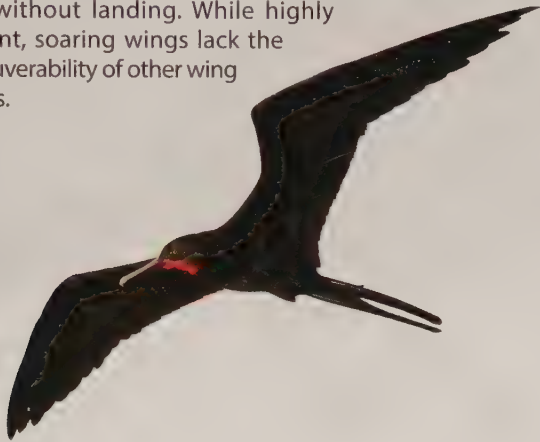


BIRD WINGS

High-lift wings are large and convex and provide a tremendous amount of lift even at low speeds. The gaps between the long contour feathers at the ends of the wings enable the bald eagle (*Haliaeetus leucocephalus*, directly below) to soar by riding thermal air currents, changing course with subtle movements of its wing tips.



Soaring wings are long and thin, a pattern followed in the design of a glider. These wings enable the magnificent frigatebird (*Fregata magnificens*, below) to expend a minimum of energy in staying aloft over the ocean for days without landing. While highly efficient, soaring wings lack the maneuverability of other wing shapes.

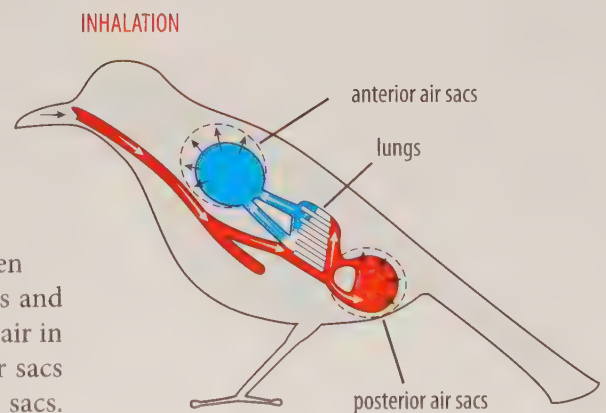


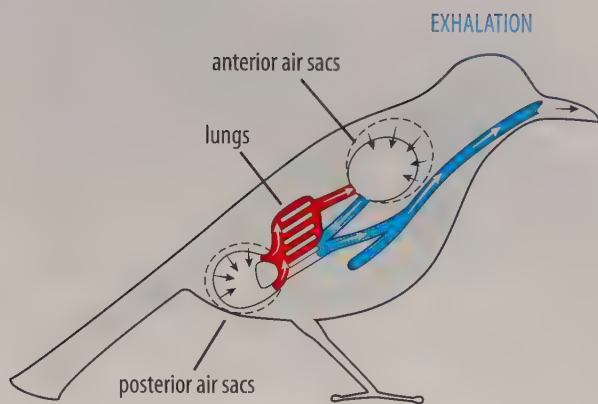
High-speed wings have a long, thin, tapered shape that generates little drag in the air. The white-throated needletail (*Hirundapus caudacutus*, above right) uses its high-speed wings to reach level-flight speeds of over 100 km/h.

Elliptical wings are short and wide and provide for quick take-offs and landings, low-speed flight, and maximum maneuverability. The elliptical wings of the West Indian woodpecker (*Melanerpes superciliosus*, right) permit it to change direction quickly in its forest habitat.



But feathers, a lightweight, strong, and fairly rigid skeleton, and wings suited to flight are not all that a bird needs to keep it flying. Muscles need sufficient oxygen to keep from tiring; a bird would not be able to fly very long without a constant supply of oxygen. Birds have no diaphragm and their lungs don't expand very much, but they have the most efficient respiratory system known. In addition to their lungs, they have nine **air sacs** that fill up much of their body cavity and even fill the hollow spaces in some of their larger bones. When a bird inhales, most of the air moves into the posterior air sacs and then is exhaled into the lungs. When the bird inhales again, the air in the lungs then moves out of the lungs and into the anterior air sacs while air from the atmosphere rushes to refill the posterior air sacs.





When the bird next exhales, oxygenated air from the posterior air sacs rushes into the lungs again and deoxygenated air in the anterior air sacs is released from the body. This system keeps oxygenated air and deoxygenated air from mixing, so the bird has a supply of oxygen nearly all the time. As the air enters and exits through the trachea, it passes through the **syrix**, which the bird uses to make the characteristic songs and calls that endear them to so many people.

A bird's air sacs also help it maintain its internal temperature. As an endothermic animal, a bird builds up heat from its metabolism, but it also needs a way to release heat when it becomes overheated. As air passes through the sacs, it picks up heat from the tissues and carries it out of the body. Some birds pant when they become overheated to increase this cooling effect.



As the air passes through the bird's lungs, oxygen diffuses into the blood. The blood then travels to the four-chambered heart, entering the left atrium, then moving into the left ventricle, from where it is pumped to the rest of the body. When the blood returns to the heart, laden with carbon dioxide from the body's cells, it enters the right atrium and moves to the right ventricle, which pumps it to the lungs to release its load of carbon dioxide and pick up a new supply of oxygen. The avian heart is large for the size of the body, and its heart-beat is very fast. Some of the smaller birds have heart rates of 1000 beats per minute or faster during times of activity. The size and rate of a small bird's heart causes its blood pressure to be quite high. Small birds tend to have a short lifespan, and few die of old age. A bird's life is full of many hazards. Larger birds such as the South American macaws can live for 50 years or more.

As the blood circulates through the body, it also picks up nitrogenous wastes from the body's cells and carries them to the kidneys to be filtered out. Unlike many other tetrapods, birds do not have a bladder for storing urine. Instead the kidneys release wastes as uric acid directly into the cloaca. Marine birds have special salt glands in their heads that filter salt out of their blood and release it as a concentrated salt solution through the nostrils.

All birds have a beak made of keratin that they use to capture food. Birds feed on a wide variety of organisms, from plants to animals sometimes larger than themselves, and a bird's beak is shaped in a way that is suited to its food. While birds may use their feet or beaks to tear apart larger prey, most food is swallowed whole since birds have no teeth. After the food passes through the mouth and esophagus, it enters the **crop**, a sac-like enlargement of the esophagus that stores the food until it can be digested. It then moves to the two-part stomach. The first part, the *proventriculus*, produces digestive juices, and the second part, the muscular and thick-walled **gizzard**, grinds the food. Some birds swallow small stones and grit to help grind the food and mix it with gastric juices. The food then passes into the intestine where nutrients are absorbed into the bloodstream, while the digestive wastes are released into the cloaca with the uric acid from the kidneys. Because weight is an important factor in flying, most birds empty their cloaca just before takeoff and at other frequent intervals.



Flying takes a lot of energy, and being endothermic requires a high metabolic rate. As a result, birds must eat a lot, even though the expression “eat like a bird” is used to describe someone with a poor appetite. Some smaller birds such as hummingbirds can eat their own weight in food each day.

In addition to the energy and oxygen that their muscles need to fly, birds require excellent navigation skills to dodge obstacles, avoid predators, and land safely. This kind of maneuverability is most needed by birds that live in the woods and must fly around trees trunks and through branches.

God has given birds the tools they need to traverse the air safely. Birds have very large eyes, and their sight exceeds even that of humans. Their color vision tends to be very good as well, and many can even see ultraviolet light, which is invisible to most animals. Their hearing also tends to be quite good, but many birds have poor or even no sense of smell or taste. This deficiency, however, allows the great horned owl (*Bubo virginianus*) to prey on skunks since the owl's poor sense of smell renders it immune to the skunk's noxious spray.

19.4 AVIAN REPRODUCTION

During the spring, birds sing in the air, in the trees, and on the ground looking for a mate. A male's **courtship** typically involves visual or vocal displays or a combination of both to attract a female. Since the male must attract his mate and defend the pair's territory from intruders and predators, he is often brightly colored. The female's typically duller colors camouflage her as she incubates her eggs. Courtships can be very elaborate affairs involving steep dives, like the sky dance of the golden eagle (*Aquila chrysaetos*), or structure building, as in the case of the greater bowerbird (*Chlamydera nuchalis*). Shortly following courtship, the male and female birds mate. In most species, a pair remains together for less than a year, pairing up with new mates the following year. However, a few birds, like the Canada goose (*Branta canadensis*), remain with their mates for life.

19-3

The brilliant red male northern cardinal (*Cardinalis cardinalis*) and his primarily brown mate exhibit **sexual dimorphism**—a difference in appearance between males and females of the same species.

Although most vertebrate females have two sets of *ovaries* and *oviducts*, female birds develop only one set. After internal fertilization, the ovum and sperm unite in the *oviduct*. The fertilized egg, consisting of a tiny embryo and a large amount of yolk, passes down the female's reproductive tract, which adds a protective layer of **albumen** (the white of the egg) and shell. The egg then passes out of the body through the cloaca.

Most birds build nests to serve as nurseries for their developing young, each species building its own type. Eggs will hatch only if they are **incubated**, and most birds incubate their eggs by sitting on them. The females of many birds incubate the eggs while the male's activity ranges from leaving completely, to feeding the female while she sits on the nest, to actively assisting her in incubating the eggs and young. The Australian brushturkey (*Alectura lathami*) is unusual in that it uses the heat of decaying vegetation to incubate the eggs, which are cared for entirely by the males.

19.5 BIRDS IN THEIR ENVIRONMENT

As the second largest group of vertebrates, birds live in nearly every biome of the world, and many species are quite the globe trotters. A habitat that provides perfect conditions for rearing young in the summer may be very inhospitable in the winter, so many birds deal with this problem by spending the summer nearer the poles and moving to warmer climates during the winter. Some **migrations** are relatively short, like that of the American white pelican (*Pelecanus erythrorhynchos*), which flies from the northern United States and southern Canada to Florida and Mexico. Others have far more dramatic migratory routes. The arctic tern (*Sterna paradisaea*) breeds in the Arctic and winters in the Antarctic, a round trip of 40,000 km.

Migration also makes conserving some species difficult. While nations like the United States have attempted to protect avian habitats, conservation laws in countries where birds winter are often either poorly enforced or entirely absent. As a result, many organizations are seriously concerned about declining bird populations. However,



the case of the Eastern bluebird (bottom margin, facing page), which made a strong comeback in the late twentieth century after many people began setting up bluebird houses, suggests that even small efforts on the part of concerned individuals may help our feathered friends.

With all their variety, birds occupy a number of niches in ecosystems, including some very unusual ones. Atlantic puffins (*Fratercula arctica*) spend most of their time riding the waves at sea since their wings are more suited to swimming than flying. When they do fly to land to breed, they nest in borrows dug in cliffs overlooking the sea (see page 47). The edible-nest swiftlet (*Aerodramus fuciphagus*) builds a nest almost entirely from its own saliva. These nests are harvested for use in bird nest soup, a Chinese delicacy.

CALIFORNIA CONDOR



Some of the least appreciated birds are the vultures. Most people find them disgusting with their predominately black feathers, bare heads, and habit of eating carrion, but by consuming carcasses they help prevent disease and speed up the decomposition process.

However, in the past not everyone understood the important ecological role of the vulture. For example, farmers would see vultures eating a dead farm animal and would mistakenly assume that the vultures had killed it. In the United States, one common species, the black vulture (*Coragyps atratus*), does occasionally kill calves and lambs, and since juveniles of several other vulture species look similar to the black vulture, all vultures suffer. As a result, many vultures were killed, and one, the California condor (*Gymnogyps californianus*), the largest bird in North America, was reduced to only 22 individuals in the wild. As people came to understand the important role of vultures, the indiscriminant killing subsided and vulture populations have rebounded. The California condor was the subject of an intensive captive breeding program and has since been reintroduced into the wild, though that population still numbers less than 250 individuals. Scientists today continue to study ways to help the condor population increase.

19A REVIEW QUESTIONS

1. Why can birds such as the dark-eyed junco (*Junco hyemalis*) live in snowy areas through the winter without hibernating like amphibians and reptiles?
2. You find a bird with naturally oily feathers and webbed feet. What type of bird is this likely to be?
3. Which bone structure found in most birds would an ostrich lack? Explain.
4. What would happen if a bird had a less efficient respiratory system?
5. Arrange these terms in order of largest to smallest: barb, feather, hook, and barbule.
6. In a bird, what three body systems empty into the cloaca?
7. How does the design of a female bird's reproductive system help it fly?
8. How do many species of birds survive the cold winters of their breeding grounds?



MAMMALS

How do mammals live and function in their environment?

19B Questions

- » What is a mammal?
- » How are mammals classified?
- » How does a mammal function and reproduce?
- » How should someone with a biblical world-view respond to useful research pursued by evolutionary scientists?

19.6 CLASSIFYING MAMMALS

Just as birds are distinguished by their feathers, animals in class Mammalia are set apart by their hair. Most mammals are covered by two layers of fur that protect and insulate them, and many of them possess specialized hairs that serve a variety of purposes. Some mammals, primarily aquatic ones, have only a few bristles. Notice some of the main groups of mammals.

EXPLORING MAMMALS

Monotremes. The platypus (*Ornithorhynchus anatinus*) and the four species of echidnas are the exceptions to many mammalian characteristics. Most notably, they are the only mammals to lay eggs. Their order name refers to the single opening for their digestive, excretory, and reproductive systems.

Carnivores. Meat eaters like this tiger (*Panthera tigris*) are equipped with large canine teeth for tearing meat. While bears, dogs, and large cats often come to mind, carnivores include many diverse animals, including seals, weasels, and mongooses.

Lagomorphs. The eastern cottontail rabbit (*Sylvilagus floridanus*) and other species in this order are famous for their ability to reproduce quickly, leading to the expression “multiply like rabbits.” Although rabbits and the bulkier, larger-eared hares are often difficult to tell apart, the third group of lagomorphs, the pikas, appear distinctive due to their smaller, rounded ears.

Shrew-like mammals. Although shrews, like this northern short-tailed shrew (*Blarina brevicauda*), and moles may look similar to mice, they are not rodents at all. Many species live the majority of their lives underground and have a good sense of smell but tiny eyes. Most species spend the majority of their time hunting insects and other small arthropods, which make up the bulk of their diet.





Bats. The little brown bat (*Myotis lucifugus*, left) and the other members of this order are not the monsters that many people think they are. Many bats use echolocation to navigate and find insects in the dark. A single bat can eat several hundred thousand insects in the course of a year. Other bats, like the Indian flying fox (*Pteropus giganteus*), feed on fruit while others may eat fish or frogs. And, yes, the three species of vampire bats do feed on blood.

Rodents. Some rodents, like this naked mole-rat (*Heterocephalus glaber*), are harmless or even beneficial, but others, such as the brown rat (*Rattus norvegicus*), can be some of the most destructive mammals in the world. All rodents have continuously growing incisors at the front of their mouths, allowing, even compelling, them to gnaw. Although most rodents are small, the American beaver (*Castor canadensis*) can weigh as much as 27 kg.



Odd mammals. The nine-banded armadillo (*Dasypus novemcinctus*, above) is a strange mammal. The same could be said of anteaters and sloths, the other members of this group. They used to be known as toothless mammals, but armadillos and sloths have teeth, so they are now grouped together on the basis of their unusual joints.



Odd-toed ungulates. Hoofed mammals like this Malayan tapir (*Tapirus terrestris*) have hooves but only one or three toes. A much smaller order than the even-toed ungulates, odd-toed ungulates include the tapirs, the rhinos, and the equids—horses, donkeys, and zebras.



Even-toed ungulates. Mammals that have two or four functional hoofed toes, like this Thomson's gazelle (*Eudorcas thomsonii*, right) are even-toed ungulates. This large order also includes pigs, hippopotamuses, camels, giraffes, cattle, and deer. Some of these animals have a multiple-chambered stomach that allows them to digest cellulose in the plants they eat. Bacteria in the **rumen**, the first chamber, break down the cellulose. The semi-digested food or **cud** is then brought back up to be chewed again.



Sea cows. The West Indian manatee (*Trichechus manatus*, right) and the other three species of sea cows are tropical or subtropical herbivores. They live in the coastal waters of the ocean and sometimes move into estuaries and rivers. Although they are quite large, they have a reputation for being very gentle.



Marsupials. A marsupial embryo begins to develop inside its mother's **uterus**. Shortly after birth, the tiny offspring, essentially still an embryo, crawls to its mother's pouch and attaches to one of her nipples. The young animal continues to develop in the mother's pouch for as long as seven months in the largest marsupial, the red kangaroo (*Macropus rufus*, left).

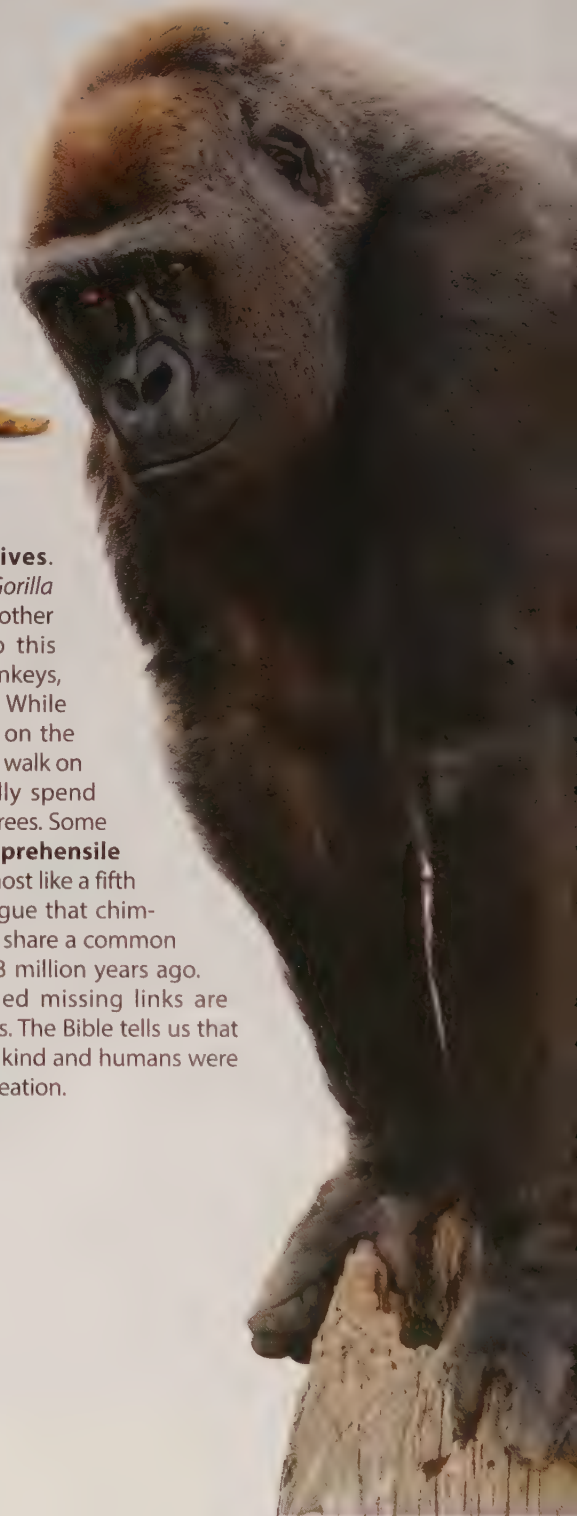


Simians and relatives.

The western gorilla (*Gorilla gorilla*, right) and the other great apes make up this order along with monkeys, tarsiers, and lemurs. While some can walk erect on the ground, they prefer to walk on all fours and generally spend most of their time in trees. Some monkeys even have **prehensile tails** that they use almost like a fifth limb. Evolutionists argue that chimpanzees and humans share a common ancestor that lived 13 million years ago. However, their alleged missing links are fraught with problems. The Bible tells us that animals of the simian kind and humans were created on Day 6 of Creation.



Trunked mammals. The African bush elephant (*Loxodonta africana*, above), like all **eutherians** (mammals other than the monotremes and marsupials), nourishes its unborn young by means of a **placenta**, an organ connecting the young to its mother's uterus. The three species of elephants are distinguished from other mammals by a flexible and highly useful trunk, which is essentially an elongation of the nose and upper lip. They also have two large tusks, which sadly often invite death at the hands of poachers involved in the ivory trade.



Aquatic mammals. Although the clever and popular bottle-nose dolphin (*Tursiops truncatus*, right) can reach 4 m in length, it is small for a cetacean. The blue whale (*Balaenoptera musculus*), the largest animal known to have ever lived, can reach 32 m in length and tip the scales at over 180,000 kg. Although cetaceans cannot live out of the water, they are mammals and must come to the surface to breathe. Several cetacean species are very social and have a relatively complex communication system in addition to echolocation that helps them navigate through the water.



19.7 MAMMALIAN STRUCTURE

Although mammals come in a great variety of shapes and sizes, they all share many characteristics that enable them to maintain homeostasis in their various habitats. Like birds, mammals are endothermic, so most of them have two layers of hair for insulation, cutting down on the amount of heat that they lose to the environment. Hair grows from follicles deep in the skin, and while the root is living, the hair itself is made of dead cells filled with keratin. Many mammals, especially those that live in water or cold regions, have a layer of fat, called **blubber**, under the skin that provides an additional level of insulation. Mammals also need a way to avoid becoming overheated. Many animals pant, releasing heat through their mouths. Some mammals, like elephants and swift foxes (*Vulpes velox*), that live in hot places have large ears that release heat from the blood into the atmosphere. Predictably, arctic foxes (*Vulpes lagopus*) of the far north have very small ears to conserve heat.

Insulation is useful only if there is a source of heat, and in endothermic animals, heat is produced by metabolism, so mammals must eat frequently. Mammals have various ways of finding food, but they all benefit by having a larger brain compared with their body weight than do other vertebrates. Aided by three bones that transmit sound in the middle ear, their hearing is extremely good. (Most other tetrapods have only one bone.) With the notable exception of primates, the mammalian sense of smell tends to be extremely keen, as demonstrated by the remarkable tracking ability of bloodhounds.

Mammalian eyesight tends to be weaker in comparison with birds' eyesight, especially in identifying color. While most mammals do have eye cells called *cones* that enable them to perceive color, they typically have relatively few of them. Furthermore, most mammals have only two types of cones instead of the three found in humans and the four found in birds, so they cannot distinguish between some colors. However, many mammals are able to see very well at night. As a rule, herbivores have eyes set in the sides of their heads, allowing them to see in almost all directions, a useful ability if you are potential dinner for large carnivores. Carnivores, on the other hand, tend to have their eyes in front of their heads, giving them better depth perception needed for attacking prey. Compare eye placement in the two mammals on the right.



19-4

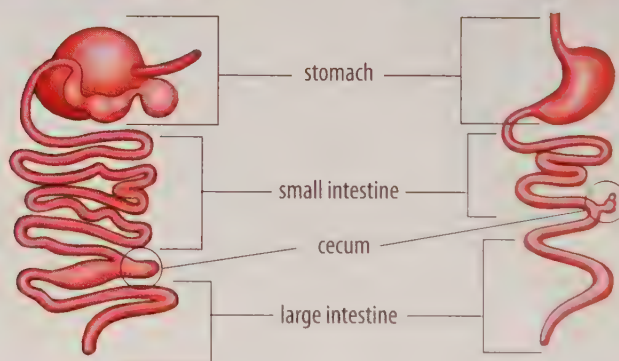
Far from being the blood-thirsty breed their name would suggest, bloodhounds are quite good-natured dogs, historically used for hunting because of their keen sense of smell.





Whether a mammal is a carnivore chasing its prey or an herbivore traveling to a new grazing area, mammals must be able to move. Like most tetrapods, they generally have an endoskeleton complete with four limbs. However, the amount of variation is large. The forelimbs of bats form wings, and whales have flippers for forelimbs but no hind limbs.

Once a mammal bites into its food, be it plant, invertebrate, or another vertebrate, the food enters the mouth and goes down the esophagus to the stomach. After being broken down by the stomach's acid and churning action (along with microorganisms and being chewed multiple times in ruminants), the food moves into the small intestine where nutrients are absorbed. Unabsorbed nutrients then move into the pouch-like extension of the large intestine called the *cecum*, where bacterial fermentation takes place. Fatty acids released in this process are absorbed in the large intestine. The cecum is especially important in nonruminant herbivores like horses, which don't have a rumen to help digest cellulose. Some mammals that feed primarily on insects lack a cecum altogether, and carnivores usually have very small ones. What is left of the mammal's food continues down the large intestine until it is expelled through the anus.



As the nutrients from the mammal's food are absorbed in the small intestine, they are carried along in its bloodstream to all the cells of the body. Along the way, the blood picks up nitrogenous wastes and carries them to the kidneys where they are removed and released as a diluted solution of urea called **urine**. Unlike other vertebrates, mammals other than monotremes have separate openings for their digestive and excretory systems.

As the blood flows through the body it also picks up carbon dioxide produced by cellular respiration. Eventually, the blood reaches the right atrium of the four-chambered heart. From there, it moves into the right ventricle that pumps it to the lungs. There, carbon dioxide diffuses into the lungs to be exhaled into the atmosphere, and oxygen diffuses into the blood and binds with a molecule called *hemoglobin* found in *red blood cells*. The blood then moves back to the heart and enters the left atrium. At this point, the blood empties into the left ventricle to be pumped to the rest of the body.

Mammals lack a bird's air sacs, but their lungs are far larger and more flexible. The **diaphragm**, a large muscle, separates the thoracic cavity holding the lungs and heart from the abdominal cavity holding the digestive organs. When the diaphragm contracts, the lungs expand, causing oxygen-rich air to rush into them. When the diaphragm relaxes, the lungs shrink, pushing carbon-dioxide-laden air back into the atmosphere. As the air exits the lungs, it flows through the **larynx** or voice box that is responsible for many of the sounds mammals make.



19.8 MAMMALIAN REPRODUCTION

Mammals have a set of structures called **mammary glands** that produce milk to nourish their young. In fact, the mammary glands are so unique among the animal kingdom that mammals derive their name from the Latin word *mamma*, meaning “breast.”

As a rule mammals are viviparous, although the five monotreme species are the exception to this and several other rules. In marsupials and eutherians, the egg is fertilized by sperm inside the mother's body, and the zygote is nourished by yolk until it begins to attach to its mother's uterus.

Once the yolk sac is depleted, eutherian embryos become attached to the wall of the uterus by a placenta made partly of the mother's cells and partly of the embryo's cells. The placenta allows the mother to provide nourishment and oxygen to the embryo and remove wastes



until the young mammal's systems are ready to function on their own. As a result, eutherians tend to have a long **gestation**, the period of time between conception and birth, producing young that are fairly well developed at birth.

Marsupials on the other hand have a very short gestation, for they are born as soon as the yolk sac is depleted. Exceedingly tiny and poorly developed, the young marsupial makes the perilous journey from the uterus to its mother's pouch where it continues development. In fact, red kangaroo joeys lack hind legs at birth. While marsupial gestation periods are much shorter than those of eutherians, the length of time female marsupials nurse their young is much longer.

Monotreme embryos remain in the uterus for an even shorter time than marsupial embryos. Often less than two weeks after they are conceived, the embryos are encased in a shell and laid as eggs. Mother echidnas guard their eggs in a pouch while platypuses lay their eggs in a burrow. While female monotremes produce milk for their young like all other mammals, the young lap the milk off their mother's fur since monotreme mammary glands lack nipples.

19.9 MAMMALS IN THE ENVIRONMENT

Mammals are extremely diverse and are found in almost every habitat, occupying many different niches from herbivore to top-level carnivore. Perhaps because of their higher intelligence, mammals have been domesticated far more than any other class of vertebrates. Horses, cattle, and camels are used as beasts of burden, dogs are used for hunting and companionship, and cats are kept as pets and to control rodents.

Many mammals are generalists, able to survive in a wide range of habitats. These often out-compete specialists, especially in the aftermath of a change in the local area. Sometimes these differences can be seen

in two very similar animals. For example, the Canadian lynx

(*Lynx canadensis*, left margin) is rarely found in areas

with a large population of humans, while the slightly

smaller but very similar bobcat (*Lynx rufus*, left)

thrives near humans. Many factors may give

the bobcat the edge over the lynx; for example,

bobcats are generalists that eat a

wider variety of prey than do lynxes.

Omnivores such as bears and foxes

also thrive near human dwellings,

as do coyotes, much to the chagrin of many sheep farmers.

Many large wild herbivores are

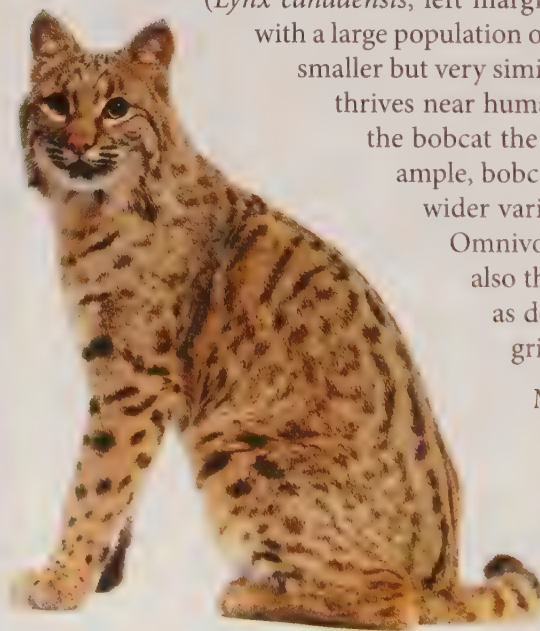
generalists that are often

hunted for food, but with

well-managed hunting seasons, many of these mam-

mals, such as moose (*Alces*

alces), have very large



populations in the wild. Even the American bison (*Bison bison*) is beginning to slowly recover from near extinction in the nineteenth century.

Large wild carnivores, on the other hand, are often scarce in developed countries. In the United States, wolves were feared and nearly hunted to extinction because they were perceived as a threat to livestock and people, especially children. The reintroduction of wolves into Yellowstone National Park in the mid-1990s has resulted in wolves expanding their range into surrounding areas. Though there have been no reports of wolves killing a human within the range of the introduced packs, human safety has been a concern. While this move remains controversial, the reintroduction of wolves has resulted in positive ecological changes in Yellowstone. Wolves have reduced the elk population, allowing tree species that the elk often eat to grow to full height. As a result of the increased tree growth, beavers have increased in numbers. The beaver dams have benefited numerous other species. The effects that one animal has on organisms throughout an ecosystem is called a *trophic cascade*.

Although many of the scientists involved with the Yellowstone project likely are evolutionists, they have had great success in managing God's world. Good science is based on data, and data is available to all scientists. Whether or not a believer, a good scientist is able to use the data that he has observed and use it for good purposes. People's worldviews still affect how they interpret data, though, and the effects of worldview become much more apparent when the scientist must extrapolate from the data he has observed.



19B REVIEW QUESTIONS

1. Which group of mammals are not viviparous? Explain.
2. What structure distinguishes marsupials from other mammals? Explain.
3. What three characteristics do all groups of mammals have?
4. What respiratory structure sets mammals apart from most other vertebrates?
5. What structure is important for digesting cellulose in nonruminant herbivores? Explain.
6. Arrange these groups of mammals in order of the length of gestation from shortest to longest: eutherian, marsupial, monotreme.
7. What structure do mammals use to nourish their young?
8. Koalas (*Phascolarctos cinereus*) feed almost exclusively on leaves from a few species of eucalyptus trees. Are koalas generalists or specialists?

REVIEW QUESTIONS

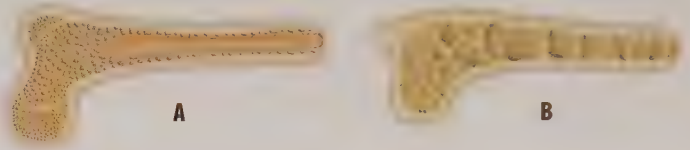
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Key Terms

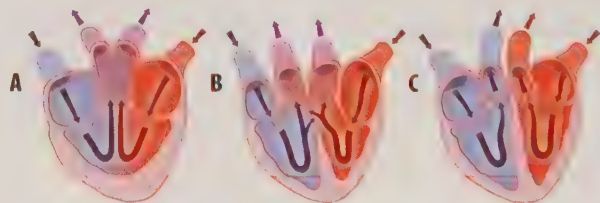
feather	375
keel	376
air sac	377
syrinx	378
crop	379
gizzard	379
courtship	380
albumen	380
incubate	380
migration	380
ungulate	383
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CONCEPT REVIEW

1. What special structures that provide insulation do birds and mammals have?
2. What purpose do layers of fat have in many endotherms?
3. What breastbone structure do some flightless birds lack?
4. How can perching birds sleep in trees?
5. Which of the two bones below belongs to a bird?



6. Create a T-graph classifying the following steps of a bird's respiration as either inhalation or exhalation: air enters the lungs, air enters the posterior air sacs, air leaves the body, air enters the anterior air sacs.
7. Some birds regurgitate food for their young. Where are they likely to store this food?
8. Contrast the ways that most birds and mammals expel digestive and nitrogenous wastes.
9. Which painted bunting (*Passerina ciris*) in the margin photo is the male? How can you tell?
10. What two layers of a bird's egg protect the embryo?
11. In which direction is a bird in the Southern Hemisphere likely to fly as winter comes?
12. What would be some negative consequences if vultures were to become extinct?
13. What structures distinguish ungulates?
14. What two groups of mammals echolocate?
15. Ungulates that chew the cud have what stomach structure?
16. A mammal with a small cecum probably has what kind of diet?
17. Which of these diagrams shows a mammalian heart?



18. Why must marsupials nurse their young longer than eutherians?
19. How are mammals different from other vertebrates in the way that they nourish their young?
20. Why are animals that are generalists better able to survive than specialists when the local environment changes?



TRUE OR FALSE

21. Endotherms have little need of insulation since they produce body heat through metabolic processes.
22. Raptors must hunt slow-moving prey because their large size and weight slows them down.
23. Elliptical wings are designed more for maneuverability than for speed.
24. Most male birds are silent during courtship.
25. A migratory bird must have two suitable habitats to survive.
26. The order of trunked mammals has a greater number of species than most other orders in class Mammalia.
27. Carnivores usually have eyes in the front of their heads.
28. The mammalian embryo is connected to its mother's placenta by the uterus.
29. Mammals have been domesticated more than other vertebrates.

CRITICAL THINKING

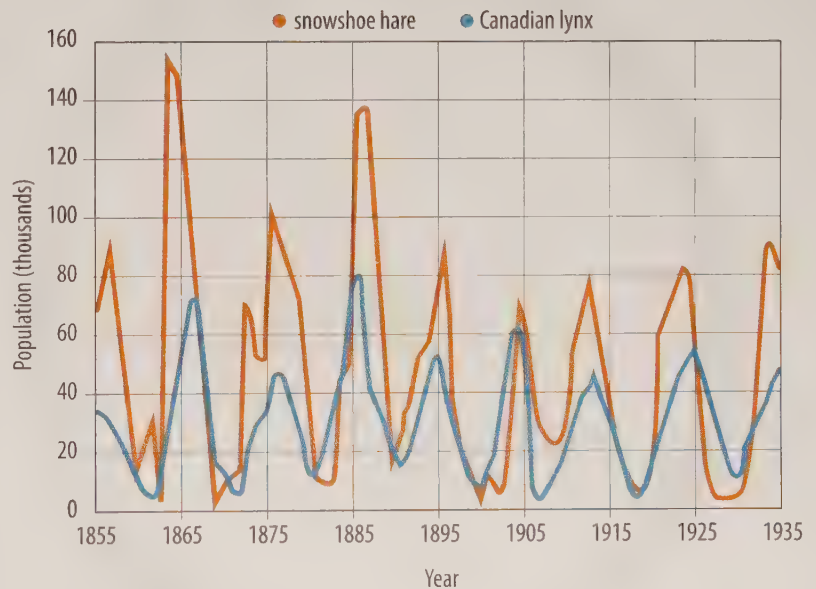
30. The shape of a bird's beak is suited to the bird's lifestyle. Which bird has a bill appropriate for probing in the mud for its food?



31. Why do you think that governments regulate hunting seasons for large herbivores?
32. The science surrounding the naked mole-rat is steeped in evolutionary philosophy. Explain why the research on this creature could still be useful.

Use the graph in the margin to answer Questions 33–38.

33. In what year between 1900 and 1930 was the hare population peak the greatest?
34. In what year in the nineteenth century did the hare population reach its lowest point?
35. In what year did the lynx population peak after the peak in the hare population in Question 33?
36. In what three 10-year periods listed on the graph did the lynx population reach its lowest points?
37. If the hare population peaks again in 2022, do you think that the lynx population is more likely to peak in 2024 or 2027? Explain.
38. On the basis of the pattern shown in the graph, if the hare population peaks in 2022, do you think that the hare population will likely peak in 2027 or 2033? Explain.



Wherever the art of medicine is loved, there is also a love of humanity."

HIPPOCRATES (C. 460–C. 370 BC),
GREEK PHYSICIAN, CALLED THE FATHER OF
WESTERN MEDICINE, WHO APPROACHED
MEDICINE WITH A SCIENTIFIC MINDSET



5 THE HUMAN BODY

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CHAPTER 20

PROTECTION

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20C THE LYMPHATIC SYSTEM AND IMMUNITY 405

LOOKING FOR A FIGHT

Ah, the joys of spring ... budding flowers, warm sun and sneezing! You probably know someone with allergies, if you don't have them yourself. In fact, allergies are the most common health problem among children in the United States, and it seems to be getting even more prevalent. About 20% of people in developed countries have allergies. But allergies can be more than just a sniffle. Some people have very dangerous reactions to foods or environmental stimuli that could endanger their lives.

Some scientists suggest that allergies may happen for an odd reason—we are too clean. **Lymphocytes** (shown here in yellow) are white blood cells, your body's secret service agents that target foreign invaders called **antigens**. Because we live in sanitized environments, these scientists hypothesize that lymphocytes don't have much to resist, so they go out looking for a fight. This makes an immune system hypersensitive. Something small, like a pollen grain, can trigger an all-out war in the body. Just like when a fight breaks out at a hockey game and everyone jumps in, more lymphocytes join the fight, triggering allergy symptoms. What can we do about allergies?

THE STUDY OF YOU

How does the human body work?

20.1 THE ESSENCE OF HUMANITY

We have been exploring a whole world full of life, but we've saved the best until last. There is one creature that has much in common with the animals, yet is special among all the living things that God made. In God's hierarchy of life, humans are higher in value and authority than plants, invertebrates, arthropods, and ectothermic and endothermic vertebrates, primarily because of one distinguishing feature: we are made in God's image. People are not just bags of chemicals; we are spiritual as well as physical beings. Though animals and plants are valuable, **human anatomy**, the study of man's physical makeup and structure, and **human physiology**, the study of human life processes, are just a little different from the other parts of biology.

We study the remarkable complexity and design in the human body because we have ethical decisions to make to help people solve health problems, such as the problem of allergies. As we study human anatomy and physiology, it is amazing to see just how well God has designed our bodies to protect us from antigens and to carry out life-sustaining processes.

For example, doctors and researchers have learned how the human immune system responds to antigens, and they have developed a way to train the immune system to ignore certain stimuli to avoid allergic reactions. This process is called *immunotherapy*. It involves giving an allergy patient shots of an increasing amount of a customized mixture of all the things they are allergic to. Eventually, most people's allergic reactions to these stimuli lessen over time.

The work, time, and money it takes to relieve human health problems are worthwhile because people are worthwhile. Studying human anatomy and physiology is one of the most effective ways to obey God's commands to wisely use His earth and care for His image bearers. We are accountable to our Creator to understand and wisely use our bodies for His glory. As we work to do this, we marvel at the infinite creativity of our loving Designer.

20A Questions

- » What makes the study of humans different from the rest of biology?
- » What is the human body made of?
- » What does each body system do?
- » How should we view the study of human anatomy and physiology?

20-1

Allergy shots are one good example of immunotherapy. Other medical interventions, such as wart treatments and vaccinations, also involve immunotherapy.

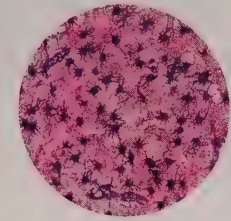


You have **nervous tissue** in your brain, spinal cord, and nerves. Without it, you couldn't move, get information about your environment, or think and feel. Nervous tissue is made of cells that receive sensory information from other sources and transmit electrical signals back to those sources through a series of chemical reactions.

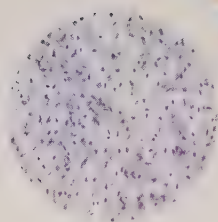
20.2 HUMAN TISSUES AND ORGANS

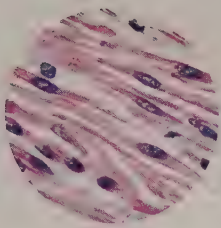
It is astounding to consider how much action is going on in your body as you read this paragraph. It all starts with cells. You learned in Chapter 5 that living things are made of cells. These cells make up tissues, groups of similar cells that serve a specific purpose. Your body is made of four types of tissues—epithelial tissue, connective tissue, muscle tissue, and nervous tissue. Tissue of one or more of these four kinds make up organs, and organs make up body systems. Smooth muscle tissue teams up with epithelial tissue and connective tissue to make an organ such as a blood vessel. Blood vessels work together with the heart to make the circulatory system function. Let's look at the different types of tissue in the human body.

EXPLORING HUMAN TISSUES



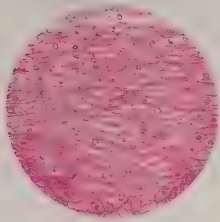
Connective tissue includes bone, blood, lymph, tendons, fat, and cartilage. There is more of this type of tissue in your body than any other type. Connective tissue supports, connects, and protects other structures in the body. Between the cells in connective tissue is a substance called a **matrix** that holds the tissue together. The matrixes in various connective tissues differ depending on the functions of the tissues.



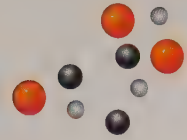


Muscle tissue is made of cells that can contract. Muscles tighten to move either the body or substances through the body. The human body has three kinds of muscle tissue—skeletal, smooth, and cardiac (heart). The photo to the left shows muscle tissue.

Epithelial tissue is made of layers of cells that cover or line surfaces, making up everything from the lining of your blood vessels to your skin. The cells in epithelial (ep uh THEE le ul) tissue are bound tightly together to protect surfaces.



Matter is made of atoms.



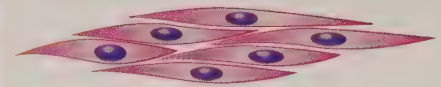
Atoms combine to make up molecules.



Molecules make up the cells' organelles, cytoplasm, DNA, and membranes.



Similar **cells** make up a tissue.



Different kinds of **tissue** make up organs.



Different **organs** work together to serve a specific purpose as an organ system in the human body.



The human body relies on many **organ systems** to maintain homeostasis.

203 HUMAN ORGAN SYSTEMS

Organs and organ systems, like the blood vessels, heart, and circulatory system, mentioned in the previous subsection, work together to maintain homeostasis in an organism. We've studied how animals use organ systems to maintain homeostasis, such as the open circulatory system in arthropods and the closed circulatory system in earthworms. Let's consider the human organ systems that we'll study in this unit.

EXPLORING HUMAN SYSTEMS



Integumentary system. This body system is made of skin, protecting the body from antigens.



Lymphatic system. Lymph nodes in this system protect the body from disease-causing antigens that make it past the skin. The lymphatic system is an important part of the body's *immune system*—the organs and tissues from several different systems that defend the body from antigens.



Skeletal system. This body system is made of a variety of bones that support and protect the body and allow it to move.



Muscular system. Muscles make up this body system, powering the motion of the bones and joints.



Respiratory system. Lungs and all the tubes that bring in outside air allow the body to breathe, exchanging gases between the blood and air.



Urinary system. This body system, like the digestive system, eliminates wastes and uses the kidneys and bladder to maintain water balance in the body.



Circulatory system. This body system involves the heart, which pumps blood through blood vessels to deliver nutrients throughout the body.



Nervous system. The brain, spinal cord, and a network of nerves coordinate and control movement and process sensory information from the body's environment.



Digestive system. The stomach and intestines in this system help the body digest food, absorb nutrients, and eliminate wastes.



Endocrine system. Body functions are controlled and regulated by hormone-secreting glands, like the thyroid in this system.



Reproductive System. Each gender has appropriate organs to allow for reproduction, or procreation.

204 HUMAN ANATOMY, PHYSIOLOGY, AND A BIBLICAL WORLDVIEW

Your body is important to you, and it is important to God too. Evolutionists believe that the human body is a product of completely random, natural processes, but believers of God's Word know that God created our bodies. We can't just use our bodies any way we want. Because God created the human body, it belongs to Him (1 Cor. 6:18–20). We are accountable to God to wisely use and care for the bodies that He has given us. We also need to help other people do that.

Though our bodies are created by God, they are also fallen. We bear God's image, but that image is twisted by sin. One of the consequences of the Fall is the shame that comes with nakedness (Gen. 3:7–10). However, doctors and textbooks inspect the uncovered body to develop our understanding of human anatomy and physiology. While realizing that there is a proper time and place to study the human body, don't allow it to dull your sense of modesty.

20-2

Though there may be things you don't like about your body, remember that God formed you in your mother's womb the way you are (Ps. 139). You are special to Him.



You might also find disturbing the sight of human blood and tissue. Though we need to be able to recognize parts of the human body so that we can understand their shape and function, we should also retain a sensitivity to violence to the human body. Viewing our bodies clinically helps us deal with this aspect of human anatomy and physiology.

Scientists sometimes misapply their knowledge of human anatomy and physiology. As scientists and doctors work to understand the human body, they learn things that they can use to advise people in how to get relief for diseases and problems. Those decisions are deeply affected by one's worldview. You are probably aware of people who have made unethical decisions about their bodies—abortion, euthanasia, and assisted suicide—sometimes even following the advice of doctors.

It is possible to develop an understanding of anatomy and physiology in the context of a biblical worldview so that we can use this science in a way that glorifies God. You'll be amazed when you learn how complex and sophisticated God has made your body.

20A REVIEW QUESTIONS

1. Discuss the similarities between the human body and the bodies of animals.
2. How is mankind different from other organisms?
3. What makes one type of tissue different from another type?
4. Which one type of tissue is found most often in each of the following systems?
 - a. nervous system
 - b. skeletal system
 - c. muscular system
 - d. integumentary system
5. Give an example of a body system and two organs in that system.
6. List each of the eleven systems in the human body and summarize the purpose of each with one word.
7. Compare the purposes of the integumentary and lymphatic systems.
8. How can knowledgeable doctors sometimes give patients bad advice, as when they, for example, advise abortion?
9. From a biblical worldview, why is immunotherapy a good tool of anatomy and physiology?

THE INTEGUMENTARY SYSTEM

What is the body's first line of defense made of?

20.5 THE STRUCTURE OF THE INTEGUMENTARY SYSTEM

Let's study the human body, starting with the outside. In fact, the largest organ in your body is right there—skin! Your skin, hair, and nails cover an area of about 19 square feet. Skin has varying thicknesses over your body, averaging 0.1 in., and is a vital part of maintaining your body's homeostasis.

Skin consists of two layers. The top layer of skin is the **epidermis**, made of epithelial tissue. The bottom layer of skin is the **dermis**, made of connective, muscular, epithelial, and nervous tissues, so it is the more complex layer. Under the dermis is the **subcutaneous layer**, a layer of cells made of connective tissues. Although the subcutaneous layer isn't a layer of skin, it is part of the integumentary system.

20B Questions

- » What is skin made of?
- » What does your skin do for you?
- » How does your skin work with the rest of your body?



20-3

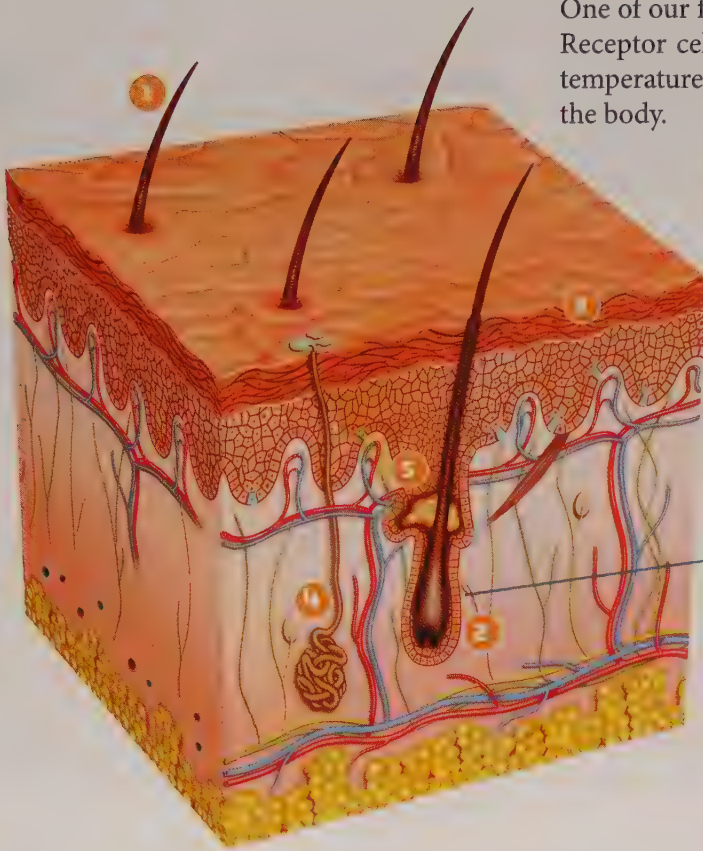
Ever looked at your skin close-up? Get out a magnifying glass and try it.

EXPLORING THE INTEGUMENTARY SYSTEM

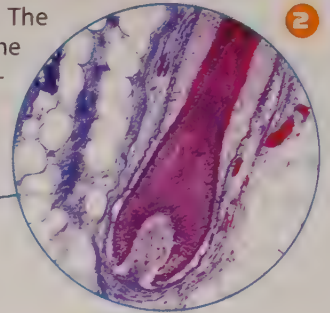
Human skin naturally looks a little pink from the blood showing through the skin layers. But this pink color can be masked by **melanin**, a brownish black pigment produced by cells in the epidermis in differing amounts for each person. These cells can be stimulated by ultraviolet light to produce melanin, making some people tan in the summer. Be careful though—any exposure to ultraviolet light can lead to skin problems, such as sunburn and skin cancer.



One of our five senses is touch, and the skin has a lot to do with that! Receptor cells made of nervous tissue collect texture, pressure, and temperature information from the environment to send to the rest of the body.



1 Hair can be found everywhere on the body except on the palms and the soles of the feet. It grows from a root called the **hair follicle** **2** buried deeply in the dermis. Hair follicles with elliptical openings produce curly hair, while those with round ones produce straight hair. The visible part of hair is called the **shaft**. It is made of a collection of dead, protein-filled cells. That's why it doesn't hurt to get a haircut!



3 The **epidermis**, the top layer of skin, is completely replaced about every 25 days. Old cells build up keratin and die, to be sloughed off and replaced by new cells generated beneath the epidermis. When you get a cut, cells along the cut can regenerate to heal the wound in the same kind of process.

4 **Sweat glands** are found in the dermis. You can guess what these glands release! Sweat, or *perspiration*, is about 99% water, 0.5% salts, and 0.5% organic substances such as sugars, amino acids, and urea. Sweat cools the body to maintain homeostasis.

5 **Sebaceous glands** are also found in the dermis, usually near hair follicles. They release oils, fats, and cellular waste products, collectively called **sebum**. Sebum helps skin keep out bacteria and viruses. However, sebaceous glands can become inflamed and build up white blood cells and sebum, causing acne.



Fingernails and toenails grow in a way similar to the way that hair does. They develop from the skin and form a layer composed of dead cells filled with keratin. Fingernails are completely replaced every six months, while toenails grow more slowly, taking a year to replace.



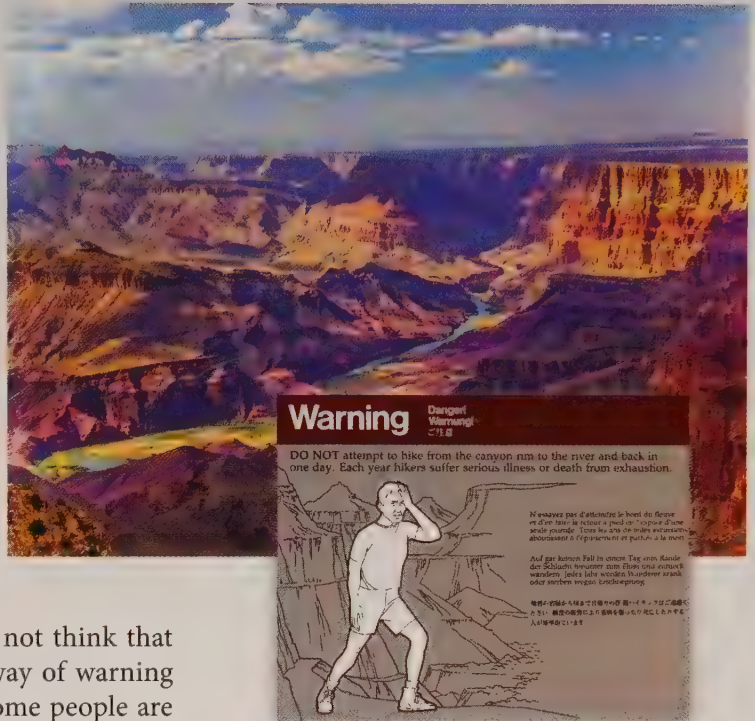
20.6 THE FUNCTION OF THE INTEGUMENTARY SYSTEM

One of the main functions of the integumentary system is to protect the human body from antigens, including bacteria, viruses, and foreign objects. These all can wreak havoc on the processes necessary to sustain life in the human body, causing illness and sometimes even death. The fact that people who lose large portions of skin have difficulty surviving testifies to the protective power of skin.

Another important function of skin is to keep your body's temperature under control. Why is this important? If you get too hot or too cold, your body isn't able to carry on the processes that it needs to survive. Keeping your body at just the right temperature is an essential part of homeostasis. Skin helps keep you warm by providing insulation in the fats found in the subcutaneous layer. It keeps you cool as sweat glands release perspiration, which cools you off as it evaporates. On a hot day with strenuous activity, you can lose almost two gallons of water!

The same process that cools you down also helps with another part of homeostasis—ridding the body of harmful waste products. Both the sebaceous and sweat glands help with this function of the integumentary system.

The neural receptor cells in the dermis also provide valuable feedback from the environment. You might not think that feeling pain is a good thing, but pain is the body's way of warning us that there is a problem somewhere in the body. Some people are born with a mutation in a gene that causes them to *not* feel pain. This is extremely dangerous, and many people with this disorder develop injuries without even knowing it. Touch receptors help us avoid parts of our environment that can harm the body. Even considering the discomfort of pain, we can see how God's design is for our good.



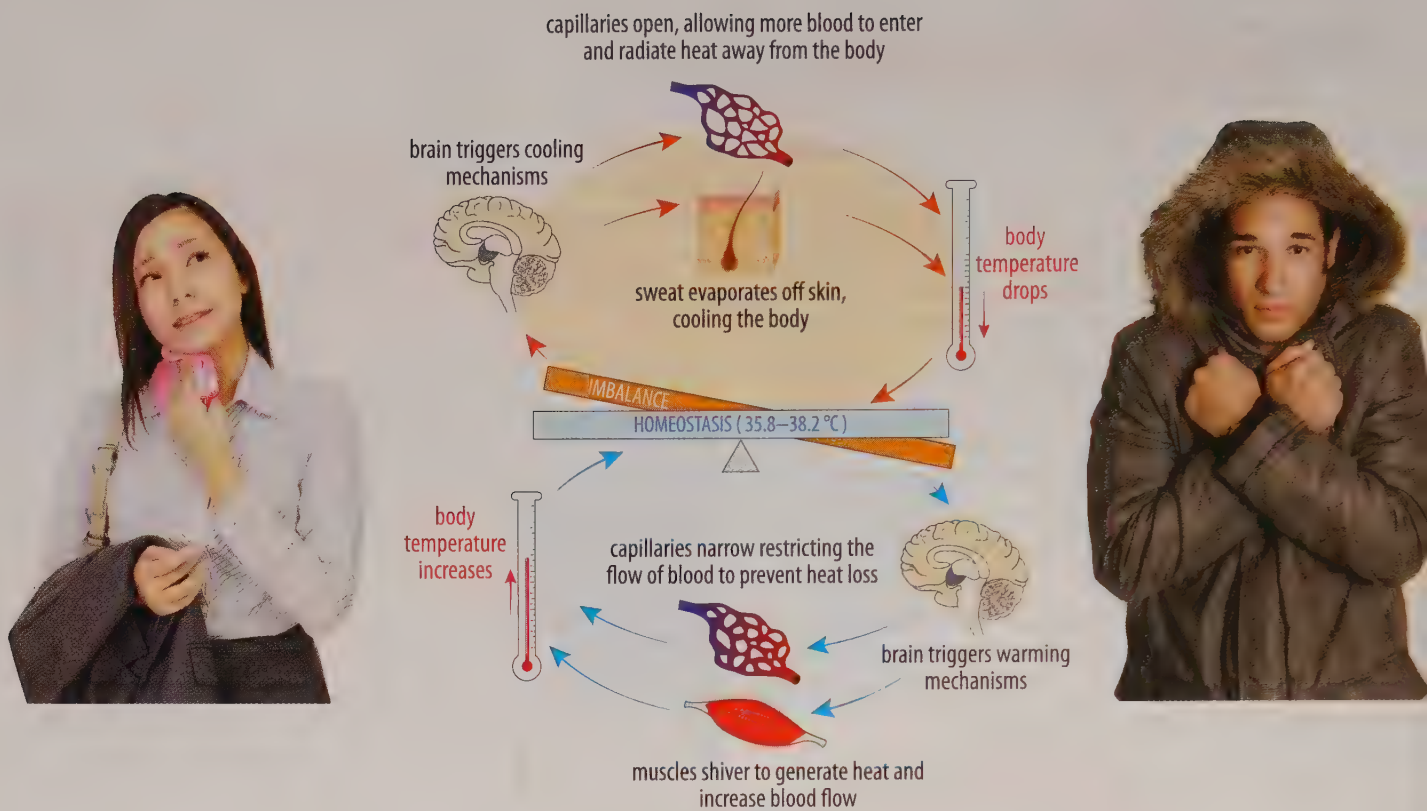
20-4

At the Grand Canyon, hikers need to beware of losing too much salt in their sweat. It is possible to lose too many salts or drink too much fluid and dilute the salts that are in your bloodstream.

20.7 THE INTEGUMENTARY SYSTEM IN THE HUMAN BODY

The integumentary system isn't a loner—it's a team player! It works together with the other organ systems of the human body to give them what they need to maintain homeostasis. Protection is the first order of business. The integumentary system teams up with the lymphatic system to protect the human body. We can see when this process goes awry as people develop skin cancers or allergic skin reactions such as hives and eczema.

Temperature regulation is the second main way that the integumentary system works with other systems in the body. It feeds neural information from the nerve receptors in the dermis to the nervous system. This can include information about temperature, causing the



body to sweat or stimulating the muscular system to shiver to warm up the body. Fats in the subcutaneous layer provide insulation.

The integumentary system also works with several other systems. Sweat glands and sebaceous glands team up with the urinary system to help release waste products from the body. Skin can't manage this on its own however. The kidneys (part of the urinary system) eliminate most waste products. Skin also uses sunlight to produce vitamin D, which provides nutrients for the skeletal system to make bones and for the digestive system to absorb calcium from food.

20B REVIEW QUESTIONS

1. List the three layers of the integumentary system in order, starting with the outer layer.
2. How is the structure of the dermis different from the other layers of the integumentary system?
3. Review the types of tissue from Subsection 20.2. Suggest the purpose of each layer of the integumentary system on the basis of the tissues(s) that compose it.
4. How does the integumentary system help the human body maintain homeostasis?
5. Draw a concept map that shows the interactions of the integumentary system with other systems.
6. Moles, clumps of melanin-producing cells, sometimes become cancerous. On the basis of what you learned about cancer on pages 166–67, what causes skin cancers such as melanoma?

THE LYMPHATIC SYSTEM AND IMMUNITY

How does the body eliminate cell waste and diseases?

20.8 THE STRUCTURE OF THE LYMPHATIC SYSTEM

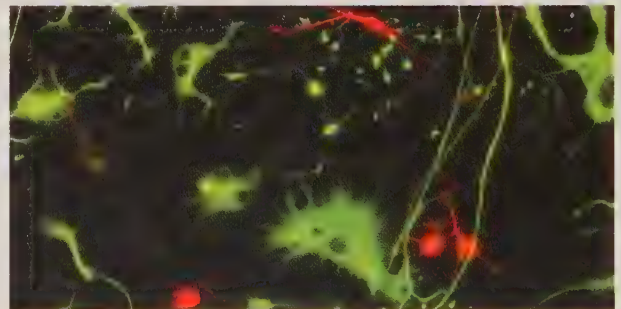
You're on the soccer team, and you have been playing for a few weeks when one day after the trees have started to bloom your eyes become red, itchy, and teary. Your body is undergoing an **inflammatory response**. The inflammation that you are experiencing is a signal to the immune system for an attack. In this case, your body is having an allergic response, probably to the pollen from the blooming trees. But inflammatory responses can happen as a result of an infection. That's a good thing—this reaction rallies your immune system to eliminate an antigen.

The lymphatic system is an important part of the immune system, the parts of the body that protect it from antigens. The structures of the human immune system are difficult to spot—many are tiny and are parts of other systems that carry out one step of the defense process. Since the battle against pathogens happens wherever they invade the body, much of the immune system involves chemicals and blood cells that can easily transport through different parts of the body. The immune system produces proteins called **antibodies** that allow the body to fight off antigens to keep them from disturbing the body's processes of life.

TAKING OUT BRAIN TRASH

Scientists have wondered for centuries how the brain keeps itself clean. It's not connected to the body's major cleaning system, the lymphatic system, so why aren't everyone's heads full of dead cells and metabolic waste? Dr. Maiken Nedergaard, a neuroscientist from Sweden, recently answered this question when she discovered how a group of cells enters the brain after a person falls asleep. The cells flow through little alleys in the brain that open up during sleep, allowing the cells to connect to the lymphatic system and clean up the brain. As soon as the person wakes up, those cells quickly retreat to the spinal fluid (where they came from) and take their cellular garbage with them. The discovery of this nighttime cleaning crew, named the *glymphatic system* by Dr. Nedergaard, led researchers to wonder why no one had noticed this before. Before, most neuroscientists believed that the alleys in a sleeping brain were leftovers from human evolution. But now the glymphatic system is being thoroughly studied for its potential to reverse the effects of Alzheimer disease. When we approach

science with a biblical worldview, our thinking is freer to see reality and use our understanding to help people.



20-5

Glial cells (shown above in green) are the worker cells of the glymphatic system, working very similarly to cells in the lymphatic system.

20C Questions

- » What is the lymphatic system?
- » How does the lymphatic system keep you healthy?
- » What are some of the good and bad reactions of the immune system?

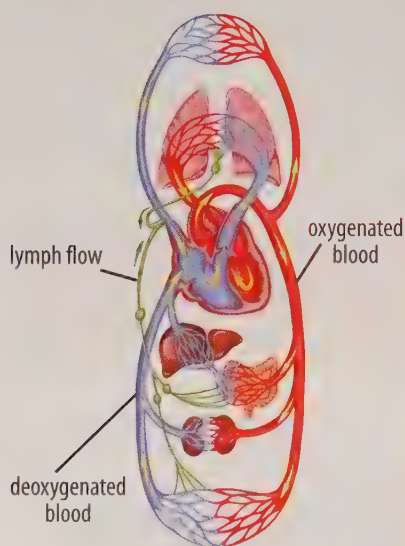


The lymphatic system uses a clear fluid called **lymph** to transport antigen-fighting cells and proteins through a network of vessels similar to blood vessels. Lymph comes from blood and is identical to plasma. It contains about 90% water along with other dissolved chemicals that supply nourishment to body tissues. Let's explore how the structure of the lymphatic system defends your health.

EXPLORING THE LYMPHATIC SYSTEM

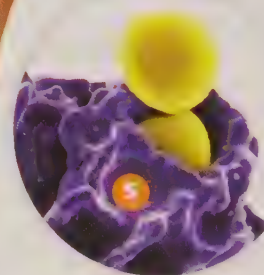
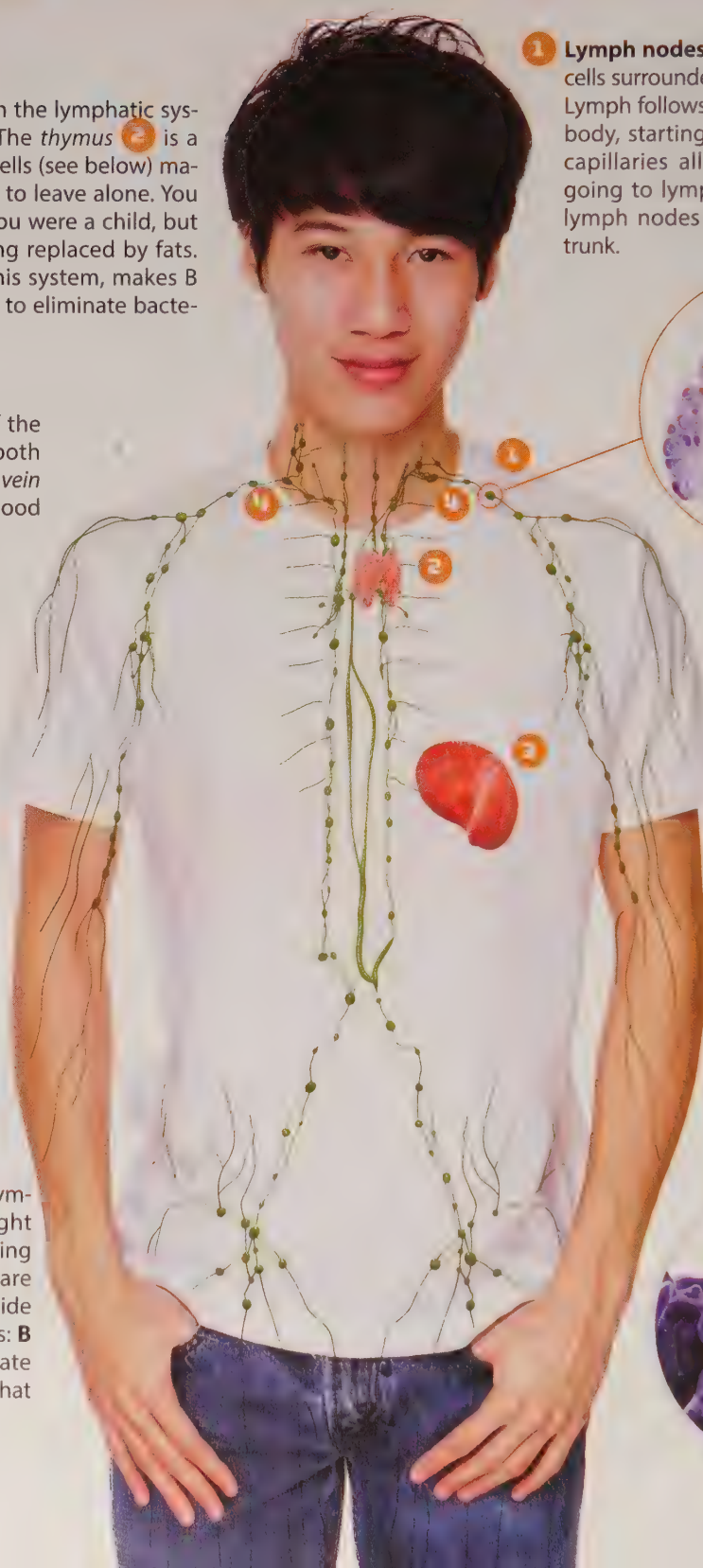
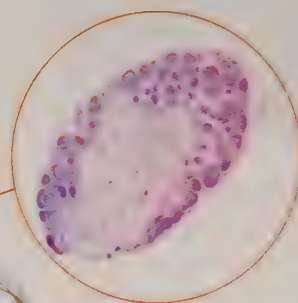
Two organs associated specifically with the lymphatic system are the thymus and the spleen. The *thymus* **2** is a gland located near the heart where T cells (see below) mature and learn what to fight and what to leave alone. You had a fully developed thymus when you were a child, but by now your thymus is gradually being replaced by fats. The *spleen* **3**, the largest organ in this system, makes B cells (see below) that make antibodies to eliminate bacteria and viruses.

Eventually, all lymph travels to one of the large veins near the collar bone on both sides of the body called the *subclavian vein* **4**. At this point, lymph rejoins the blood stream.



There are two types of warriors in the lymphatic system. **Macrophages** **5** fight antigens in the lymph nodes by grabbing and holding antigens. **Lymphocytes** are white blood cells that are produced inside bone marrow; there are two main types: **B cells** and **T cells**. Lymphocytes stimulate the production of antibodies, proteins that latch onto and attack antigens.

1 Lymph nodes are made of groups of cells surrounded by connective tissue. Lymph follows pathways through the body, starting out in tiny lymphatic capillaries all over the body, then going to lymphatic vessels, then to lymph nodes located in the body's trunk.

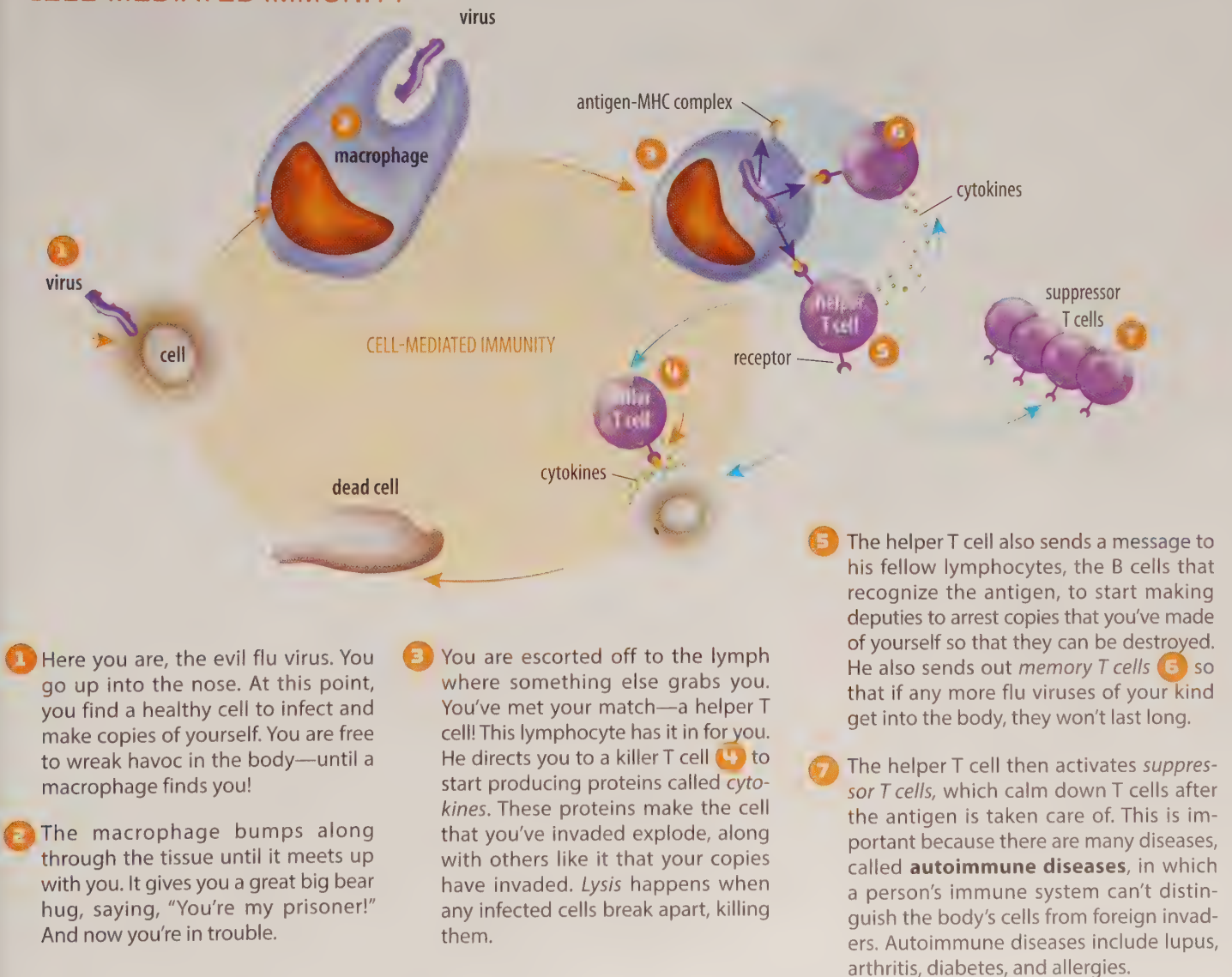


20.9 THE FUNCTION OF THE LYMPHATIC SYSTEM

The main function of the lymphatic system is to protect the body from antigens. This is why it is such an important part of the immune system. There are two ways that your body can get protection. When someone is given antibodies from another organism, the person experiences **passive immunity**. This kind of immunity doesn't last long since the body hasn't produced these antibodies. But when the body makes its own antibodies to protect itself, it acquires **active immunity**.

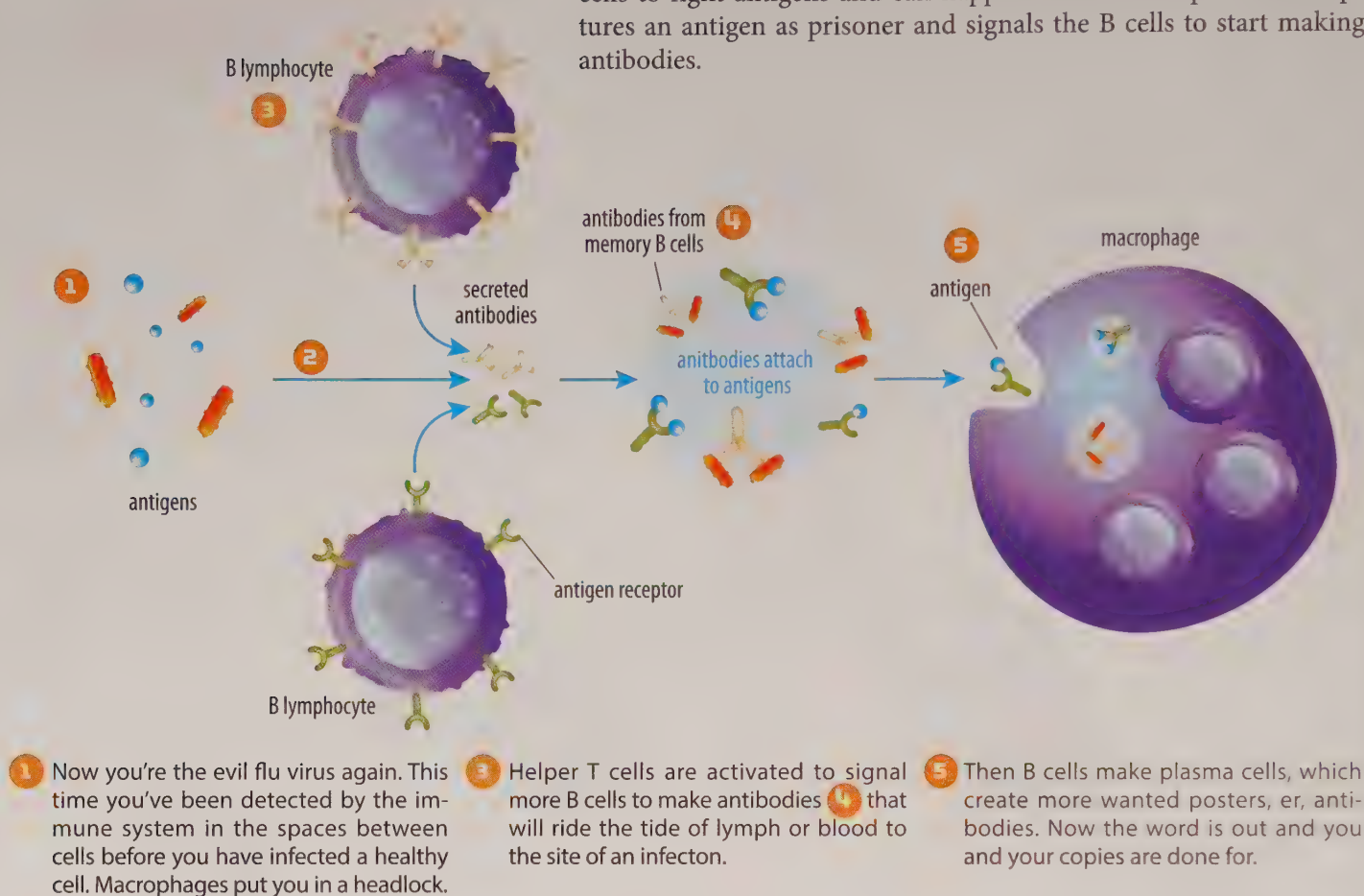
To study two kinds of active immunity, let's put a different spin on it. Imagine that you are an evil flu virus that has entered a human body through inhalation. The whole scenario you trigger is just one way the human body uses the lymphatic system to protect itself from antigens. This process, which uses mostly T cells to fight antigens that infect cells, is called **cell-mediated immunity**. Macrophages *generally* identify antigens, while T cells and B cells *specifically* identify them.

CELL-MEDIATED IMMUNITY



HUMORAL IMMUNITY

Another way that your body can fight antigens is through **humoral immunity**. Instead of activating T cells, this process uses mostly B cells to fight antigens and can happen when the helper T cell captures an antigen as prisoner and signals the B cells to start making antibodies.



1 Now you're the evil flu virus again. This time you've been detected by the immune system in the spaces between cells before you have infected a healthy cell. Macrophages put you in a headlock.

2 Oh no . . . you've been spotted! B cells make more B cells that recognize you, the antigen, by your wanted poster—their customized antibody!

3 Helper T cells are activated to signal more B cells to make antibodies **4** that will ride the tide of lymph or blood to the site of an infection.

5 Then B cells make plasma cells, which create more wanted posters, er, antibodies. Now the word is out and you and your copies are done for.

Cell-mediated immunity takes place when an antigen is spotted by the immune system. Humoral immunity takes place in between cells and relies on fluids, or *humors*. Both of these kinds of active immunity are called a body's *primary response* to an antigen just like you, the evil flu virus.

So what happens when this person is exposed to the flu again? If you as the evil virus haven't experienced any mutations, the person's memory T cells and memory B cells are prepared to fight the virus quickly. This is called the *secondary response* since the body has seen you and your copies before, and it knows just what to do.

Sometimes doctors penetrate the defensive layer of skin by giving a **vaccination**, which exposes a person to an antigen in the form of a pathogen, in a safe way, to train his immune system to respond properly to it. The pathogen could be dead, or it could be live but weakened in some way. A vaccine can be administered as a shot or orally. Recall the polio vaccine from chapter 12, which can be administered in both ways.

The secondary response is the primary reason why people are vaccinated for serious diseases such as smallpox, measles, and whooping cough. Doctors use vaccines to stimulate the body to produce antibodies or to activate T cells to provide just as much protection as those formed as a response to the disease. For some diseases, people need booster shots to remind the body to produce memory cells and antibodies in order to maintain immunity.

20.10 IMMUNITY IN THE HUMAN BODY

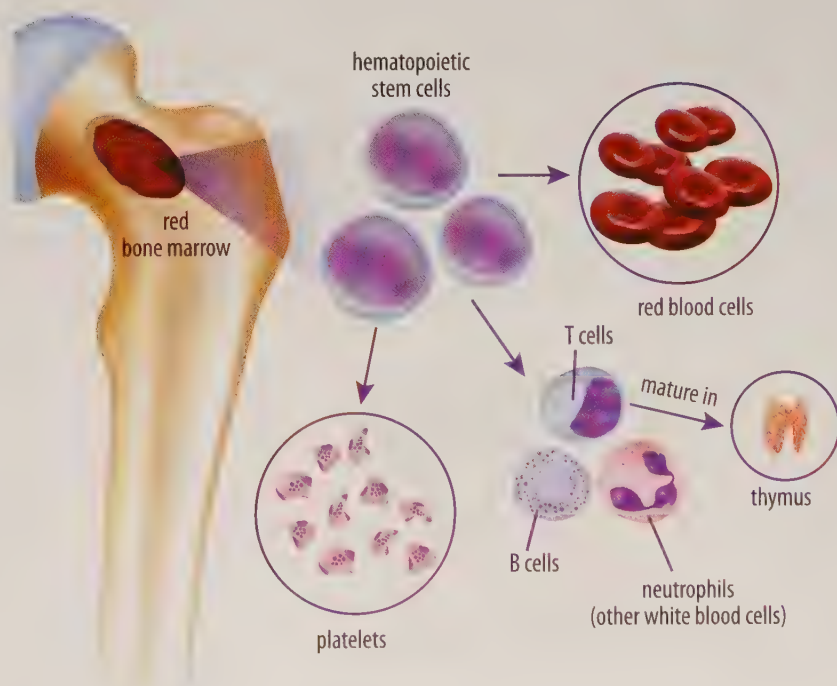
The lymphatic system is the interstate for your body's immune defense. It works with other organs in other systems to help protect you from disease.

The first line of defense is the skin, which keeps out most antigens and pathogens. There are other barriers in the body besides skin that section it off and contain any antigens that penetrate the skin's defenses. One example of a barrier is the blood-brain barrier, which keeps blood and nervous tissue separate.

When an antigen gets past the skin, the body keys up the immune response, perhaps triggering inflammation near an antigen. When you get a fever, your brain is firing up the immune response to an antigen.

Organs in other systems support the work of the lymphatic system. Muscles push lymph through lymphatic vessels; there is no pump equivalent to the circulatory system's heart. Bone marrow in the skeletal system produces lymphocytes, both B cells and T cells. B cells mature in bone marrow. The lymph system also works closely with the circulatory system to get lymphocytes where they need to go to fight antigens. There are even lymphatic tissues in your tonsils and appendix, all part of your digestive system. The digestive system also relies on the lymphatic system to help it remove fats.

God has fearfully and wonderfully made our bodies (Ps. 139:14), providing for our needs even in a fallen world where there are many diseases to plague us. Though God has provided us with bodies having amazing abilities to protect us, sometimes in His wisdom He allows us to experience sickness, disease, and suffering. We can trust the Creator of life on Earth—including human life—to do what is best for us. Through our knowledge of human anatomy and physiology we can not only help people who are sick but also worship a Creator who put us together and knew every cell of our bodies even before we were born.



PUTTING A STOP TO CHICKENPOX

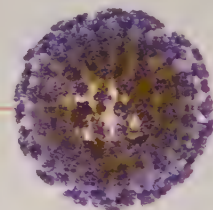
Ever catch chickenpox? There used to be as many cases of chickenpox worldwide each year as there were people born! Chickenpox is a very contagious disease, caused by the airborne varicella zoster virus (bottom right). Before a vaccine became available in 1995, parents would purposefully expose their children to infected children—just to get the disease over with. Four million children got chickenpox every year in the United States. Children who caught the disease would develop a painful and itchy rash that lasted 5–10 days. It was something that almost every child experienced. Once they were infected with the virus, they were immune to it for life.

However, once the varicella zoster virus enters your body, it never goes away. It infiltrates nerve tissue, sometimes reactivating and emerging later in life in a new phase of infection called *shingles*. One in three people who had chickenpox as a child develops shingles as an adult, and it isn't pleasant. Shingles produces a skin rash and can cause significant nerve pain.

But now the number of people who are infected with chickenpox in the United States is down 90%. What made the difference? In 2006 the US Advisory Committee on Immunization

Practices recommended that children be vaccinated to protect them from the varicella zoster virus. The vaccine for chickenpox uses a less harmful version of the virus to help children build immunity. A more potent form of the vaccine is administered to adults to help protect them from shingles.

In the United States, vaccines reduce the occurrence of many different diseases like chickenpox, but they work best if many people get them. Even the few people who don't receive the vaccines experience some protection because most of the people around them are immune and the disease isn't as prevalent. This is called *herd immunity*. But if not enough people are vaccinated, the herd immunity diminishes to the point where it can't protect people who haven't been immunized. This could include children too young to be immunized, those who are on drugs, like chemotherapy, which suppress their immune systems, or those with diseases who can't be vaccinated. When people get vaccinated, they are helping protect not only themselves, but also those who are too weak or too young to be vaccinated.



20C REVIEW QUESTIONS

1. You get a fire ant bite that turns red, swollen, and itchy. What is your immune system doing?
2. Outline the path that lymph travels, starting at the extremities of the body and moving toward the center.
3. How does the lymphatic system help to maintain homeostasis in the body?
4. Create a T chart comparing T cells and B cells. Include their places of origin and maturation, type of immunity they contribute to, and the different cells they activate.
5. Why is it important that lymphocytes not stay in the lymphatic vessels all the time?
6. Compare the *cells involved* in cell-mediated immunity and humoral immunity.
7. Compare the *locations of the antigen* in cell-mediated immunity and humoral immunity.
8. Classify cell-mediated immunity and humoral immunity as either active or passive immunity. Explain your answer.
9. How do the integumentary and lymphatic systems work together to protect the human body from antigens?
10. Why is the presence of muscular tissue necessary in lymphatic vessels?
11. On the basis of what you have read in this chapter, suggest a reason why there is currently no vaccine for HIV, the virus that causes AIDS.
12. Using the information in the box above, explain why your skin won't protect you from chickenpox.

REVIEW QUESTIONS

CONCEPT REVIEW

1. Why is the study of human anatomy and physiology important?
2. Review the discussion of animal body plans on page 305. What kind of symmetry if any does the human body display?
3. List the four kinds of tissue found in the human body.
4. Blood vessels are organs made of three kinds of tissues, not including nervous tissue. Why don't blood vessels need nervous tissue?
5. Which kind of tissue lines the small intestine?
6. What is the single purpose of every organ system in the human body?
7. Which two body systems are mostly responsible for movement?
8. Which two body systems transport needed nutrients around the body?
9. Which two body systems are most closely related to immunity?
10. Which two body systems are most closely related to water intake, eating, and nutrition?
11. Which two body systems help the body control itself in its environment?
12. Draw and label the three layers of the integumentary system.
13. What part of the skin does sunburn most often affect? Why is this?
14. List which one of the ten other body systems the integumentary system most closely works with for each of the following functions.
 - a. sense of touch
 - b. shivering
 - c. immunity
 - d. sweating
15. Trace the path of lymph through the body from the extremities to the bloodstream by putting the following steps in order.
 - 1 Lymph between cells in the finger migrates to a nearby lymphatic capillary.
 - 2 Lymph in lymph nodes travels through lymphatic vessels to the subclavian vein.
 - 3 Lymph in the subclavian vein enters the blood stream.
 - 4 Lymphatic capillaries merge in lymphatic vessels.
 - 5 Lymphatic vessels bring lymph to collection stations in lymph nodes.
16. Name two organs of the lymphatic system.
17. What is the purpose of the lymphatic system in the body?
18. Create a T chart comparing cell-mediated and humoral immunities. Include the types of lymphocytes involved, the location of antigens, the use of macrophages, the cells produced, and the occurrence of lysis in your comparison.

Key Terms

lymphocyte	394
antigen	394
human anatomy	395
human physiology	395
nervous tissue	396
connective tissue	396
matrix	396
muscle tissue	397
epithelial tissue	397
epidermis	401
dermis	401
subcutaneous layer	401
melanin	401
hair follicle	402
sweat gland	402
sebaceous gland	402
inflammatory response	405
antibody	405
lymph	406
lymph node	406
macrophage	406
lymphocyte	406
B cell	406
T cell	406
passive immunity	407
active immunity	407
cell-mediated immunity	407
autoimmune disease	407
humoral immunity	408
vaccination	408



20-6

A sunburn is normally a first degree burn.

19. A person develops an allergic response when an antigen from the environment called an *allergen* is identified by the immune system. Helper T cells initiate the inflammatory response. What kind of immunity do allergies involve?
20. What is the main difference between a primary and secondary response to an antigen?
21. List which one of the ten other body systems the lymphatic system most closely works with for each of the following functions.
 - a. keeping antigens out of the body
 - b. the production of lymphocytes
 - c. the onset of fever

TRUE OR FALSE

22. Man has all the attributes that animals have.
23. The organ systems in the body work independently of each other.
24. Skin is another name for the integumentary system.
25. The lymphatic and immune systems are identical systems.
26. T cells and B cells are types of lymphocytes.
27. A T cell is an organ of the lymphatic system.
28. Lymphatic vessels are lined with epithelial tissue to facilitate the flow of lymph.
29. B cells can produce plasma cells and memory cells.
30. Cell-mediated and humoral immunity are types of passive immunity.

CRITICAL THINKING

31. There are three severities of burns: first, second, and third degree. Suggest how these would relate to the layers of the integumentary system.
32. In hatcheries, many fish are confined in a contained area (see Figure 20-7). Fish have immune systems that are slow to respond, so managers use broad spectrum antibiotics to head off an epidemic rather than take the time to figure out exactly what is causing the problem. How would this compare with human immune systems and handling epidemics?
33. The tonsils and the appendix are part of the lymphatic system, both producing antibodies. However, they were once deemed vestigial organs, evolutionary relics with no specific purpose. In light of this example of premature conclusion, how do you think one's worldview affects the progress of science?



20-7

Fishery managers have to control disease because of crowded conditions and stresses on fish populations.

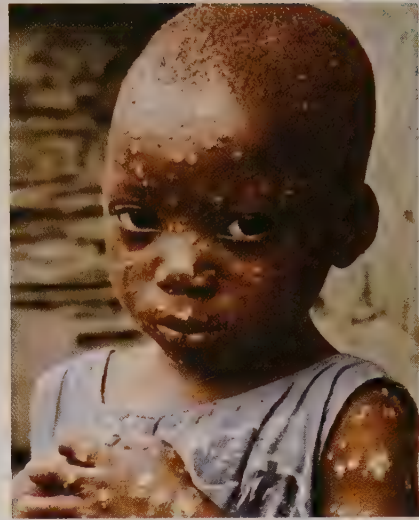
Use the Case Study and graph below to answer Questions 34–38.

CASE STUDY: SMALLPOX

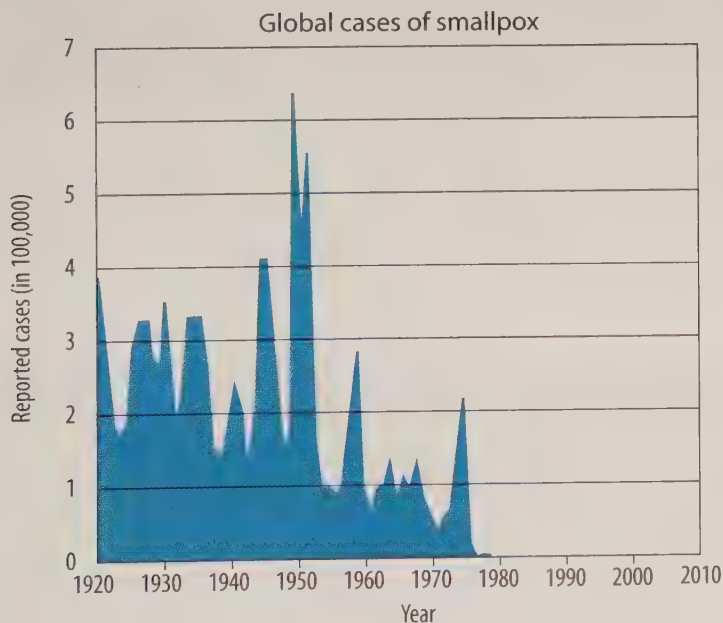
Smallpox has killed people for centuries. Ramses in Egypt, Mozart in Austria, George Washington in the United States, and Joseph Stalin in the Soviet Union all got smallpox in different places and at different times in history.

Smallpox is caused by a virus that attacks the integumentary system and produces blisters. Epidemics of smallpox have swept over Europe, affecting mostly children. Some people who caught smallpox died because no one ever found a cure. Those who lived were immune for life.

But smallpox doesn't kill people anymore. In 1958 the World Health Organization organized a campaign to eliminate smallpox. A key part of this was vaccinations, which have been administered for smallpox for centuries, though safely only for decades. Smallpox is one of the few human diseases to be eliminated worldwide.



34. When was the highest worldwide incidence of smallpox?
35. Relate the answer you gave in Question 34 to the World Health Organization's campaign to exterminate smallpox.
36. Suggest a reason why there were no reported cases of smallpox after 1980.
37. Why don't we vaccinate for smallpox today?
38. How is the development of a safe smallpox vaccine a good application of science?





CHAPTER 21

SUPPORT AND MOVEMENT

THE SKELETAL SYSTEM 425

THE MUSCULAR SYSTEM 420

MAD MOTOR SKILLS

Paraplegics can't walk. At least most can't. But in May 2012, the London Marathon was completed by a paraplegic woman using a ReWalk™ system. The ReWalk system is a battery-powered exoskeleton that straps to the wearer and allows him to walk, stand, sit, and even climb stairs. The user controls the ReWalk through a mix of vocal, posture, and manual cues. Now people who have not been able to walk for years due to spinal injuries are able to walk again as the exoskeleton does the job of the user's bones and muscles. The technology has even been approved by the FDA. The ReWalk system is a great example of using science to help other people.

THE SKELETAL SYSTEM

What is the structure and function of the skeleton?

21.1 THE STRUCTURE OF THE SKELETAL SYSTEM

Claire Lomas, the paraplegic woman who walked the 26.2 mile London Marathon course in 17 days, used her ReWalk exoskeleton to provide her with support that the bones of her legs once provided her. The exoskeleton also took the place of her leg muscles in helping her walk. While both the bones and muscles have multiple functions, their most obvious functions—support and movement—are intimately connected. Knowing how the bones and muscles function enables us to help those among God's image bearers whose bodies do not function properly as a result of a birth defect or injury.



An infant's skeleton contains 270 bones made of flexible **cartilage**, but as the child grows, his bones undergo **ossification**, becoming harder and more rigid, except in a few places such as the nose and ears. As the bones ossify, some of them begin to fuse, so an adult has only around 206 bones, though the exact number may vary slightly from one person to another.

21A Questions

- » What does the skeleton do?
- » What is the skeleton made of?
- » How are bones formed?
- » How are bones connected to each other?

EXPLORING THE HUMAN SKELETAL SYSTEM

● The **axial skeleton** is comprised of 80 bones, including the skull, ribs, sternum, and vertebral column.

● The 126 bones of the **appendicular skeleton** are found in the arms, legs, and pectoral and pelvic girdles.

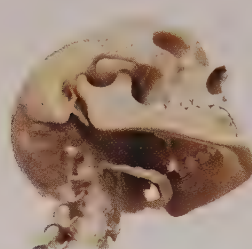
cranium
orbit
zygomatic arch
mandible

clavicle

scapula

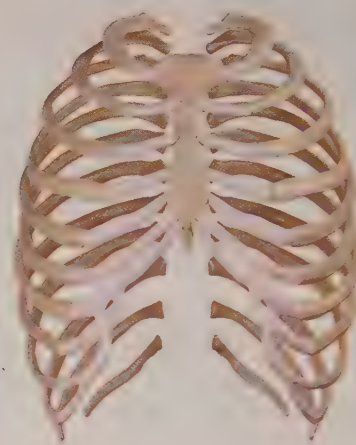
sternum

humerus

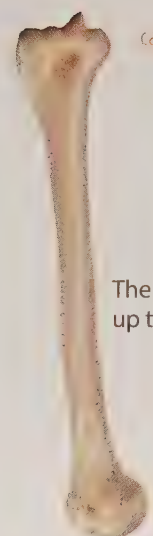


Irregular bones include the jaw bone, the vertebrae, and other bones that have a variety of shapes and do not fit into any of the other categories.

The ribs are some of the *flat bones*.



While most of the cartilage in a child's bones ossifies, some cartilage remains at the very ends of the bones to cushion them where they meet at a **joint**. Strong bands of connective tissue called **ligaments** attach to the **periosteum**, the bone's outer covering, to hold the bones together. A connective tissue sheath called the **joint capsule** covers the ends of the bones forming the joint. The synovial membrane lines the inner surface of the joint cavity and produces *synovial fluid*, which lubricates the joint and absorbs shocks. Synovial membrane tissue is also found in sac-like structures called *bursas*, which are located between moving parts of joints, such as ligaments and bones, and reduce friction between the structures as they move.



The *long bones* make up the arms and legs.

The carpals and tarsals, located in the hands and feet respectively, are good examples of *short bones*.



metacarpal
phalanges



tibia

fibula

tarsals

phalanges

femur

patella

metatarsals

periosteum

ligament

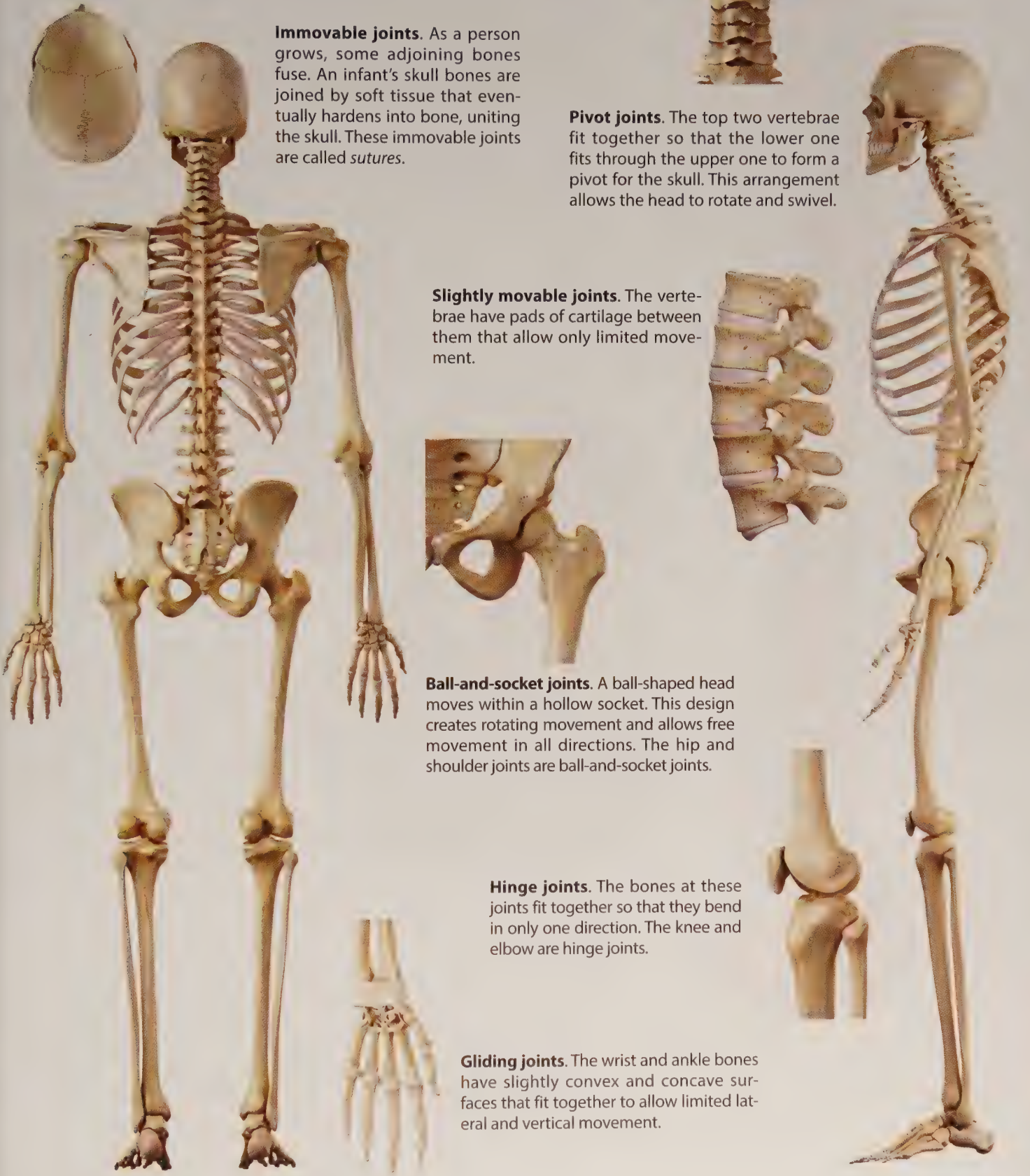
synovial fluid

articular cartilage



EXPLORING JOINTS

Joints are often classified according to how the two bones move in relation to one another. Let's take a look at the different types.



Immovable joints. As a person grows, some adjoining bones fuse. An infant's skull bones are joined by soft tissue that eventually hardens into bone, uniting the skull. These immovable joints are called *sutures*.

Pivot joints. The top two vertebrae fit together so that the lower one fits through the upper one to form a pivot for the skull. This arrangement allows the head to rotate and swivel.

Slightly movable joints. The vertebrae have pads of cartilage between them that allow only limited movement.

Ball-and-socket joints. A ball-shaped head moves within a hollow socket. This design creates rotating movement and allows free movement in all directions. The hip and shoulder joints are ball-and-socket joints.

Hinge joints. The bones at these joints fit together so that they bend in only one direction. The knee and elbow are hinge joints.

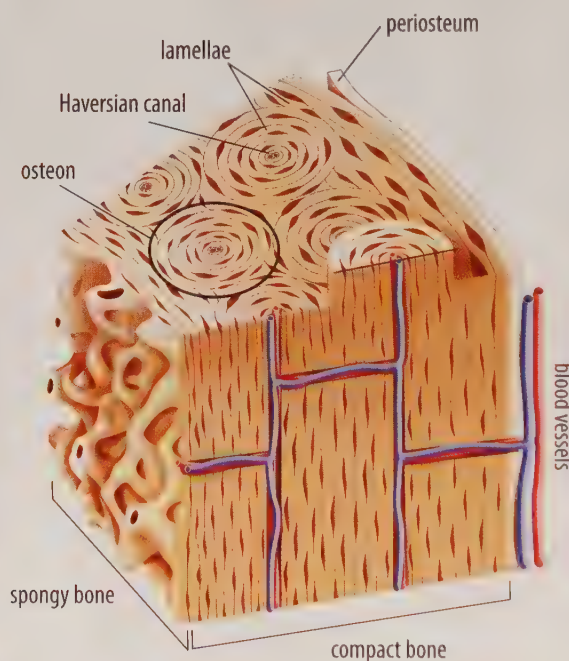
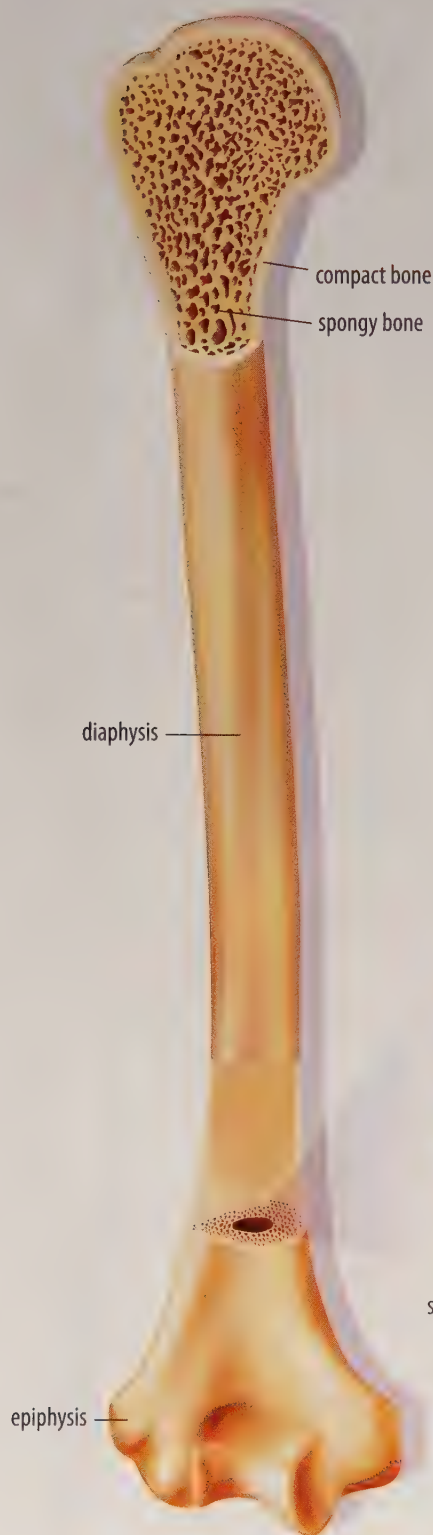
Gliding joints. The wrist and ankle bones have slightly convex and concave surfaces that fit together to allow limited lateral and vertical movement.

21.2 THE FUNCTION OF THE SKELETAL SYSTEM

The sutures in the skull form as a person's skull bones grow together. While we often think of bones as dead, the bones of a living person are living and changing. As you learned in Chapter 20, the cells of connective tissues such as bone are embedded in a matrix that differs from one type of connective tissue to another. In bones, the collagen matrix contains a large amount of calcium salts that make bones hard and strong.

During ossification, cells called **osteoblasts** begin replacing the disintegrating cartilage with **spongy bone**. In spite of its name, spongy bone is not at all soft. In fact it is quite hard and strong. Its name comes from its irregular, pitted appearance.

As some osteoblasts are creating spongy bone to replace cartilage, other osteoblasts located just under the periosteum are laying down **compact bone**. Unlike the irregularly shaped spongy bone, compact bone is organized into circular units called **osteons**. An osteon consists of circular layers of hardened matrix called **lamellae** (le MEL ee; s. lamellum). Bone-forming cells called **osteocytes** live between the lamellae. Blood carrying nourishment to the osteocytes flows through vessels in a tiny passageway called the **Haversian canal** at the very center of the osteon.



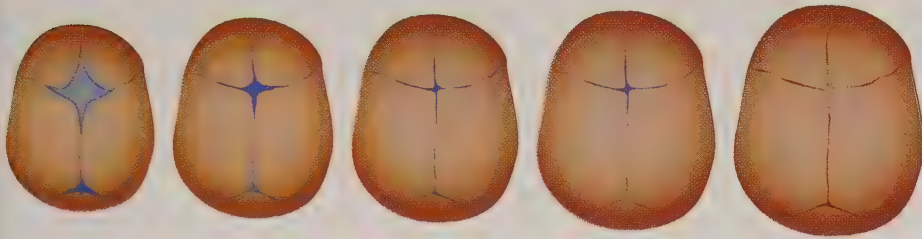
A long bone is divided into the shaft or **diaphysis** and the two ends or **epiphyses** (s. epiphysis). While the diaphysis contains much of the compact bone, the epiphysis remains spongy bone. Bone itself doesn't really grow; instead, a small layer of cartilage called the **growth plate** remains between the diaphysis and each of the two epiphyses. This layer of cartilage continually divides and the older layers are ossified to increase the length of the bone. When a person has reached his full height, the growth plate becomes bone entirely, halting growth.

While the growth plate is increasing the length of the bone, the bone must also increase in diameter. A long, thin bone would be in constant danger of breaking. Cells called **osteoclasts** destroy the inner spongy bone of the diaphysis. Osteoblasts and osteocytes form new compact bone using the material that the osteoclasts release. In fact, bones continue to be in a constant state of remodeling even after a person has finished growing. Bones may develop stress points that

would weaken the entire bone, but osteoclasts remove the bone material to allow osteoblasts and osteoclasts to build new, stronger bone. In fact, bones that constantly undergo stress from exercise become larger, so a runner's femur bones tend to be thicker and stronger than those of the average person.

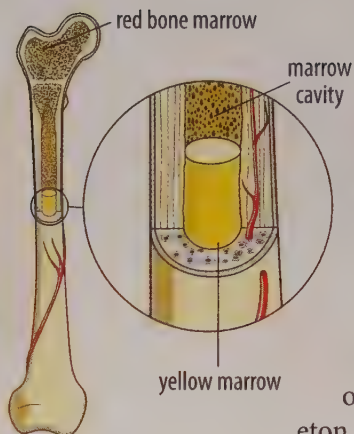
21.3 THE SKELETAL SYSTEM IN THE HUMAN BODY

Skull bones fuse into one structure to form a single plate to protect the brain. In fact, protection is one of the main functions of the skeletal system. Since the central nervous system controls most of the other organ systems, it is essential that it be protected. While the brain is protected by the skull, the spinal cord must run the length of the torso, and so it is protected by being surrounded by the vertebrae. The ribs form a protective cage around the heart and lungs, and the pelvic girdle provides some protection to the intestines and reproductive organs.



The skeleton is also a major storage site for certain minerals that your body needs. As the osteoclasts break down bone material for the osteoblasts and osteocytes to use, some of that material can be removed from the bone altogether if the body needs it. Calcium is especially important to the body since the muscular, nervous, and reproductive systems all use it. The bones store calcium in the form of calcium phosphate, so when calcium is released, so is phosphate. Phosphate forms part of ATP and the nucleic acids, connecting the skeletal system to both cellular respiration and information storage. Moving calcium and phosphate to or from the bones is controlled by hormones from the endocrine system. If a person's diet does not include enough calcium, the body may be forced to remove calcium from the skeletal system, leading to brittle bones that fracture easily. On the other hand, if the calcium in the diet is greater than the body needs, the excess can be stored in the bones until it is needed.

The skeletal system is also connected to the circulatory system. At the center of bones lies the *bone marrow*. At birth, all the bone marrow is *red* bone marrow, which makes red blood cells, platelets, and several types of white blood cells. Eventually, most of the bone marrow in the diaphysis becomes *yellow* bone marrow, which has a high fat content



but still makes some white blood cells. However, some red bone marrow remains in the spongy bone of the epiphyses of long bones and in some of the flat bones. If the body's supply of blood becomes severely depleted, some of the yellow bone marrow can transform back into red bone marrow to increase blood production.

When God made Adam and Eve, He provided them with skeletal systems that performed many roles, but the most obvious function of the skeletal system is support. The skeleton allows humans to stand upright and hold their shape. It also provides a rigid framework for the muscles to attach to, and the bones and muscles together allow the whole body to move.

21A REVIEW QUESTIONS

1. Are long bones found more in the axial skeleton or in the appendicular skeleton? Explain.
2. What two tissues form the outside covering of bones?
3. What long bone connects the scapula to the sternum?
4. Which type of joint are the knuckles? Explain.
5. What types of cells live in compact bone?
6. What type of bone is found in the epiphyses?
7. What type of bone marrow is most common in a 60-year-old man? Explain.
8. How does the skeletal system affect the circulatory system?
9. What essential element is stored in the bones?

21B

THE MUSCULAR SYSTEM

How do the different parts of the muscular system keep the body moving?

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THE STRUCTURE OF THE MUSCULAR SYSTEM

The muscular system is intimately connected with the skeletal system. In fact, without the muscles, the bones wouldn't even hold their position, and we'd all be stuck lying on the ground unable to move. Many muscles connect two or more bones, one of which moves while the others remain essentially stationary. The place on the stationary bone where the muscle attaches is called its *origin*. The muscle's attachment location on the movable bone is called its *insertion*. Practically your entire body is covered with muscles, but you are probably not aware of many of them until you strain one.



21B Questions

- » What kinds of muscles are there?
- » How do muscles move?
- » Why does exercise cause fatigue?

EXPLORING THE HUMAN MUSCULAR SYSTEM

The name of an individual muscle may reflect its size, shape, function, or number of origins.

MUSCLE TYPES



Size

major—large muscle
minor—small muscle
maximus—largest muscle in a region

Shape

deltoid—triangular-shaped muscle
trapezius—trapezoid-shaped muscle
obliques—fibers arranged obliquely (in a slanting direction)

Function

adductor group—adducts (draws in) the thigh

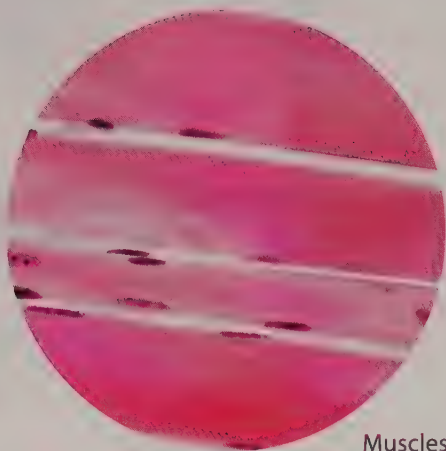
Number of Origins

biceps brachii—has two origins (bi-, two; -ceps, head)

Location

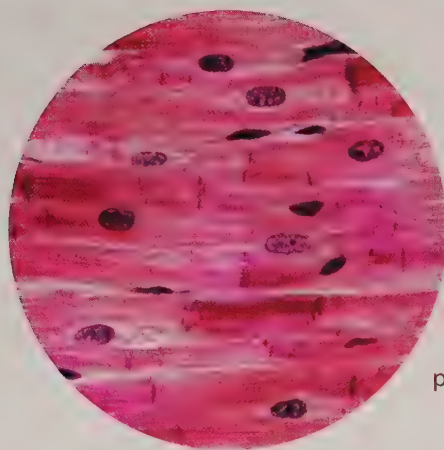
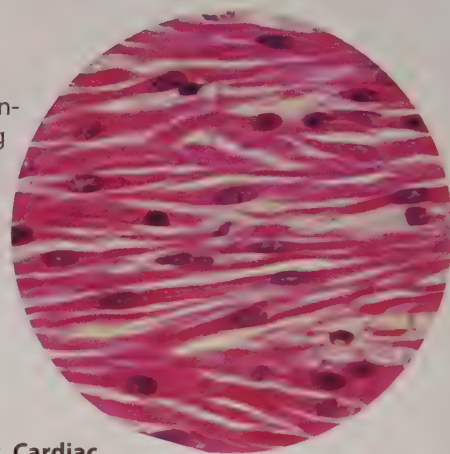
sternocleidomastoid—origin at the sternum and clavicle and insertion at the mastoid process

MUSCLE TYPES



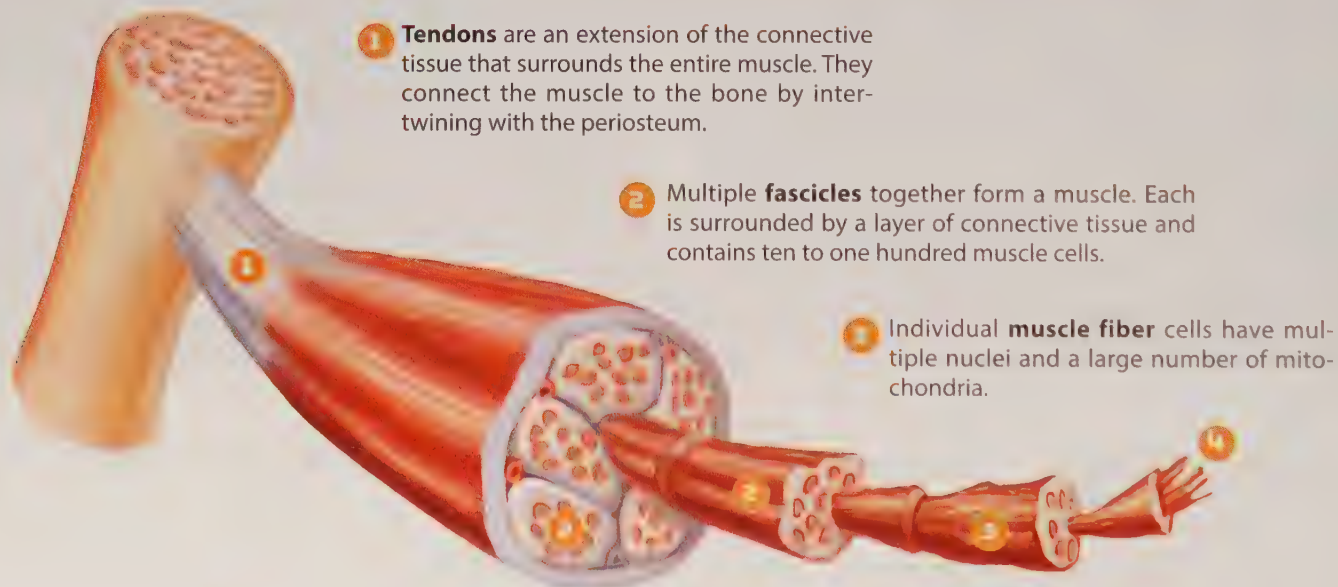
Usually attached to bones, **skeletal muscle** is also called **striated muscle** because of the dark and light stripes in its cells. These striations are filaments of protein in the muscle cells. Skeletal muscle is also known as *voluntary* muscle tissue because it is controlled primarily by conscious thought. You can move your arm by just thinking about it. Your brain sends a signal to the muscles that control your arm, such as the trapezius and the pectoralis major.

Muscles also help move food through your alimentary canal, but you don't have to think about doing these activities. All **smooth muscle** tissue is involuntary—it is not directly controlled by conscious thought. This type of muscle typically forms the walls of internal organs such as the stomach, intestines, blood vessels, and urinary bladder. It is called smooth muscle because it lacks the dark and light stripes of skeletal muscle.



The third type of muscle is found only in the heart. **Cardiac muscle** is both striated like skeletal muscle and involuntary like smooth muscle. However, the striations are not as regular and distinct as those in skeletal muscle. Cardiac muscle fibers branch and join together, allowing nerve impulses to spread quickly through the muscular walls of the heart and produce effective pumping of the blood.

EXPLORING SKELETAL MUSCLE TISSUE



1 Tendons are an extension of the connective tissue that surrounds the entire muscle. They connect the muscle to the bone by intertwining with the periosteum.

2 Multiple **fascicles** together form a muscle. Each is surrounded by a layer of connective tissue and contains ten to one hundred muscle cells.

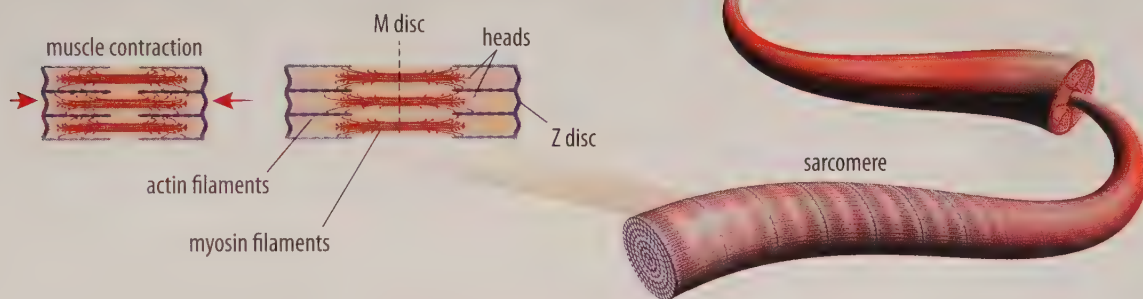
3 Individual **muscle fiber** cells have multiple nuclei and a large number of mitochondria.

4 Tiny threadlike structures called **myofibrils** run parallel to one another down the length of the muscle fiber. Myofibrils are composed of two protein structures—thick filaments made of **myosin** and thin filaments made of **actin**. The repeated overlapping arrangement of these filaments produces the striated appearance of skeletal muscle.

21.5 THE FUNCTION OF THE MUSCULAR SYSTEM

It is the myosin and actin filaments that produce muscle contractions. The individual actin filaments, which look like a strand of twisted beads, are connected at one end by a protein structure called the *Z disc*. The Z discs form the edges of a **sarcomere**, the functional unit of muscle contraction. Actin filaments alternate with myosin filaments so that they partially overlap. The myosin filaments have tiny structures called *heads* that resemble the head of a golf club.

When a nerve impulse reaches the muscle, calcium ions prepare the actin to bind to the myosin. ATP binds to the myosin heads and allows them to bind to the actin filament and bend toward the center of the sarcomere, pulling the actin filaments. The myosin head releases the actin filament and then, with the addition of another ATP molecule, repeats the process. As the myosin filaments pull on the actin filaments, the area where actin and myosin overlap increases, while the sarcomere unit shortens. The myosin filaments in a sarcomere are connected to each other at their midpoints by a protein structure called the *M disc*. The M discs allow the myosin filaments in a sarcomere to act together as a unit.



The contraction caused by myosin filaments pulling actin filaments occurs in multiple sarcomeres in multiple myofibrils in multiple muscle fibers. A strong muscle contraction occurs when many of the fibers in a muscle contract while a more gentle contraction occurs when only a few of the fibers contract. When the nerve impulse ends, the myosin filaments cease pulling on the actin filaments, and the sarcomere returns to its original size.

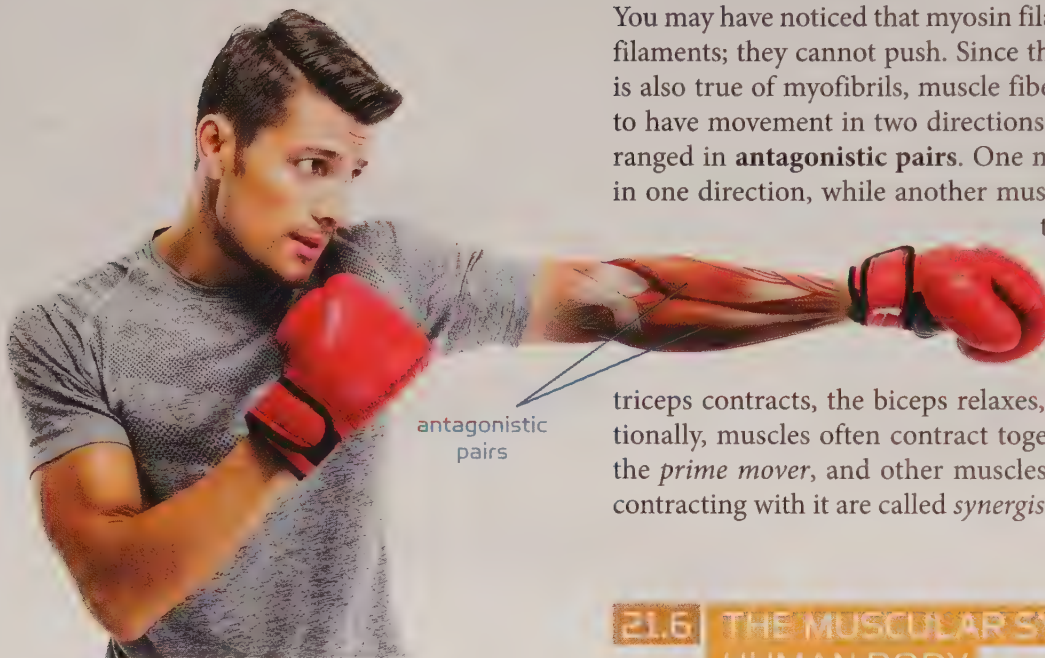
A myosin filament uses a lot of ATP as it pulls on its neighboring actin filaments. Muscle fibers contain a high number of mitochondria to supply the myosin filaments with the ATP they need. As you learned in Chapter 7, normal cellular respiration is an aerobic process; it takes oxygen. When you exercise vigorously, your muscles begin to use more ATP than the mitochondria can supply with the available oxygen. As the available oxygen runs low, your muscle cells begin to perform lactic acid fermentation. The reduction in oxygen in the muscle cells causes you to breathe heavily, a feeling often described as being out of breath.

After a person finishes a strenuous activity, the mitochondria in muscle cells begin to regenerate ATP using the oxygen that is becoming available. The lactic acid that was produced during lactic acid fermentation is carried by the blood to the liver where it is converted into glucose. However, this process takes more ATP, requiring even more oxygen. The additional need for oxygen resulting from strenuous activity is called *oxygen debt*. While exercising does not increase the number of muscle fibers in a person's muscles, it does increase the number of filaments. In other words, a strong person doesn't have more muscle cells; he just has larger muscle cells. Exercising also increases the number of mitochondria in a person's cells so that his muscle fibers can sustain strenuous activity for a longer period of time before they have to switch to fermentation.

You may have noticed that myosin filaments can only pull on the actin filaments; they cannot push. Since this is true of myosin filaments, it is also true of myofibrils, muscle fibers, and whole muscles. In order to have movement in two directions at a hinge joint, muscles are arranged in **antagonistic pairs**. One muscle or group of muscles pulls in one direction, while another muscle or group of muscles pulls in the other direction. For example,

when the biceps brachii contracts, the triceps brachii relaxes, allowing the arm to bend at the elbow. When the

triceps contracts, the biceps relaxes, and the arm straightens. Additionally, muscles often contract together. The main muscle is called the *prime mover*, and other muscles that assist the prime mover by contracting with it are called *synergists*.



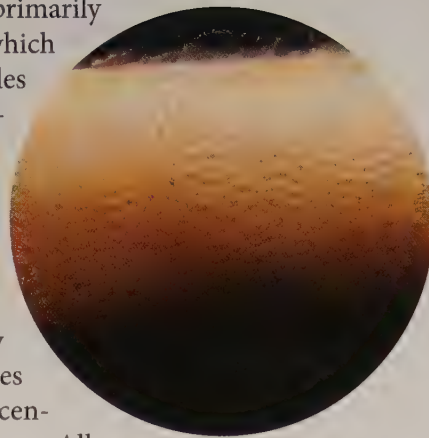
21.6 THE MUSCULAR SYSTEM IN THE HUMAN BODY

Like any system of the body, the muscular system interacts with the other systems in order to function properly. Without the respiratory system, the muscles would not have the supply of oxygen they need. Without the digestive system, they would not have a supply of glucose to make ATP. On the other hand, the respiratory system would not be nearly as effective without the diaphragm. This muscle pushes down on the organs in the abdominal cavity and allows the lungs to expand, drawing in air. Thus a muscle aids the respiratory system in obtaining oxygen for the muscles and all the other cells of the body.

The hardest working muscle in the body is the heart. During an average person's lifetime, his heart may beat several billion times, pumping blood through all the blood vessels of the body and carrying nutrients and oxygen to all the cells of the body in addition to removing their metabolic wastes.

Muscles are also involved with the integumentary system, primarily in reaction to cold. Muscles in the skin cause shivering, which generates heat. Other tiny muscles called *arrector pili* muscles are attached to hair follicles and contract, causing goosebumps to form on the skin. When this occurs, the hair from the follicle stands erect, holding a layer of air next to your body, creating an additional degree of insulation.

The muscles are also dependent on the nervous system to function properly. Claire Lomas, who completed the London Marathon in the ReWalk exoskeleton, was crippled by a spinal cord injury in a riding accident. Although her bones and muscles were not directly affected, the injury to her central nervous system limits her skeletal and muscular systems. All the systems of the body work together, so if one is severely damaged, the rest are affected. By understanding how the skeletal and muscles systems work, people in multiple areas of science and medicine are making devices such as the ReWalk exoskeleton possible. As a result, people who have been crippled for years may be able to walk, and quality of life is improving for God's image bearers.



21B REVIEW QUESTIONS

1. Judging from their names, which do you think is larger, the teres major or the teres minor?
2. Identify each muscle as skeletal, smooth, or cardiac muscle.
 - a. wall of the right atrium
 - b. soleus
 - c. pyloric sphincter between the stomach and small intestine
3. Arrange the following from largest to smallest: muscle fiber, muscle, myosin filament, fascicle, myofibril.
4. One end of which type of filament is attached to the structure at the edge of the sarcomere? Explain.
5. What myofibril structure contains heads?
6. If the amount of oxygen available to muscle cells runs low, what substance is produced as an indirect result of ATP production?
7. What systems of the body does the muscular system rely on for oxygen and glucose to make ATP?
8. How can a Christian use knowledge of the skeletal and muscular systems to help others?

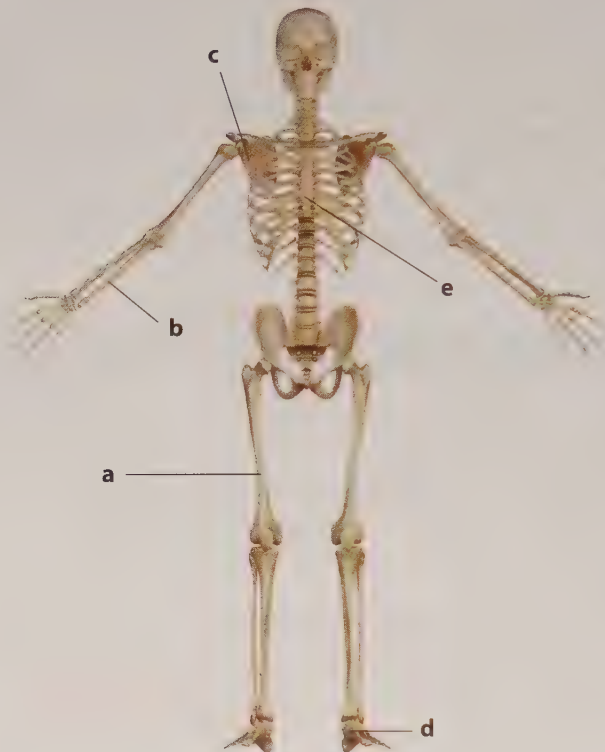
REVIEW QUESTIONS

T Key Terms	
cartilage	415
ossification	415
axial skeleton	416
appendicular skeleton	416
joint	416
ligament	416
periosteum	416
osteoblast	418
spongy bone	418
compact bone	418
osteon	418
osteocyte	418
Haversian canal	418
growth plate	418
osteoclast	418
skeletal muscle	422
striated muscle	422
smooth muscle	422
cardiac muscle	422
tendon	422
fascicle	422
muscle fiber	422
myofibril	422
myosin	422
actin	422
sarcomere	423
antagonistic pair	424

CONCEPT REVIEW

1. Which of the two main divisions of the human skeleton protects many of the vital organs? Explain.

Use the image below to answer Questions 2–4.



2. Write the label of the ulna.
3. What bones are labeled *d*?
4. What is the name of the only labeled bone that is part of the axial skeleton?
5. What type of joint connects the femur to the pelvis?
6. Explain the role of cartilage in a joint.
7. Explain the role of ligaments in a joint.
8. What type of cells dissolve bone as part of the remodeling process?
9. In which section of a bone would you expect to find osteons? Explain.
10. What two types of bones typically contain some red bone marrow in an adult?
11. The biceps brachii muscle connects the scapula and the radius. Which of these two bones is the insertion of the biceps? Explain.

Use the diagram below to answer Questions 12–15.



12. Write the label of the pectoralis major muscle.
13. What muscle is labeled *a*?
14. What muscle is labeled *c*?
15. What muscle is labeled *d*?
16. How many origins does the quadriceps have?
17. What structure connects muscle to bone?
18. Under what conditions do muscle cells produce lactic acid?
19. Which structure of the myofibril binds to ATP?
20. What determines the strength of a muscle contraction?

TRUE OR FALSE

21. Spongy bone is relatively soft and bendable.
22. The skeletal system stores calcium in the body.
23. The left ventricle of the heart is made of smooth muscle.
24. Fascicles are divided by M discs.
25. A synergist is one of two muscles in an antagonistic pair.

CRITICAL THINKING

CASE STUDY: BONE DENSITY

Your bones are permanently in remodeling mode. Osteoblasts and osteocytes continuously build bone while osteoclasts continuously dissolve it. This remodeling is necessary for healthy bones, and as long as the two processes balance each other, all is well. However, many older people, especially women, experience *osteoporosis*, the result of osteoclasts dissolving bone faster than it can be built. Many people do not even know they have it until a bone breaks as a result of a minor injury. In many cases, the femur breaks, usually in the epiphysis that forms a joint with the pelvis.

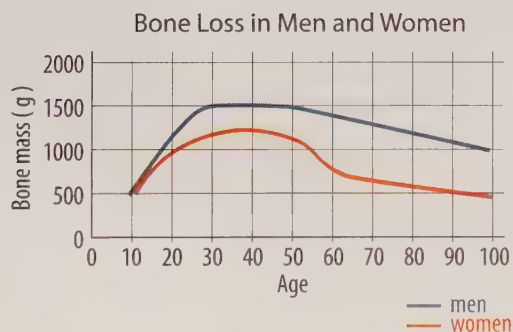
Astronauts experience similar loss of bone density in space because the microgravity environment doesn't put enough stress on their bones to encourage osteoblasts and osteocytes to continue building bone. So the International Space Station (ISS) is a perfect place to test potential treatments for osteoporosis.

Exercise is a major guard against loss of bone density, but it has its limits. It is most effective on Earth when a person has exercised all his life. In space, exercise can only slow bone loss; it cannot stop it. In addition to regular exercise, some osteoporosis sufferers need medication and a balanced diet high in calcium and vitamin D, a vitamin that helps the body absorb calcium.



Use the Case Study above to answer Questions 26–29.

26. The most common medication used to treat osteoporosis is *bisphosphonate*. Astronauts aboard the ISS have also benefited from this medicine. It works by stopping osteoclasts from dissolving bone. How does this slow bone loss?
27. A rare side effect of bisphosphonates is a break in the diaphysis of a femur. Given what you know about the role of osteoclasts, why might this occur?
28. Osteoporosis-related fractures occur in 33% of women over the age of 50 but in only 20% of men of the same age. This disparity is the result of a drop in hormone levels that occurs in women around age 50. Using the graph on the left, determine the other reason that osteoporosis occurs more in women than in men.
29. Would women astronauts, most of whom are under age 50, likely experience a higher rate of bone loss in space than male astronauts? Explain.
30. Claire Lomas can't walk because of a spinal cord injury. Injuries to the spinal cord are difficult to treat because nerve cells do not regrow the way bones and muscles do. A lot of research is being done to find ways to trick the spinal cord into healing itself. While such long-term solutions are being researched, shorter-term solutions such as the ReWalk are being developed. Both take a lot of research money to develop. What is the balance between developing both short- and long-term solutions?





CHAPTER 22

TRANSPORT

22A THE RESPIRATORY SYSTEM 430

22B THE CIRCULATORY SYSTEM 434

THE AIR UP THERE

A group of tourists gathers in the crowded airport of Kathmandu, Nepal. They are from all over the world, but they have one mission: to climb Mount Everest. Just getting to base camp is a challenge—they will hike for one to two weeks just to reach that goal—let alone the summit. Why so much time, when they flew to Nepal in a day or less? It's because of Everest's elevation.

Mount Everest base camp is at an elevation of 17,600 feet, higher than most of the tallest mountains in North America. The human body has to gradually adjust, or *acclimatize*, to air that is thinner. It is 20% oxygen, just like the air at sea level—there is just less of it up there. Nobody can live permanently above 20,000 feet, and most people need supplemental oxygen to climb Mount Everest. If hikers ascend to base camp too quickly, they can develop possibly fatal altitude sickness that causes the brain and lungs to swell. In fact, if a person were instantaneously brought from sea level to the summit of Everest, he could lose consciousness and die within minutes.

22A Questions

- » What are the parts of the respiratory system?
- » How does oxygen get from the air to the blood?
- » How does breathing work?
- » How does the respiratory system work with the rest of the body?

Pretend you're hitching a ride on an oxygen molecule in the air. You get sucked in through someone's nose (yuk!) into their **nasal cavity** ①. This hollow area in the head, lined with epithelial tissue, has sensory receptors that enable a person to smell. The air is warmed, moisturized by mucus, and filtered by hairs before it goes any farther.

THE RESPIRATORY SYSTEM

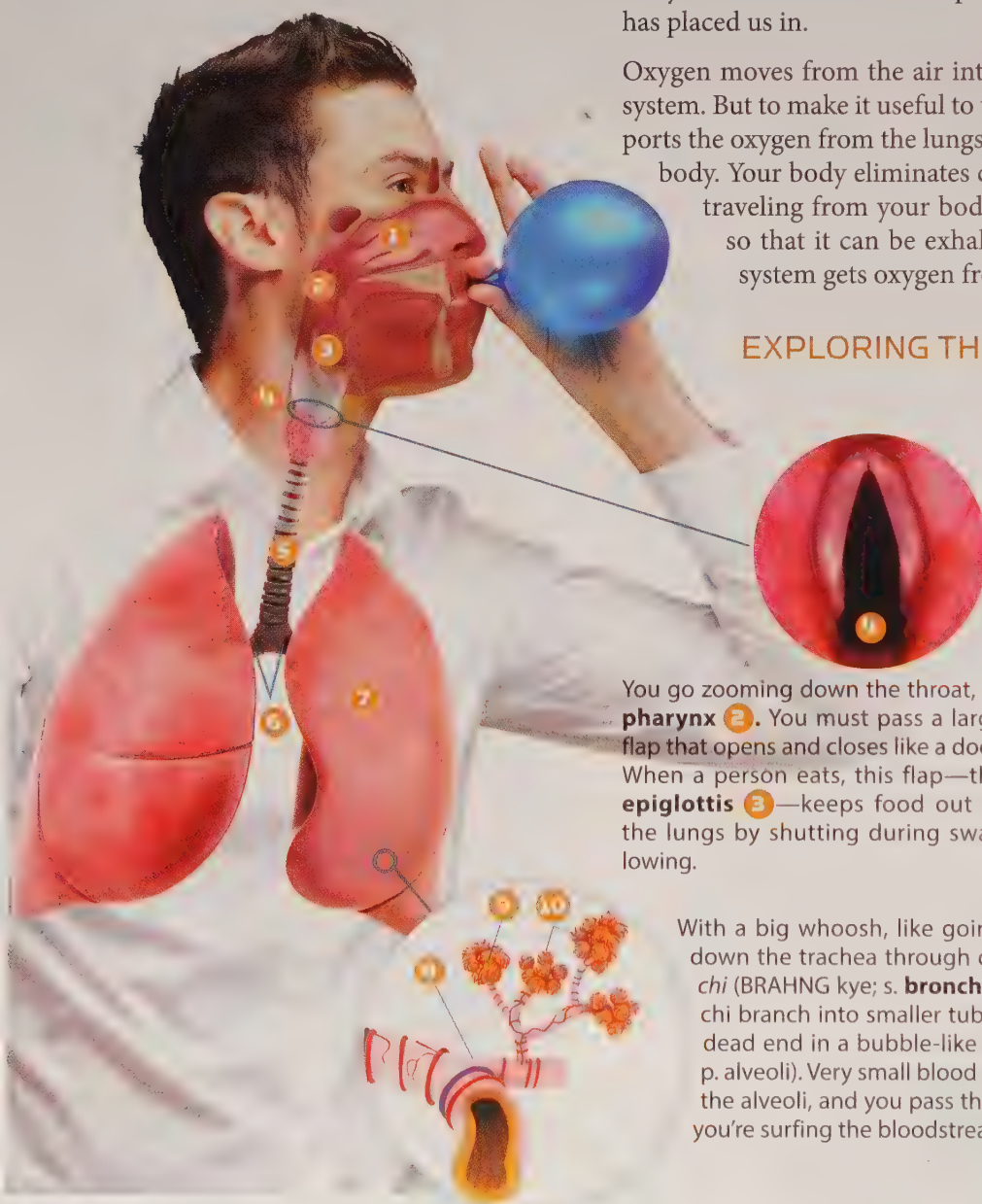
How does the body get oxygen and eliminate carbon dioxide?

22.1 THE STRUCTURE OF THE RESPIRATORY SYSTEM

Everyone knows that people need to breathe, but do you know why? As we learned about cell processes in Chapter 7, cells need to get oxygen and the body needs to eliminate carbon dioxide in order to get energy from food through cellular respiration. Just as the well-being of people who climb Mount Everest is affected by their ability to obtain sufficient oxygen (see Chapter opener), the health of individual cells in the body is likewise affected. By understanding the human body, we are better able to explore and wisely use the world that God has placed us in.

Oxygen moves from the air into your lungs through the respiratory system. But to make it useful to the body, the circulatory system transports the oxygen from the lungs into the blood to carry it to the entire body. Your body eliminates carbon dioxide by the reverse process, traveling from your body to the blood, and then to the lungs so that it can be exhaled. Let's explore how the respiratory system gets oxygen from the air into your lungs.

EXPLORING THE RESPIRATORY SYSTEM



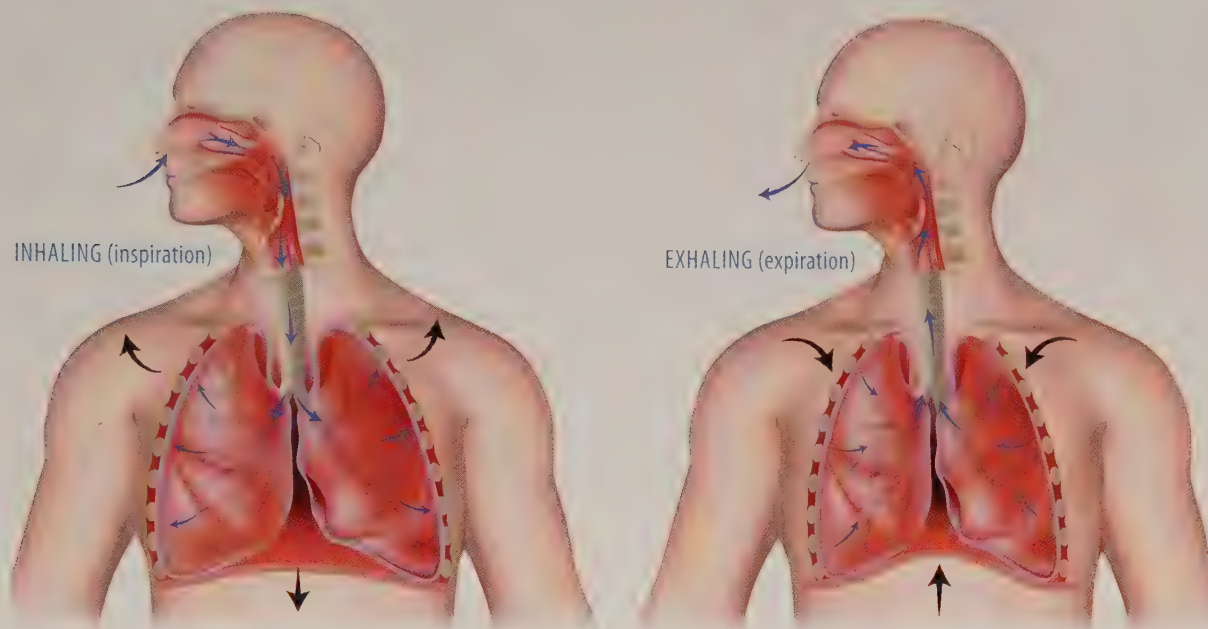
You go zooming down the throat, or **pharynx** ②. You must pass a large flap that opens and closes like a door. When a person eats, this flap—the **epiglottis** ③—keeps food out of the lungs by shutting during swallowing.

After passing the epiglottis, you go through a pair of flaps into the **larynx** ④, or voice box. When a person speaks or sings, air travels over these flaps (called **vocal folds**) to produce sound, like a bow on the strings of a violin. Then you move into the **trachea** ⑤, or wind-pipe, which filters and moisturizes the air one last time with cilia and mucus before the air enters the lungs. Cartilage gives flexible support to the trachea and epiglottis in the respiratory system.

With a big whoosh, like going downhill on a rollercoaster, you pass down the trachea through one of two branching tubes, called **bronchi** (BRAHNG kye; s. **bronchus**) ⑥, into the **lungs** ⑦. Then the bronchi branch into smaller tubes called **bronchioles** ⑧. You come to a dead end in a bubble-like sac called an **alveolus** ⑨ (al VEE uh lus; p. alveoli). Very small blood vessels called **capillaries** ⑩ wind around the alveoli, and you pass through the alveoli into the capillaries. Now you're surfing the bloodstream!

22.2 THE FUNCTION OF THE RESPIRATORY SYSTEM

Now, how do all those organs of the respiratory system work together to help you breathe? There are two phases of breathing—inhaling, or *inspiration*, and exhaling, or *expiration*.



When you breathe in (inspiration), a muscle under the lungs—the **diaphragm**—contracts, moves down, and becomes flatter. At the same time, muscles between your ribs contract to increase the volume in your chest cavity. The air pressure in your lungs becomes less than the pressure outside your body, and air rushes through the nasal cavity, pharynx, and trachea down into the lungs. It's similar to what happens when you use a syringe to siphon a liquid.

The opposite process happens when you breathe out (expiration). The diaphragm and the muscles between the ribs relax, reducing the volume in your chest cavity. This causes the air pressure in your lungs to become greater than the pressure outside your body, forcing air out of your lungs.

When you breathe in and out normally, your body takes in and gives out about 0.5 L of air. But when you take in a really deep breath, like when you're getting ready to dive into the deep section of a pool, you breathe in as much as 3 L of air. When you deliberately and forcefully breathe out, you can release about 1 L of air. Adding up all these numbers gives us about 4.5 L, the measure of a person's **lung capacity**.

Most people have a lung capacity of about 4.5 L, but people with lung disease or lung problems like asthma, which constricts the bronchioles, have a smaller lung capacity. On the other hand, people who are healthy and exercise regularly can have a greater lung capacity. A few climbers on Mount Everest with unusually large lung capacities have been able to summit Everest without supplemental oxygen.



22.1

In 1978, Reinhold Messner (above) and Peter Habeler were the first people to reach the summit of Everest without bottled oxygen. Messner later wrote, "I am nothing more than a single narrow gasping lung, floating over the mists and summits."

22.3 THE RESPIRATORY SYSTEM IN THE HUMAN BODY

OXYGEN EXCHANGE

So air gets into the lungs and somehow it transfers from the alveoli to the capillaries that wrap around them. The only reason oxygen leaves the air and enters the lungs and bloodstream is because there is more oxygen in the air and less in us! It's a matter of diffusion from a high to a low concentration.

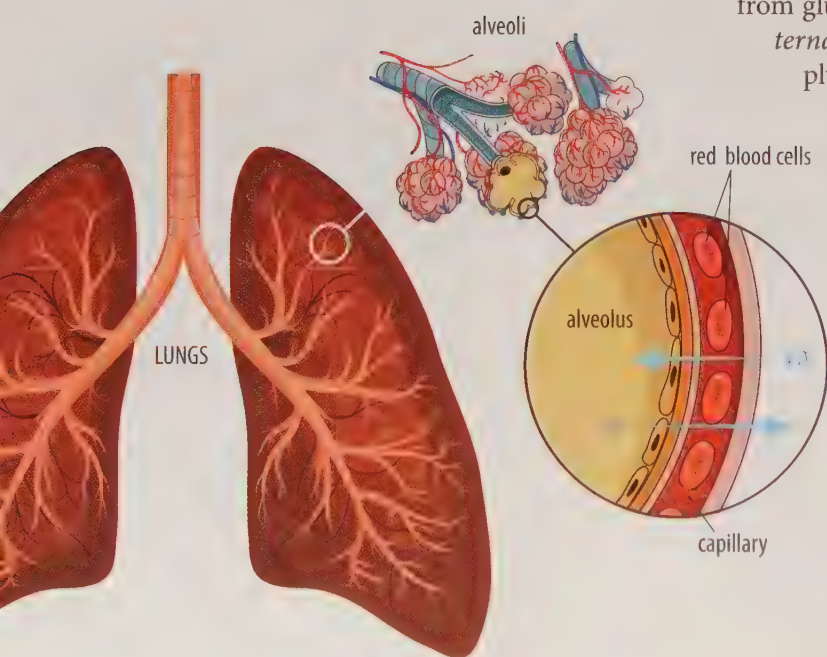
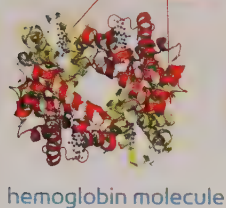
But how are oxygen and carbon dioxide transported in the body? Do they travel as tiny bubbles alongside blood cells? Actually, gases in the blood are either dissolved in or chemically combined with blood substances. Almost all the oxygen in the blood (98%) is combined with **hemoglobin**, the oxygen-carrying protein found in red blood cells. Hemoglobin is what makes blood bright red—this protein has iron in it, which binds with the oxygen to form *oxyhemoglobin*. Blood that carries oxygen is called *oxygenated blood*.

To move oxygen to the rest of the body, the respiratory system relies on the circulatory system. Oxygen (O_2) diffuses through the walls of the alveoli. Red blood cells carry oxyhemoglobin through the capillaries, which provide tissues with blood. In these capillaries, oxygen leaves the oxyhemoglobin to go to the body cells because there is a greater concentration of oxygen in the blood cells than in the cells of the body. The blood absorbs carbon dioxide (CO_2) produced by cellular respiration for the same reason. Hemoglobin can carry carbon dioxide as well, even carrying it at the same time as oxygen since these two molecules have different bonding sites on hemoglobin. However, hemoglobin holds carbon dioxide with a stronger bond than it holds oxygen.

So oxygen goes through the respiratory system, to the bloodstream, and then to the heart, which pumps the blood through vessels to cells in tissues. The body uses the oxygen in tissues to release energy from glucose. This shows the three stages of respiration—*external respiration* (inhaling air), *internal respiration* (supplying cells with oxygen), and *cellular respiration* (using oxygen to produce energy from glucose). Many body systems team up with the respiratory system to make this happen, especially the muscular and circulatory systems.

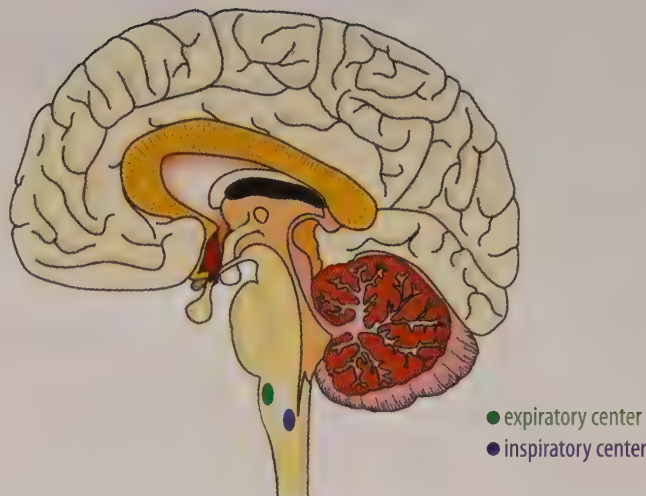
CONTROL OF BREATHING

But what controls this whole process? You think about breathing when you speak, sing, or swim. But what about when you're sleeping? The nervous system takes over in response to different chemicals produced by the body and environmental stimuli to control breathing.



The nerve cells in the part of the brain that controls breathing make up what is called the *respiratory center*. It monitors the level of carbon dioxide in the blood by keeping an eye on the blood's pH, which is affected by both dissolved oxygen and dissolved carbon dioxide. When too much carbon dioxide builds up in the blood, it stimulates the muscles involved in breathing to speed up and increase the respiration rate to raise oxygen and lower carbon dioxide in the blood. This can happen when you exercise or when you climb to Mount Everest base camp! This is another feedback mechanism for maintaining homeostasis in your body. The lungs can respond to these signals by expanding alveoli to increase oxygen in the blood and by involving more alveoli to exchange gases with the blood.

When climbers traveling to Mount Everest base camp acclimatize, their bodies get used to a different atmospheric pressure. This involves helping their brains to adjust how deeply they breathe and to determine how many alveoli are involved in gas exchange. These changes affect how much oxyhemoglobin is in the blood and how quickly blood circulates. More red blood cells carry oxygen and pass more rapidly through the blood vessels. Almost makes you want to climb a mountain!



22A REVIEW QUESTIONS

1. Which kind of tissue—nervous, connective, epithelial, or muscular—lines the nasal cavity, pharynx, larynx, and bronchioles? Suggest the primary purpose of this tissue.
2. On the basis of what you know about tissue types, what kind of tissue is the cartilage in the respiratory system? (*Hint:* See Chapter 20.)
3. Give five examples of organs in the respiratory system and indicate the function of each.
4. Study the diagram on page 430. Suggest why people cough and sneeze and describe how this works.
5. What happens when you breathe in and out?
6. List two factors that can affect a person's lung capacity.
7. Suggest why the quality of air that a person breathes—eroded by pollution and smoking—affects his overall health.
8. Through what process does oxygen leave the lungs and enter the bloodstream?
9. British mountaineer George Mallory died during a 1924 attempt to climb Mount Everest. When asked why he wanted to climb Everest, Mallory responded, "Because it's there." From a biblical worldview, justify exploration like this, considering the risks.



22-2

The most polluted cities in the world are in China. Air that has been polluted by industry may be wreaking havoc on the country's health, especially causing lung cancer—the deadliest cancer known to man.

22B Questions

- » What are the parts of the circulatory system?
- » What does blood do?
- » How is blood flow in an artery different from that in a vein?
- » How does the heart pump blood?
- » How does the circulatory system work with other organ systems?

THE CIRCULATORY SYSTEM

How does the circulatory system repair the body and supply it with oxygen and nutrients?

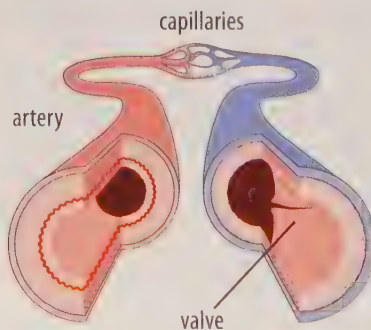
224 THE STRUCTURE OF THE CIRCULATORY SYSTEM

There's an interstate system in your body, with taxis, police cars, and, yes, even traffic jams! That interstate system is your circulatory system. This organ system works with the others in your body to transport nutrients to just the right places to keep you up and going.

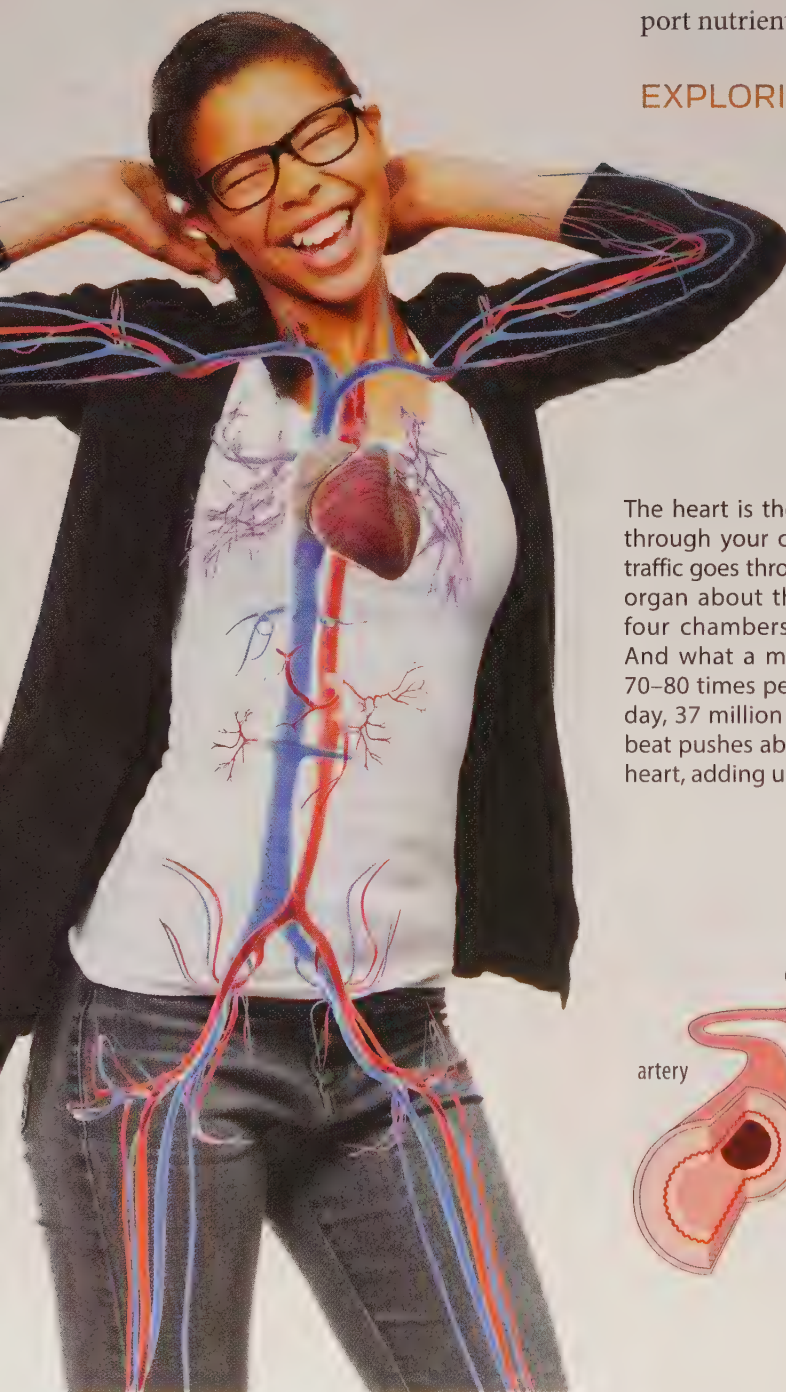
EXPLORING THE CIRCULATORY SYSTEM

When you think of the circulatory system you probably think of blood, the current of travelers on your body's internal interstate system. **Blood** is the marvelous red river that transports oxygen, nutrients, and hormones to all body cells and helps in removing waste products from the body. A healthy adult has almost 5 L of blood. You can lose about a quarter of your blood without any serious problems.

The heart is the muscle that pumps blood through your circulatory system. All blood traffic goes through the heart. It is a hollow organ about the size of your fist and has four chambers made of muscular tissue. And what a muscle! Your heart contracts 70–80 times per minute, 100,000 times per day, 37 million times per year. Every heart-beat pushes about 80 mL of blood from the heart, adding up to about 8000 L per day.



The “roads” in your circulatory system are blood vessels, and there are three kinds—arteries, veins, and capillaries. **Arteries** carry blood away from the heart, **veins** carry blood toward the heart, and capillaries connect the two. Veins have flaps called **valves** that act like double doors that open only one way to regulate flow to the heart. Valves in the veins open when muscles around them contract. Nearly every cell in your body is located next to a capillary so that cells can exchange nutrients, oxygen, and waste products with your blood.

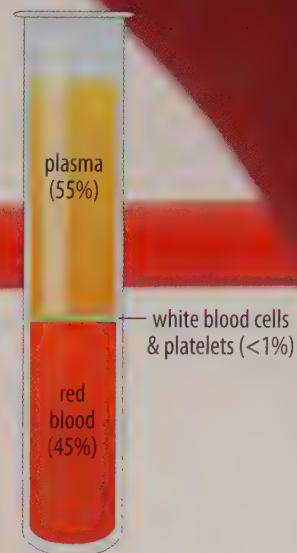


22.5 THE FUNCTION OF THE CIRCULATORY SYSTEM

Now that you know the basic organs of the circulatory system, let's look at each of these parts in depth and see what they do to move substances around in your body. Let's start by taking a close look at blood.

EXPLORING BLOOD

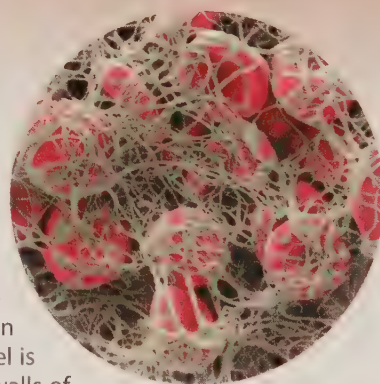
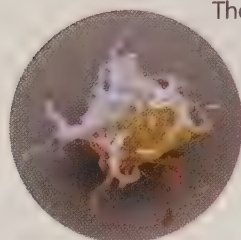
In Chapter 20, we learned that **plasma** is a yellow fluid that makes up the highest percentage of blood. It is 90% water and is almost identical to lymph. The remaining 10% is made of proteins, dissolved gases, minerals, vitamins, nutrients, hormones, and waste substances. The components of plasma can change after you've finished a big meal or drank a lot of water.



Leukocytes, or white blood cells, are the policemen of your internal interstate system. Lymphocytes like T cells and B cells are types of leukocytes, and they are about twice as big as erythrocytes. They migrate from the lymphatic system to rid the body of antigens through phagocytosis. In a healthy person, you will find about 1 leukocyte to every 600 erythrocytes in blood. When a person has an infection, a blood sample will show that they have a greater ratio of leukocytes to erythrocytes.

Though plasma is yellow, your blood, of course, is red! The interaction between the iron in hemoglobin and oxygen that binds to it makes blood red. Red blood cells, or **erythrocytes**, aren't really cells at all; they are disc-shaped molecules that hold hemoglobin. This shape gives them a greater surface area to do their job—carrying oxygen. Erythrocytes are the most common component in blood besides plasma. If your circulatory system is like an internal interstate system, erythrocytes are the taxicabs that deliver hemoglobin and oxygen.

The last and smallest of the components in blood are **platelets**, or **thrombocytes** (left). Platelets are cell fragments that lack a nucleus and are less than half the size of an erythrocyte. When you get a cut or bruise, broken blood vessels must be sealed to prevent blood loss. Platelets clump together in a complex process with several feedback mechanisms to form a *clot* (right) with a microscopic mesh that entangles red blood cells. This process is called **coagulation**, and it can happen in as quickly as a few minutes! If the injury to the blood vessel is minor, the platelets release a chemical that makes the smooth muscle walls of the blood vessels clamp down to stop blood loss.



Now let's consider the muscle that pumps this blood. The *heart* has several parts and pieces that work together, using two different loops, to keep blood moving to both your lungs and the rest of your body.

THE HEART

The heart is made of muscular tissue. The thickest part of the heart wall is called the *myocardium* **1**. It contracts to pump blood.

The **septum** **2** is the muscular wall that separates the heart into a right and left side. The sides of the heart are based on the orientation of the person. The left side of the heart is on the left side of the body, i.e., the right side to an observer.

The heart has four chambers, or rooms. The top two small chambers are called *atria* (s. **atrium**) **3** and **4**. The bottom two larger chambers are called **ventricles** **5** and **6**.

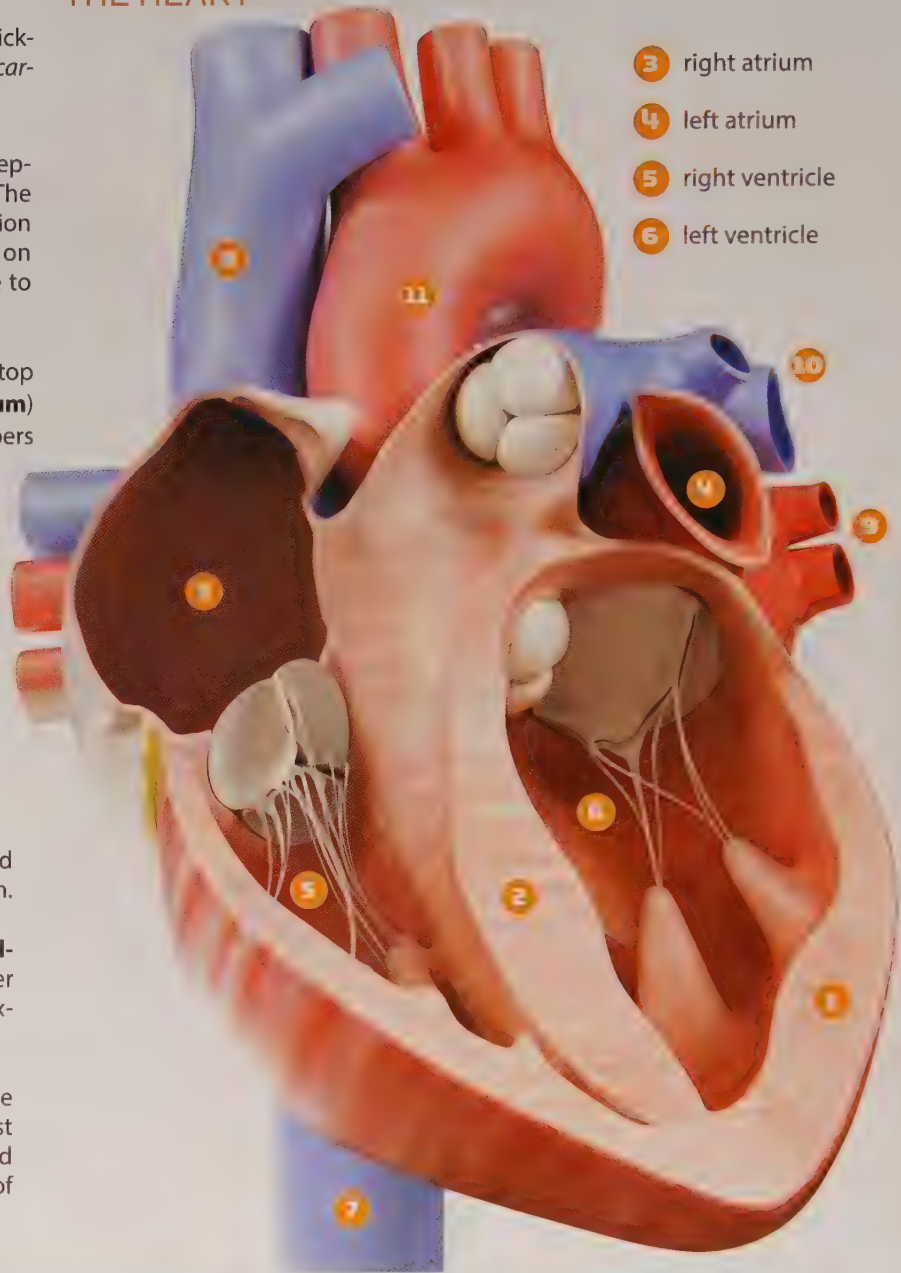
Blood enters the heart in several places. Oxygen-depleted blood (called *deoxygenated blood*) from the lower body enters the right atrium of the heart through the **inferior vena cava** **7**.

Deoxygenated blood from the upper body above the diaphragm enters the right atrium of the heart through the **superior vena cava** **8**.

Pulmonary veins **9** deliver oxygenated blood to the heart, entering at the left atrium.

Blood also leaves the heart through the **pulmonary arteries** **10**. These arteries deliver deoxygenated blood to the lungs to exchange carbon dioxide for oxygen.

Oxygenated blood leaves the left ventricle through the **aorta** **11**, one of the strongest arteries in the body. It arches around and forks to provide the upper and lower parts of the body with blood.



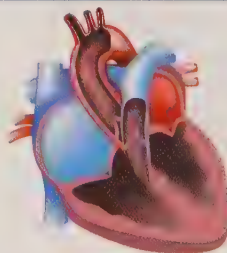
- 3** right atrium
- 4** left atrium
- 5** right ventricle
- 6** left ventricle

IN A HEARTBEAT

What happens in a heartbeat? There are two parts to a heartbeat, or a *cardiac cycle*. The heart muscle goes through one complete contraction and one complete relaxation cycle. Both sides of your heart are working at the same time to relax and contract. And your heart does this about 70–80 times per minute!

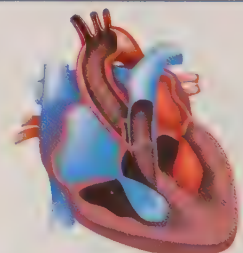
1

The heart relaxes, and deoxygenated blood flows from the body through the vena cava into the right atrium. Oxygenated blood flows from the pulmonary veins into the left atrium.

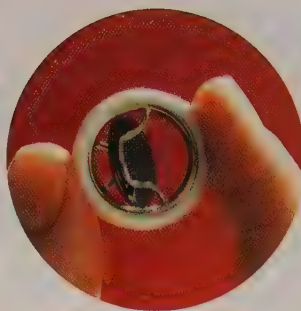


2

A nerve pulse at the right atrium activates the heart into contracting. This nerve pulse, your natural pacemaker, sets the pace for how fast your heart beats.



Valves regulate blood flow through the heart. There are valves between the atria and ventricles and at the major arteries that connect to the heart. The “flub-dub” sounds of the heart are caused by closing valves. Heart valves don’t move by themselves—they move in response to the flow of blood. Here you can see an artificial valve that will be used to replace a diseased valve in the aorta of a human patient.



HEART ATTACK!

Kevin Murphy was working his job in the seafood department at a local grocery store in Long Hill, New Jersey, when he collapsed with a sudden heart attack. The store manager rushed to his side. A police officer who just happened to be at the store came running to the scene. The two began to do CPR (cardio-pulmonary resuscitation) and use an AED (automated external defibrillator) to resuscitate Kevin, who had stopped breathing and had turned blue. Quick intervention saved his life!

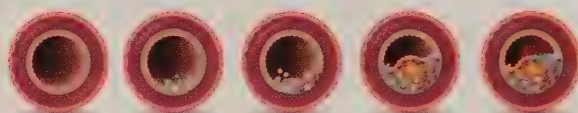
Each year, over 745,000 Americans have a heart attack, and over 610,000 die because of heart disease. Heart attacks happen when part of the heart muscle is damaged because a blood vessel supplying oxygen to that part of the muscle is blocked. An AED delivers an electric shock to a person suffering a heart attack, jolting the heart back into rhythm. These devices are stationed in many public places to help people who have sudden heart problems.



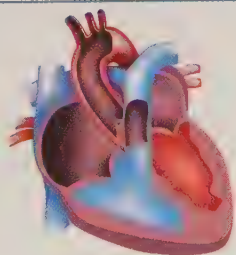
Both men and women can have heart attacks, though the symptoms are different for each. It’s very important to treat a person early if they are suspected of having a heart attack. A timely response can save a life, like it did for Kevin.

How can you make healthy choices now to avoid heart disease? Smoking is a major contributor to heart disease, affecting both the circulatory and respiratory systems. Choosing not to smoke is one of the most effective ways to reduce your risk of heart disease.

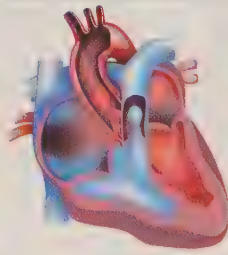
But there are other ways to reduce your risk. If you don’t exercise, then get moving! Any physical activity such as walking can significantly reduce your risk of heart disease. Do some research to see what kinds of diet changes you should make. However, take care of your body not just for yourself. Remember your friends and family, and glorify the Lord with the way that you use the body He gave you.



You may think of plaque being something on your teeth, but it can build up in your arteries if you have a genetic disposition for heart problems or when you don’t eat right, eventually causing a heart attack.



The left and right atria contract first, sending oxygenated blood into the left ventricle and deoxygenated blood into the right ventricle, respectively. About 0.1 s later, the impulse reaches the ventricles after they have filled with blood.

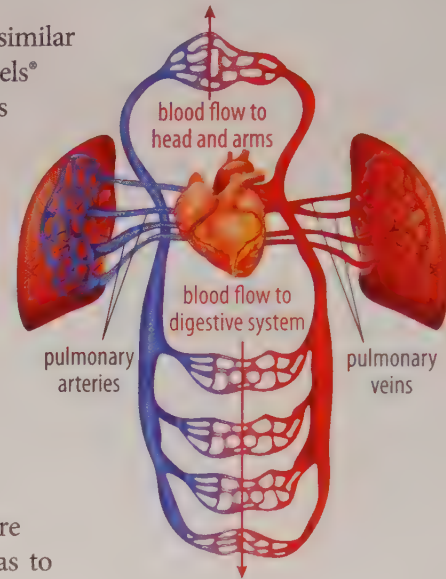


Oxygenated blood is squeezed out of the left ventricle into the aorta to supply the body with oxygenated blood. Deoxygenated blood is squeezed out of the right ventricle into the pulmonary arteries to take on oxygen from the lungs.

22.6 THE CIRCULATORY SYSTEM IN THE HUMAN BODY

We've seen what happens when the heart beats. But where does the blood go? There are a whole lot of organs in the body that need nutrients and oxygen from the blood!

Your heart is the hub of two loops, similar to two toy car loops on a Hot Wheels® track. One loop goes to the lungs and back, and the other goes to the body and back. The flow of blood to the lungs is called **pulmonary circulation**, carrying deoxygenated blood to the lungs for gas exchange. This involves about 0.5 L of blood and requires only a few seconds to cover the loop. The flow of oxygenated blood from the left ventricle to the extremities is called **systemic circulation**. It involves much more blood and takes longer, since it has to cover more distance.



So if you were riding a red blood cell and hopped on for a ride at the heart, you would first go to the lungs and pick up oxygen. Then it would be back to the heart to get enough energy to travel to the limbs of the body. At the limbs you'd drop off your oxygen load as you traveled through the capillaries. Then it's back to the heart via veins and lungs for another oxygen load. This double loop keeps every cell in your body supplied with enough oxygen to carry on cellular respiration.

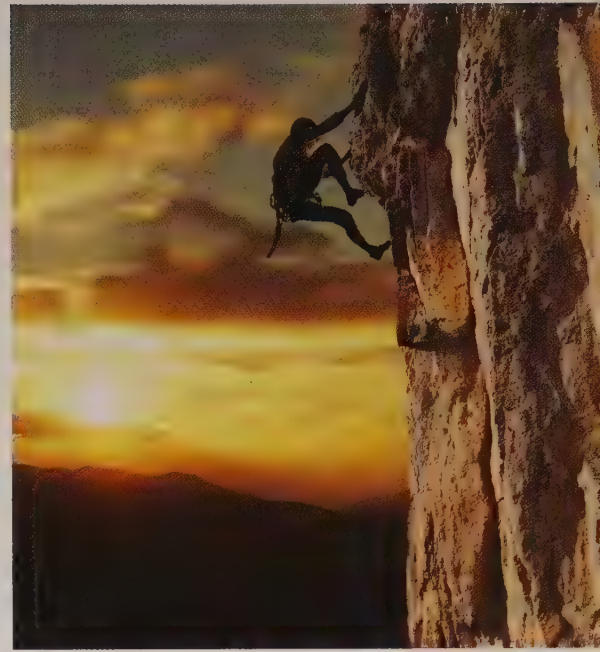
All the organs in your body need oxygenated blood, even your heart and lungs! Though oxygen is the most crucial substance that your body needs, it must also obtain nutrients and eliminate waste products. Carbon dioxide, a waste product of cellular respiration, is transported in the blood to the lungs so that it can be exhaled. Capillaries near the intestines pick up nutrients absorbed from food to distribute to the body in the bloodstream. The kidneys and liver filter the blood to remove waste products, toxins, and old red blood cells to be excreted in urine. Of course, the heart also relies on the brain and nervous system to control and monitor the cardiac cycle. And the plasma in blood regularly interacts with the lymphatic system.



It is easy to see why it is important to take good care of the bodies that God has given us, eating well and exercising to maintain a healthy heart and lungs. Our bodies don't belong to us; they belong to God. As we develop an understanding of the complexities of the human body, we can better help people to maintain good health so that they can have the strength to explore and wisely use God's world.

22B REVIEW QUESTIONS

1. What are the main parts of the circulatory system, and what is the function of each?
2. Describe the basic structure of the heart in your own words.
3. How do both blood vessels and the heart use muscular tissue?
4. How are veins different from arteries?
5. List the three particles found in blood plasma and give their main purpose.
6. Identify the blood vessels that *enter* the heart.
7. Identify the blood vessels that *leave* the heart.
8. How does the circulatory system work with the respiratory system?
9. Put the following events in the circulation of carbon dioxide and oxygen in the heart and lungs in order by number, beginning with ①.
 - ① Oxygenated blood leaves the left ventricle.
 - ② Deoxygenated blood leaves the right ventricle.
 - ③ Deoxygenated blood picks up oxygen and drops off carbon dioxide in the capillaries near the alveoli.
 - ④ Oxygenated blood travels through the aorta.
 - ⑤ Deoxygenated blood travels through the inferior and superior vena cavae.
 - ⑥ Oxygenated blood travels to the intestines and kidneys to provide them with oxygen, pick up nutrients, and filter out waste products.
10. Which of the steps in Question 9 are involved in pulmonary circulation?
11. Which of the steps in Question 9 are involved in systemic circulation?



REVIEW QUESTIONS

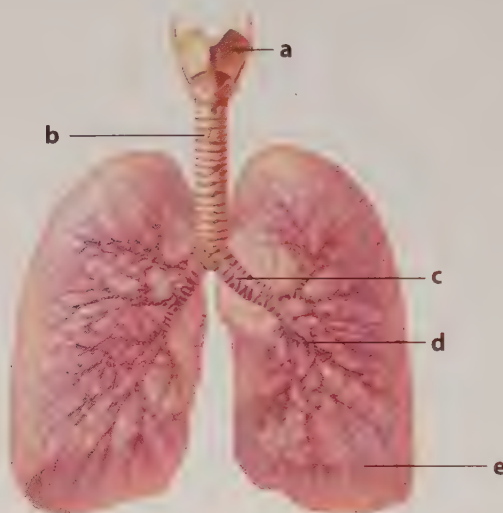
T

Key Terms

nasal cavity	430
pharynx	430
epiglottis	430
larynx	430
trachea	430
bronchus	430
lung	430
bronchiole	430
alveolus	430
capillary	430
diaphragm	431
lung capacity	431
hemoglobin	432
blood	434
artery	434
vein	434
valve	434
plasma	435
leukocyte	435
erythrocyte	435
platelet	435
coagulation	435
septum	436
atrium	436
ventricle	436
inferior vena cava	436
superior vena cava	436
pulmonary vein	436
pulmonary artery	436
aorta	436
pulmonary circulation	438
systemic circulation	438

CONCEPT REVIEW

1. What are the three major organs of the respiratory system located in the head and throat? Describe the function of each.
2. Order the following organs according to the sequence in which air passes through each: alveoli, bronchi, bronchioles, larynx, nasal cavity, pharynx, trachea.
3. Match the following terms by associating them with the letter on the bronchial tree: alveolus, bronchiole, bronchus, larynx, trachea.



4. Use a table to compare inspiration and expiration. Include in your comparison the movement of air, the relative size of the chest cavity, and the state of the diaphragm.
5. How do lung disease and age affect lung capacity?
6. How does oxygen move from the air in the lungs to the bloodstream?
7. How does your body sense when it is time to breathe?
8. While chopping vegetables, you slice your finger! Describe the component(s) in blood that help(s) you recover.
9. What is the purpose of plasma in the blood?
10. List the chambers of the heart. Indicate which pump oxygenated and de-oxygenated blood.

- 11.** Label the following parts of the heart by matching them with the letters on the diagram to the right.

aorta, left atrium, right atrium, heart muscle, pulmonary artery, pulmonary vein, septum, inferior vena cava, superior vena cava, right ventricle, left ventricle

- 12.** How do pulmonary and systemic circulations differ?
- 13.** How does your body eliminate the carbon dioxide that is produced as a byproduct of cellular respiration?
- 14.** Why is it important to know about and take care of our bodies?

TRUE OR FALSE

- 15.** Gas exchange happens in capillaries all over the body.
- 16.** The diaphragm is part of the lungs.
- 17.** When exhalation occurs, the size of the chest cavity is smaller than when inhalation occurs.
- 18.** Oxygen and carbon dioxide travel in the blood as tiny bubbles.
- 19.** Your body can involuntarily control your breathing.
- 20.** The heart is the only part of the circulatory system that uses muscular tissue.
- 21.** Erythrocytes are cells.
- 22.** Pulmonary veins carry deoxygenated blood.
- 23.** Blood from both sides of the heart mixes in the heart during circulation.
- 24.** Your lung cells get oxygen for cellular respiration directly from the air.

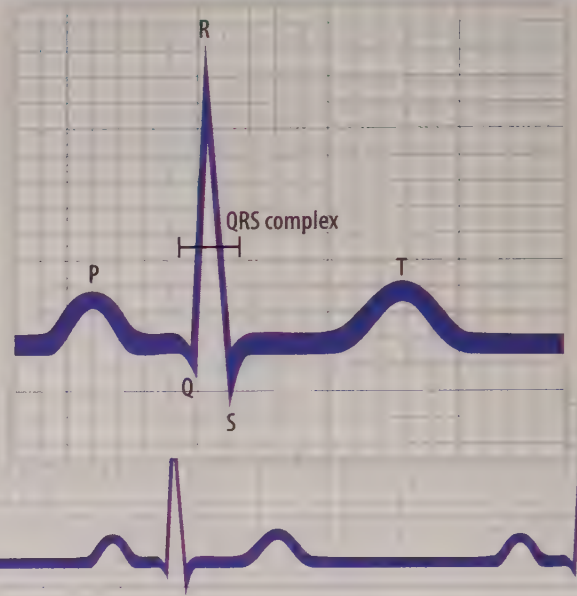
CRITICAL THINKING

- 25.** What are some of the advantages that a double loop circulatory system has over a single loop?
- 26.** Why doesn't drinking carbonated beverages elevate the levels of carbon dioxide in your blood?
- 27.** Suggest why most people have three lobes in their right lung and only two in their left.
- 28.** Do some research to determine what makes breathing difficult for people with asthma.
- 29.** Blood clots are helpful to prevent blood loss during an injury. Do some research to determine a few major problems that can develop when blood clots develop in the wrong places.



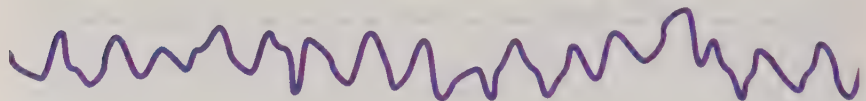
CASE STUDY: THE EKG

Doctors investigate heart health with a special test called an *EKG*, or an *electrocardiogram*. An *electrocardiograph* records the electrical activity of the heart, measuring its electrical pulses and muscle contractions. Each cycle on an EKG reading represents one complete cardiac cycle. A normal heartbeat includes three waves. The P wave represents the atria contracting, the QRS complex shows the ventricles contracting, and the T wave shows how the heart electrically recalibrates to prepare for the next contraction. This repeating cycle is called the *normal sinus rhythm*. Now you can be a student cardiologist!



Use the Case Study above to answer Questions 30–34.

30. If the vertical axis represents the size of the heart muscle contraction, what does the horizontal axis represent?
31. What do the flatter parts of an EKG represent?
32. How could you determine the heart rate from an EKG?
33. Compare the EKG below with the normal EKG above. What do you notice?



34. Do some research on the abnormal pattern above and suggest what a cardiologist might do for a patient with this EKG reading.



CHAPTER 23

ENERGY

23A THE DIGESTIVE SYSTEM 

23B THE URINARY SYSTEM 

ENERGY CRISIS

In the United States, there's an energy crisis. It's not a lack of fossil fuels, or a nuclear meltdown—we actually have too much stored energy! Americans are eating too much of the wrong thing and it's killing them. Many Americans are overweight and as a result are developing diseases at a rate that has steadily risen over the past several decades.

Most people gain weight because they eat more calories than they burn. When many try to lose weight, they find it physically and emotionally difficult, and they often quit in discouragement. Yet caring for our bodies by learning to manage our caloric energy is an important part of glorifying God in all we do. Our bodies are the first area over which we have stewardship. How can we motivate and show love to people struggling to balance their food intake and activity level?

23A Questions

- » What does eating and drinking do for the body?
- » How does the body use food and water?
- » What parts of the body participate in digestion?
- » How does digestion produce energy?

sphincter: (Gk. *sphinkter*—to bind tight); a muscle that surrounds an opening and restricts what passes through it

23A

THE DIGESTIVE SYSTEM

How does energy come from food?

23.1 STRUCTURE OF THE DIGESTIVE SYSTEM

Eating is both something we enjoy and something we need. Food tastes good! And our bodies are very efficient at extracting nutrition from food as it moves along the **alimentary canal**, which is sometimes called the *gastrointestinal (GI) tract*. Many **accessory organs** also contribute to the digestive process by releasing digestive chemicals into the alimentary canal. Let's take a look at the digestive system, including the alimentary canal and accessory organs.

ALIMENTARY CANAL

- 1 Oral cavity.** Food enters the alimentary canal through the mouth. God has given us large *incisors* for cutting food and pointed *cusps* for tearing it before the *premolar* and *molar* teeth grind it. This variety of teeth allows us to eat both meat and vegetables.
- 2 Esophagus.** The tongue pushes food through the pharynx into the esophagus as a ball-like **bolus**. As food travels down the esophagus, it is propelled by **peristalsis**, muscular contractions that continue throughout the alimentary canal.
- 3 Stomach.** When a bolus of food reaches the end of the esophagus, it passes through the *lower esophageal sphincter* into the stomach. There the food is digested with a combination of mechanical grinding and chemical action of enzymes and hydrochloric acid. The digested food leaves the stomach through the *pyloric sphincter* as a thick, semiliquid paste called **chyme**.
- 4 Small intestine.** Most of the digestive enzymes in the body are found in the small intestine. Tiny, finger-like *villi* (s. villus) lining the inside of the small intestine use diffusion and active transport to absorb most of the nutrients that the body needs.
- 5 Large intestine.** By the time the chyme exits the small intestine, the body has already extracted most of the nutrients from it. The large intestine absorbs water and some remaining nutrients, including important vitamins. The undigested material passes through the **rectum** **6**, the last section of the large intestine, and is expelled through the **anus** as feces.



ACCESSORY ORGANS

1 Salivary glands. Saliva from the salivary glands mixes with food during chewing. It lubricates the food for swallowing and also contains some digestive enzymes.

2 Liver. The liver is the largest internal organ in the body and has a multitude of functions. As you learned in Chapter 22, the liver filters toxins and wastes from the blood. It also produces **bile**, a greenish fluid that helps digest fats in the small intestine.

3 Gallbladder. After the liver makes bile, the gallbladder stores it until it is needed in the small intestine. Bile contains a large amount of water, some of which the gallbladder removes, concentrating the bile. However, sometimes the solutes in bile precipitate, forming gallstones, which occasionally become so problematic that the gallbladder must be removed. A person without a gallbladder usually has little difficulty digesting fats since the liver continues to produce bile.

4 Pancreas. The pancreas is the primary producer of digestive enzymes. These different enzymes are carried along by *pancreatic juice* into the small intestine where they break down carbohydrates, fats, proteins, and nucleic acids. The pancreas also helps neutralize the pH of the extremely acidic chyme entering the small intestine from the stomach.

5 Appendix. The appendix attaches to the large intestine just below where it joins the small intestine. Its exact purpose is still a matter of debate. It is composed of lymphatic tissue, so it may be involved in helping lymphocytes recognize pathogens. Or the appendix could also be a reservoir for beneficial bacteria. It's also possible that the appendix serves a different, yet unknown function.



23.2 FUNCTION OF THE DIGESTIVE SYSTEM

As the food you eat passes through your GI tract, your digestive system extracts the **nutrients** that your body needs. While your body requires many different molecules to remain healthy, your dietary needs fall into six categories.

NUTRIENTS IN FOOD

Vitamins. Your body can't make most of these organic molecules, but it needs them to aid your metabolism. Some vitamins serve as coenzymes that enable enzymes to perform their roles in the body while others regulate metabolic processes. Although they are necessary for health, our body needs them in much smaller amounts than most of the other nutrients. However, since your body can't make sufficient amounts of a vitamin, they must come from the diet.

Minerals. You learned in Chapter 21 that bones store calcium for added strength and for other uses in the body. Calcium is just one of the minerals that your body needs. These inorganic substances are found naturally in soil and are absorbed by plants. Minerals are important for nerve and muscle function, blood coagulation, blood pH maintenance, enzyme function, and many other uses.





Water is essential to most of the chemical reactions in the body because they occur in an aqueous environment. Water also dissolves some foods for easier digestion, and it balances fluids, blood pH, and body temperature.

Fats are used to form cell membranes, protective membranes around nerve cells, and certain hormones. They also serve to cushion delicate structures and provide energy. The body stores excess energy as fats in *adipose tissue*, so a low-fat diet with too many calories can still cause a person to build up adipose tissue.



Carbohydrates include sugars, such as fructose and sucrose, and more complex molecules such as starch and glycogen. Although the body can use several carbohydrates as energy sources, all are broken down to glucose before being used in cellular respiration.

Proteins make up about 50% of the body's dry weight; they are found in all living cells and in nonliving structures such as hair, nails, and the matrix of connective tissues. Most enzymes and some hormones are also proteins, and while proteins are most important for growth and repair, they may also be used for energy production. Proteins are formed from chains of complex molecular structures called *amino acids*. Your body can make some of these amino acids, but others must come from your diet.



Now that we've covered the digestive organs and the different classes of nutrients, let's discuss how your digestive organs function to extract nutrients. The digestive system uses a combination of mechanical and chemical digestion. *Mechanical digestion* consists of physically breaking down the food. *Chemical digestion* involves the breakdown of food by acids and enzymes.

CHEMICAL DIGESTION

MOUTH

Saliva from salivary gland

» Amylase (enzyme) breaks down maltose (disaccharide) and starch.

STOMACH

Gastric juices from stomach lining

» Pepsin (enzyme) breaks down protein fragments.

SMALL INTESTINE

Pancreatic juices from pancreas

» Amylase (enzyme) breaks down maltose, sucrose, and lactose (disaccharides).

» Lipase (enzyme) breaks down fatty acids and glycerol.

» Enzymes trypsin and chymotrypsin break down proteins.

Intestinal juices from intestinal lining

» Enzymes maltase, sucrase, and lactase break down monosaccharides.

» Lipase (enzyme) breaks down fatty acids and glycerol.

» Peptidase (enzyme) breaks down proteins.

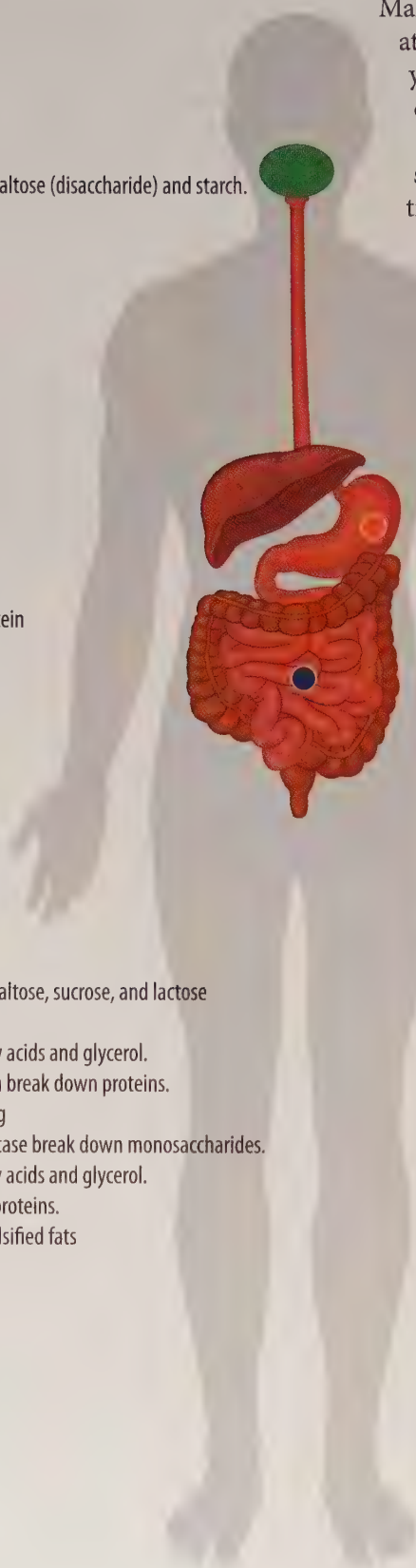
Bile from the liver breaks down emulsified fats

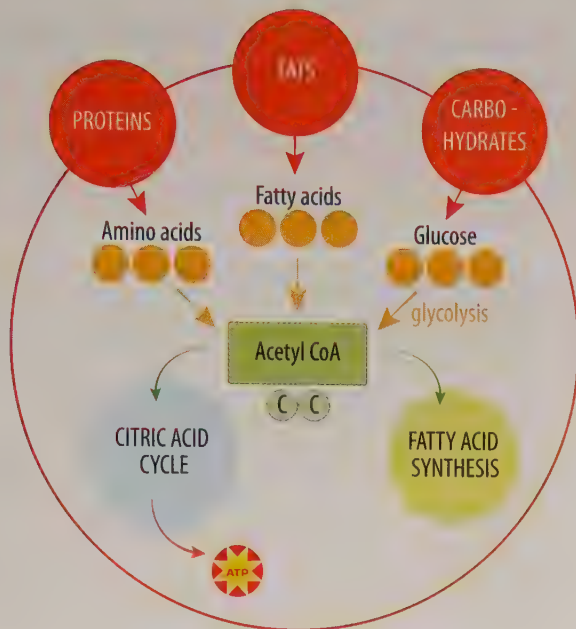
Many organs use both mechanical and chemical digestion at the same time. The teeth grind food while **amylase** in your saliva begins to break down starch, a large carbohydrate polymer. The stomach mashes and grinds the food while the enzyme **pepsin** begins to split proteins into smaller units of amino acids. The small and large intestines continue to mix chyme as it passes through, while bile begins to separate molecules of fat to make it easier to digest. Various enzymes all work to break food molecules into usable nutrient molecules.

Most digestive enzymes come from the pancreas and small intestine. The pancreas releases additional amylase to further digest carbohydrates and **lipase** to digest fats. The pancreas and small intestine release several enzymes to finish the digestion of proteins begun in the stomach by pepsin. In Chapter 2 you learned that enzymes have active sites that their substrates fit into. If the pH of the environment is not correct, the shape of the enzyme changes, so the substrate will no longer fit in the active site. Pepsin can function only in the extremely acidic environment of the stomach, while lipase would not work there at all. This is one of the reasons why the pH of the chyme must be changed in the small intestine. Most of the digestive enzymes would not work on the chyme

that comes from the stomach until the acid has been neutralized.

Once the small intestine has absorbed these nutrients, they can be used by the body. Carbohydrates serve many different purposes, but their primary purpose is to provide the energy necessary to make ATP during cellular respiration. All carbohydrates can enter glycolysis, though some enter at different points in the process. If the body runs short on glucose, the cells can use fats and amino acids in cellular respiration. Fats and some amino acids are converted to *acetyl CoA*, which then enters the citric acid cycle. Other amino acids are fed into the citric acid cycle later in the process.





Under normal circumstances, fats and amino acids are used throughout the body. The liver processes fats and creates the various molecules needed by the body. Amino acids serve many different purposes, but they carry a danger with them—nitrogen. When amino acids are used for energy or converted to fats for storage, they release ammonia (NH_3). You will learn how this issue is remedied in the section on the urinary system.

23.3 THE DIGESTIVE SYSTEM IN THE HUMAN BODY

Like the other systems of the body, the digestive system works in conjunction with other systems. The digestive system wouldn't function at all without the muscles that form sphincters and line the alimentary canal and provide peristalsis. This is smooth muscle and, as you learned in Chapter 21, it is controlled involuntarily.

Once your small intestine absorbs the nutrients from your food, distribution of those nutrients relies on other systems. Carbohydrates, amino acids, minerals, vitamins, and water are transported by cells in the villi of the small intestine to the blood stream. The circulatory system then carries these nutrients throughout the body.

The small intestine treats fats very differently than it does other nutrients. Fat molecules are absorbed by the villi just like other nutrients, but they are transported to lymphatic vessels called *lacteals*. From there, the fat molecules are carried through the lymphatic system until it empties into a subclavian vein. The circulatory system then distributes the fat molecules to the rest of the body.

The digestive system also interacts with the integumentary system. The intestines cannot absorb calcium without sufficient vitamin D. While some vitamin D must come from food, some of it also comes

from the skin. Ultraviolet light causes the epidermis to form vitamin D. The newly formed vitamin is transported by the circulatory system, and some reaches the intestine where it increases the absorption of calcium. But before you rush out to catch some rays and maximize your calcium absorption, remember that the same ultraviolet rays also cause skin cancer. Moderation is best when it comes to being in the sun.

Finally, the digestive system takes in nutrients to build your cells and tissues and to provide the energy you need, but if you take in more energy than your body can use, the excess is stored as fat. Many people in the western world, especially in the United States, struggle with consuming more energy than they use. This problem is due not only to the typical American diet, but also to insufficient exercise. Exercise increases the rate of cellular respiration and improves respiratory and circulatory efficiency.

As believers, we have a responsibility to glorify God with our bodies (1 Cor. 6:20). This includes eating a healthy diet and exercising so that our bodies will be useful for the Lord's service.



23A REVIEW QUESTIONS

1. Mechanical digestion takes place in which two digestive organs?
2. Describe peristalsis.
3. What is the role of bile in the small intestine?
4. Which two accessory organs produce amylase?
5. A bacterium that normally lives in the mouth moves to the stomach. Is it likely to cause an infection? Explain.
6. Make a T-chart that divides nutrients into organic and inorganic substances.
7. Which type of nutrient is not transported *directly* by the small intestine to the circulatory system? Explain.

Use the Case Study and table below to answer Questions 8–10.

CASE STUDY: EXERCISE



Exercising is one way to increase the number of calories you burn. However, different activities burn calories at different rates. Running for half an hour takes more energy than walking for the same amount of time. Various websites and apps are available to help you calculate the approximate number of cal-

ories that a person burns while doing an activity for a specified length of time.

It might seem common sense to pick the exercise form that burns the most calories, but it's not that simple. One of the biggest problems many people have with exercising is consistency. It's hard to keep up an exercise routine. It's better to choose an exercise that you enjoy since you're more likely to continue that routine than one you dislike. Sometimes injury can also lead a person to find a less stressful exercise even though it may burn fewer calories per hour than some others.

So what's the point of finding out how many calories you burn during an activity? It gives you an idea of how much time you should spend doing that activity in order to burn the target number of calories. If your favorite activity doesn't burn a lot of calories, you would need to spend a longer time each week doing that activity, or you could find a second, more energetic activity.

Calorie Expenditure

Activity	Cal/lb/hr	130 lb	180 lb
baseball	2.27	295	409
basketball	3.63	472	654
cycling (moderate)	3.63	472	654
flag football	3.63	472	654
hiking	2.72	354	490
jogging	3.63	472	654
martial arts	4.54	590	817
rollerblading	5.45	708	981
running (7.5 mph)	6.13	797	1103
soccer	4.54	590	817
swimming	2.72	354	490
ultimate frisbee	3.63	472	654
walking	1.50	195	270

8. Which activity burns the most calories per hour?
9. Jordan, a 110-pound teenager, wants to increase his calorie expenditure, but he doesn't enjoy running for running's sake. However, he likes to play ultimate frisbee. How many hours a week would he have to play ultimate frisbee to use the same number of calories that he would use running 3 hours a week?
10. Rachel, a 35-year-old mother of three who weighs 130 lbs, wants to burn an extra 1500 calories a week. She exercises only about 3 hours a week, and her schedule doesn't allow her to play organized sports. She used to run, but she developed plantar fasciitis, a medical condition resulting in pain in her heel. What new exercise would you suggest for her?

23B

THE URINARY SYSTEM

How does the body remove metabolic waste?

23B Questions

- » What are the parts of the urinary system?
- » What do the kidneys do?
- » What other organs excrete waste?
- » Why does drinking lots of water keep you healthy?

23.4 THE STRUCTURE OF THE URINARY SYSTEM

In the last section, you learned that the body produces ammonia when it catabolizes amino acids. Ammonia is highly toxic, but the liver changes it to urea, a much less harmful chemical. However, even urea must be removed from the blood, or it will eventually poison the body. This important task is performed by the urinary system. While all the organs below are integral to the urinary system, the kidneys are the primary and most structurally complex of them.

EXPLORING THE HUMAN URINARY SYSTEM

The two **kidneys** ①, which look like large kidney beans, filter urea from the blood to be excreted from the body as **urine**.

Each kidney connects to a tube called a **ureter** ② that uses peristalsis to conduct the urine away from the kidney.

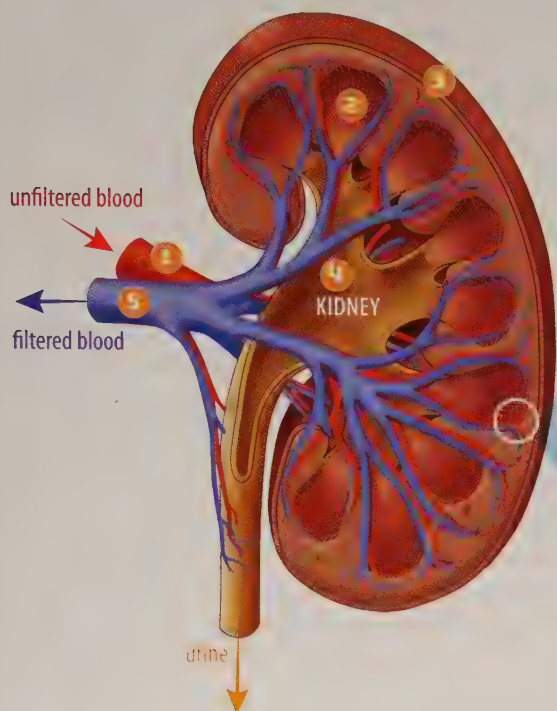
Urine exits the ureters into the **urinary bladder** ③, which collects the urine until it can be excreted.

Urine exits the urinary bladder through the **urethra** ④, which conducts the urine outside the body. The urethra has two sphincters. One opens involuntarily, and the other is voluntary. (The anus has a similar design.)

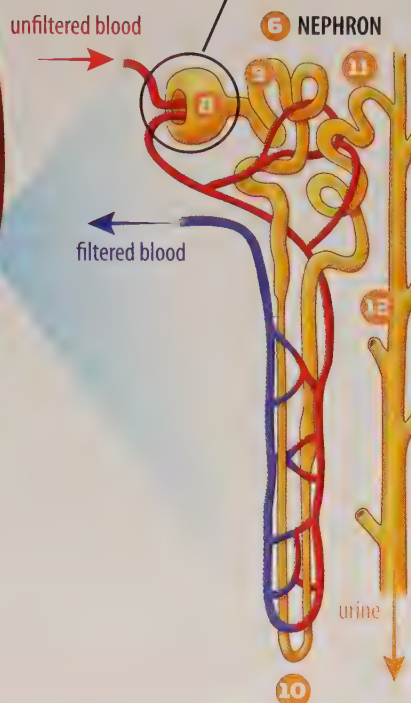
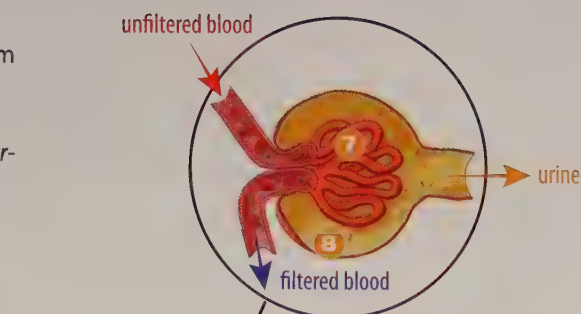


THE KIDNEYS

- 1 The **renal artery** carries **metabolic wastes** from the liver into the kidneys.
- 2 Cone-shaped masses of tissue called **renal pyramids** make up the **renal medulla**.



URETER



- 3 The **renal cortex** forms the outer layer of the kidney. Extensions of the renal cortex called **renal columns** lie between the renal pyramids.

- 4 The **renal pelvis** collects the urine from the renal pyramids and releases it into the ureter.

- 5 The **renal vein** conducts the filtered blood out of the kidney and back into the rest of the circulatory system.

- 6 The **nephron** is the functional unit of the kidney, and a single kidney contains on average a million of them. Much of the nephron lies in the renal cortex, and the remainder forms part of the renal pyramids.

- 7 glomerulus

- 8 Bowman's capsule

- 9 proximal convoluted tubule

- 10 loop of Henle

- 11 distal convoluted tubule

- 12 collecting duct

23.5 THE FUNCTION OF THE URINARY SYSTEM

To rid the body of wastes, the kidney performs three major functions: *filtration*, *reabsorption*, and *secretion*. A renal artery carries the waste-laden blood into a kidney and then divides into several branches that further divide multiple times to carry blood to the nephrons. When the blood reaches a nephron, it passes into a collection of capillaries called the **glomerulus** 7, which is surrounded by a cup-shaped structure called the **Bowman's capsule** 8. Because the blood flowing into the glomerulus is under higher pressure than the fluid in the Bowman's capsule, plasma moves from the glomerulus into the Bowman's capsule. This plasma carries smaller molecules such as urea, vitamins, salt, and glucose with it, while blood cells and larger molecules like whole proteins remain in the blood vessel. This process is



one of filtration. The fluid and substances that enter the Bowman's capsule are called the *filtrate*.

When the filtrate flows from the Bowman's capsule into the *proximal convoluted tubule* **9**, it enters the reabsorption phase. The tubule is designed to contain the wastes and ensure that the beneficial molecules and minerals are reabsorbed into the capillaries that surround it. Glucose, sodium, potassium, and calcium ions are actively transported back into the capillaries. As the concentrations of these molecules increase in the blood vessels, most of the water in the proximal convoluted tubule and the subsequent **loop of Henle** **10** diffuses back into the capillaries by osmosis. Some reabsorption continues to occur in the *distal convoluted tubule* **11**.

In the distal convoluted tubule, additional substances move from the blood to the tubule in the secretion phase. Substances such as urea, various ions, drugs, and other waste products are secreted. Hydrogen ions may also be secreted into the tubule to adjust the pH of the blood. As the fluid flows from the distal convoluted tubule into the collecting duct, water may be reabsorbed into the bloodstream, especially if the body is becoming dehydrated. The remaining fluid that flows out the collecting ducts **12** of the renal pyramids into the renal pelvis is urine.

Normal urine is about 95% water, with the rest being solid solutes. Urea, formed in the liver from protein catabolism, is usually the most common organic solute. Uric acid, formed during nucleic acid breakdown, and creatinine, produced during muscular contraction, are also common substances in urine. A normal urine sample also contains very small quantities of pigments, hormones, enzymes, vitamins, and various inorganic substances.

23.6 THE URINARY SYSTEM IN THE HUMAN BODY

The urinary system is part of a larger body system—the *excretory system*—that removes wastes. In addition to the organs of the urinary system, the excretory system includes the liver, which creates urea from ammonia produced by the breakdown of amino acids. The skin also serves as a minor excretory organ since it releases a limited amount of urea in perspiration. Finally, the lungs release carbon dioxide as part of respiration. Since CO_2 is produced as a part of cellular respiration, this makes the lungs part of the excretory system as well.

As you learned in the section on the digestive system, water is an essential nutrient. In fact, water makes up over half of the body weight of most adults. Water forms much of the cytoplasm in your cells as well as blood plasma and lymph. Since you are constantly losing water through urination, sweat, and exhalation, you need to replace it to avoid dehydration. Three-fifths of the water your body needs comes from the fluids you drink; most of the rest comes from food you eat. While your exact fluid needs depend on many different factors, including your height, weight, and gender, you need to drink lots of fluids. If a person consistently passes clear urine, then he is sufficiently

hydrated. However, since what is “clear” is somewhat subjective, many sources suggest drinking between 64 and 100 oz of fluids a day. While this may seem like a lot, if you drank just an 8-oz glass of water every two hours between 8:00 a.m. and 10:00 p.m., you would drink 56 oz, very close to the recommended amount. Any type of fluid helps meet this requirement; water just has the added benefit that it has no calories, unlike many other beverages.

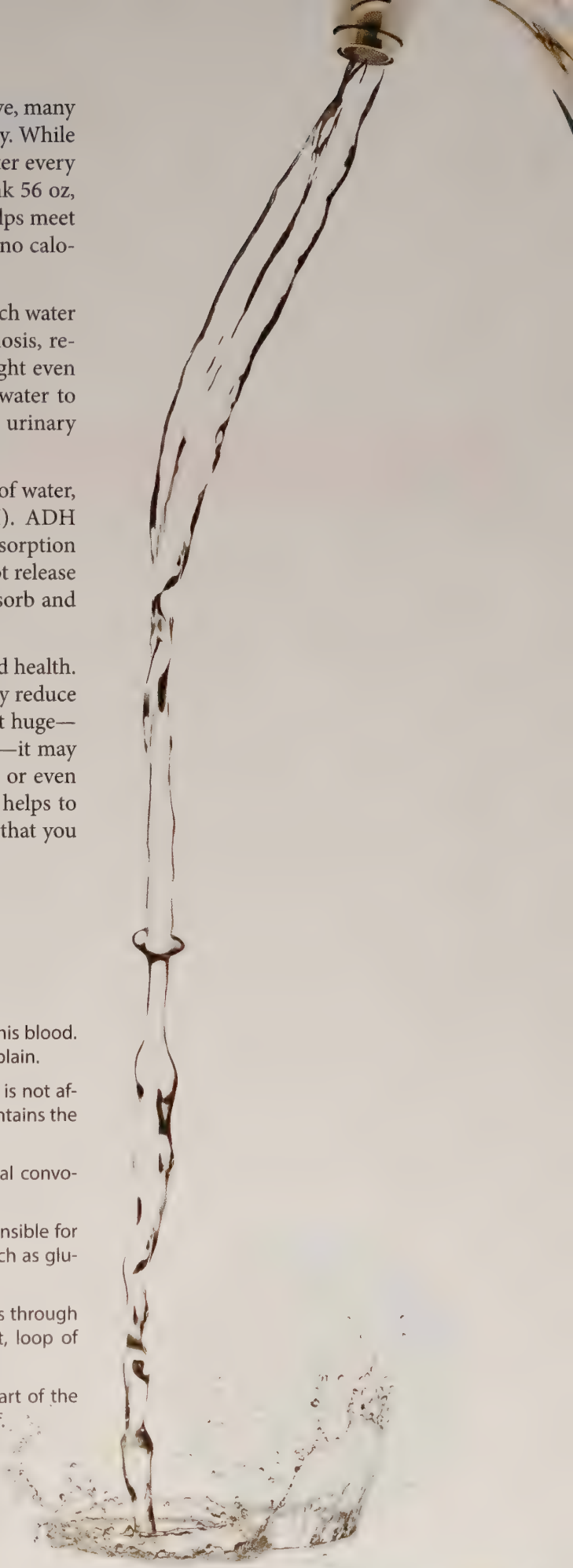
Your body must have a way of regulating water levels. Too much water in the blood plasma causes water to enter your cells by osmosis, resulting in swollen cells. If this were to continue, the cells might even start bursting. Too little water in the blood plasma causes water to leave your cells via osmosis, causing the cells to shrivel. The urinary system regulates the balance between too much and too little.

If your blood vessels have too little volume because of a lack of water, it releases a hormone called antidiuretic hormone (ADH). ADH causes the nephrons to reabsorb more water during the reabsorption phase. If the body has too much water, then the body does not release ADH, reducing the amount of water that the nephrons reabsorb and allowing more water to be released in urine.

Drinking plenty of water is also another way to maintain good health. There is some evidence that drinking enough water a day may reduce appetite and cause a person to eat less. While the effect is not huge—don’t plan on losing 10 pounds just by drinking more water—it may certainly help. And whether it helps you lose weight or not, or even if you do not need to lose weight, drinking plenty of water helps to maintain your body’s homeostasis and keeps you healthy so that you can serve the God who made you for His glory.

23B REVIEW QUESTIONS

1. Which two organs of the urinary system are essentially tubes?
2. A person is having trouble with urea not being removed from his blood. Which organ(s) of the urinary system are likely to be failing? Explain.
3. If a blood clot is preventing blood from entering a kidney but is not affecting blood flow in other vessels, which vessel most likely contains the clot?
4. Which structure of a nephron is located between the proximal convoluted tubule and the distal convoluted tubule?
5. Which one of the three major functions of the kidney is responsible for ensuring that the body does not lose beneficial molecules, such as glucose and sodium?
6. Place the following organs and tissues in the order urea passes through on its way to being expelled from the body: collecting duct, loop of Henle, renal artery, renal pelvis, ureter, urethra, urinary bladder.
7. Name one of the three excretory system organs that is not part of the urinary system, along with what other organ system it is part of.
8. What organ does ADH affect?



REVIEW QUESTIONS

T	Key Terms	
	alimentary canal	444
	accessory organ	444
	oral cavity	444
	esophagus	444
	bolus	444
	peristalsis	444
	stomach	444
	chyme	444
	small intestine	444
	large intestine	444
	rectum	444
	anus	444
	salivary gland	445
	liver	445
	bile	445
	gallbladder	445
	pancreas	445
	appendix	445
	nutrient	446
	amylase	448
	pepsin	448
	lipase	448
	kidney	452
	urine	452
	ureter	452
	urinary bladder	452
	urethra	452
	metabolic waste	453
	nephron	453
	glomerulus	453
	Bowman's capsule	453
	loop of Henle	454



CONCEPT REVIEW

- What sections of the alimentary canal would carry secretions from only one set of accessory organs? Explain.
- Which part of the alimentary canal has the lowest pH?
- Classify each substance into one of the six classes of nutrients.
 - inorganic phosphate (PO_4^{3-})
 - lactose (milk sugar)
 - lean meat
- Indicate which nutrient each enzyme digests.
 - amylase
 - lipase
 - pepsin
- What organ system are the lacteals part of?
- Rory lives in Whitehorse, Yukon Territory, Canada, and his friend Eduardo lives in Mexico City. During winter, which vitamin would Rory need to be more concerned about getting from his diet than Eduardo? Explain.
- If a single nephron ceased functioning, would it make much of a difference in the kidney's function? Explain.
- Match each description with one of the four main organs in the urinary system.
 - connecting tube
 - filter
 - exit
 - holding tank
- Match each part of a nephron with one of the following processes: filtration, reabsorption, secretion.
 - collecting duct
 - glomerulus
 - loop of Henle
- Which of the following should never be found in the urine of a healthy person: urea, water, red blood cells? Explain.
- If ADH were to be continuously released for a long period of time, what might be some of the results?
- Kidney stones are mineral deposits that form in the kidneys. While many different factors can lead to kidney stones, one of the more common causes is overly concentrated urine. What could a person do to ensure that his urine does not become too concentrated?

TRUE OR FALSE

- Approximately half of all chyme passes through the accessory organs.
- Most of a human's dry weight is composed of proteins.
- A diet high in calcium but low in vitamin D would probably not increase bone density very much.
- In the diagram to the left, if A represents the excretory system, then B represents the urinary system.
- The collecting ducts of the nephrons form part of the renal pyramids.
- The distal convoluted tubule is connected to the Bowman's capsule.

CRITICAL THINKING

19. You are a nutritionist, and one of your clients wants to lose weight by reducing his daily calorie intake from 2300 to 2000 calories a day. He suggests that he should go on a completely fat-free diet so that he can reduce the amount of fat in his body. Why won't this work?
20. Why is urinalysis a common way of testing a person for drug use?
21. You are a doctor working in an emergency room when a patient is brought in with a case of alcohol overdose. You know that alcohol blocks ADH, so what major problem should you check your patient for?

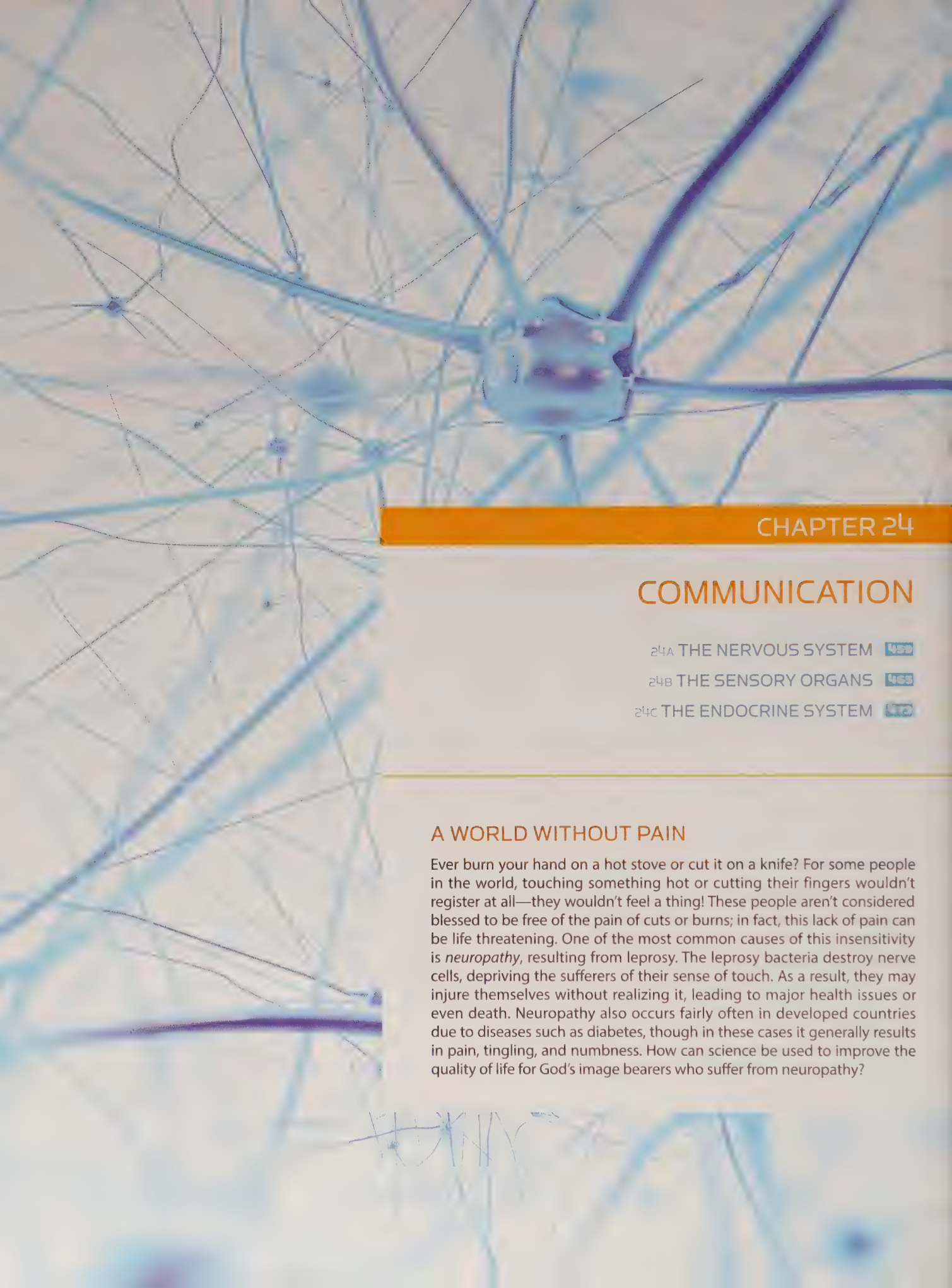
Use the Case Study below to answer Questions 22–30.

CASE STUDY: NUTRITION FACTS LABELS

The Food and Drug Administration (FDA) requires all food companies to place a label on their food packages listing the amount of fat, carbohydrates, and proteins in a recommended serving. Additionally, the label also shows what percentage of the recommended daily allowance of fats, carbohydrates, cholesterol, and sodium the product contains. A second part of the Nutrition Facts label contains information on what percentage of the daily recommended dose of specific vitamins and minerals the food product contains. The very bottom part of the label includes recommended daily allowances of fat, cholesterol, sodium, and carbohydrates.

22. How many tortillas are in this unopened package?
23. John ate three tortillas for lunch. How many grams of protein did he eat?
24. The 30 mg of sodium is said to be 1% of the daily recommended allowance. According to this, what is the recommended daily allowance of sodium?
25. According to the bottom panel, what is the daily recommended allowance of sodium?
26. Is the label misrepresenting the amount of sodium in the product?
27. Given that cholesterol is produced by animal cells, is this product more likely made with vegetable oil or lard (pig fat)?
28. The recommended daily allowance for Vitamin A is 900 mg for men over age fourteen and 700 mg for women of the same age. How many milligrams of Vitamin A would a thirty-three-year-old woman need to consume to achieve her daily recommended allowance after eating two tortillas? Explain.
29. How could a person seeking to glorify God with his eating habits use the nutrition facts label?
30. How would you respond to someone who tells you, "The Bible says that we are going to live only about 70 years anyway (Ps. 90:10). We don't have to measure every little thing we eat and spend our life exercising"?

Nutrition Facts			
Serving Per Container 2			
Serving Size 2 tortillas (51g)			
Amount Per Serving			
Calories	110	Calories from Fat	10
% Daily Value*			
Total Fat	1g		2%
Saturated Fat	0g		0%
Trans Fat	0g		
Cholesterol	0mg		0%
Sodium	30mg		1%
Total Carbohydrate	30g		7%
Dietary Fiber	2g		9%
Sugars	0g		
Protein 3g			
Vitamin A	0%	Vitamin C	0%
Calcium	2%	Iron	4%
*Percent Daily Values are based on a 2,000 calorie diet. Your Daily Values may be higher or lower depending on your calorie needs.			
	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g



CHAPTER 24

COMMUNICATION

24A THE NERVOUS SYSTEM 459

24B THE SENSORY ORGANS 465

24C THE ENDOCRINE SYSTEM 472

A WORLD WITHOUT PAIN

Ever burn your hand on a hot stove or cut it on a knife? For some people in the world, touching something hot or cutting their fingers wouldn't register at all—they wouldn't feel a thing! These people aren't considered blessed to be free of the pain of cuts or burns; in fact, this lack of pain can be life threatening. One of the most common causes of this insensitivity is *neuropathy*, resulting from leprosy. The leprosy bacteria destroy nerve cells, depriving the sufferers of their sense of touch. As a result, they may injure themselves without realizing it, leading to major health issues or even death. Neuropathy also occurs fairly often in developed countries due to diseases such as diabetes, though in these cases it generally results in pain, tingling, and numbness. How can science be used to improve the quality of life for God's image bearers who suffer from neuropathy?

THE NERVOUS SYSTEM

How does the body process and transmit information?

24.1 THE STRUCTURE OF THE NERVOUS SYSTEM

The nervous system forms a massive communication network that runs throughout the body. It receives information from the sensory organs in the nose, tongue, ears, eyes, and skin, and it processes that information at speeds that would make a supercomputer designer green with envy.

EXPLORING THE HUMAN NERVOUS SYSTEM

The *brain* and the *spinal cord* together form the **central nervous system** **1** (CNS). The CNS processes the information gathered from all parts of the body. Nervous tissue is naturally gray, giving it the name *gray matter*. Some parts of the CNS (called *white matter*) are primarily involved with communication between the different parts of the nervous system.

The color of the white matter comes from three protective layers known collectively as the **meninges** **2**. The thin *pia mater* lies on the surface of the CNS. The *arachnoid mater* attaches to the pia mater by delicate cobwebby strands that form many spaces between these two layers. The tough *dura mater* forms a protective case around the CNS.

Special capillaries in the pia mater form **cerebrospinal fluid** by allowing only specific substances to move from the blood into the spaces between the arachnoid mater and the pia mater. The fluid bathes the CNS, providing nutrition to the cells, cushioning the structures, and removing wastes. Another set of structures in the arachnoid mater above the brain allows excess cerebrospinal fluid to reenter the bloodstream.

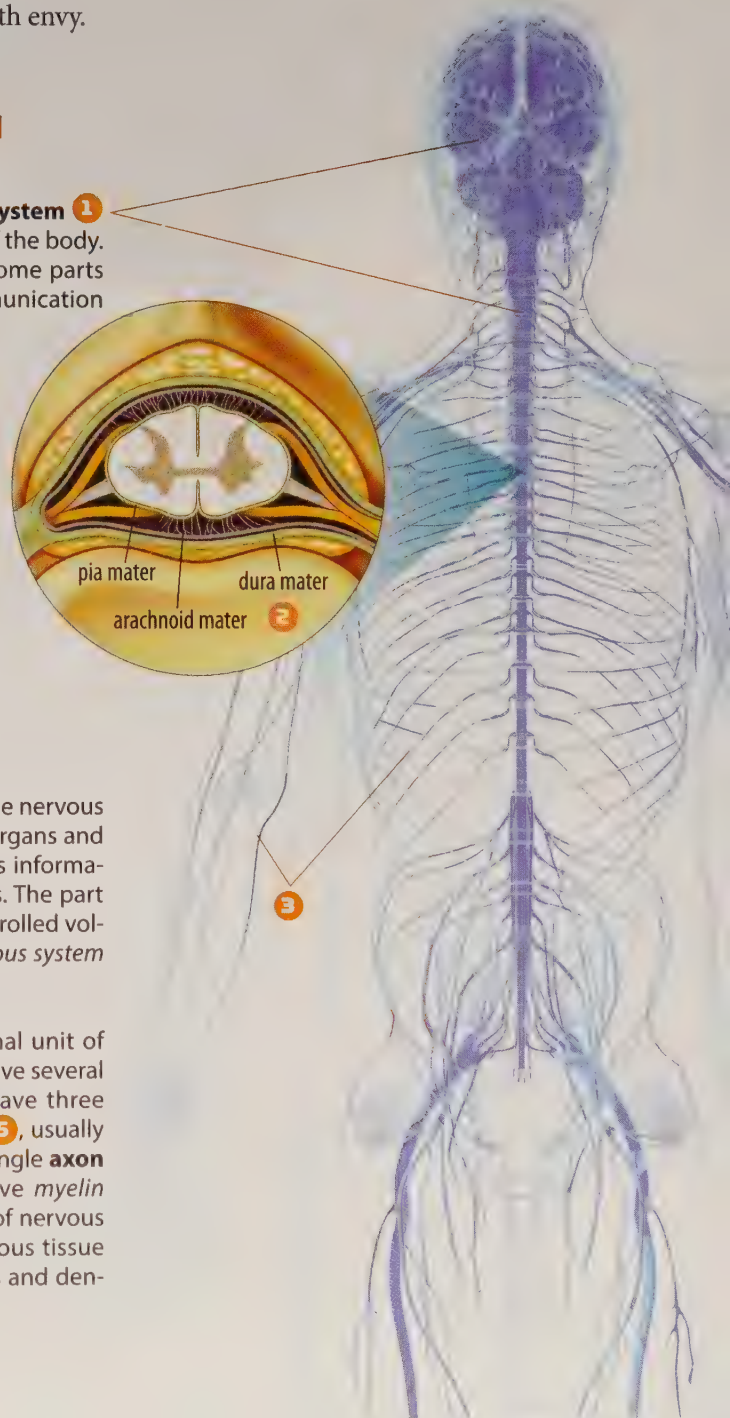
The **peripheral nervous system** **3** (PNS) forms the other half of the nervous system. Its sensory division gathers information from the sensory organs and carries it to the CNS to be processed. Its motor division then relays information from the CNS to *effectors*, usually muscles, glands, and organs. The part of the motor system that activates skeletal muscles and can be controlled voluntarily is called the *somatic nervous system*. The *autonomic nervous system* controls smooth and cardiac muscle and functions involuntarily.



The **neuron** **4** is the functional unit of the nervous system. Neurons have several different forms, but they all have three main parts: a single **cell body** **5**, usually multiple **dendrites** **6**, and a single **axon** **7**. Axons with their protective *myelin sheaths* form the white matter of nervous tissue. The gray matter of nervous tissue is usually formed by cell bodies and dendrites.

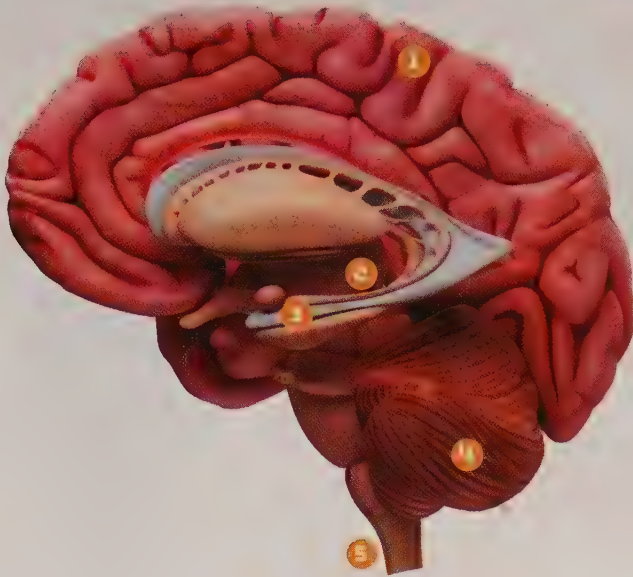
24A Questions

- » How does the nervous system work?
- » How does information get from one neuron to another?
- » What does your brain do?
- » How does information get from your body to your brain and back again?



The central nervous system and the peripheral nervous system are essential to each other. We will study the peripheral nervous system in more detail in the next section. For now, let's focus on the CNS.

EXPLORING THE HUMAN BRAIN



The **cerebrum** ① is by far the largest region of the brain and is responsible for conscious activities. The depressed areas, called *fissures*, and ridges, called *gyri* (s. *gyrus*), increase the surface area of the cerebrum.

The **thalamus** ② receives general sensations and relays the important ones to the cerebrum. Your thalamus also helps keep you awake and alert.

The **hypothalamus** ③ is a tiny part of the brain, weighing only 4 g, but it regulates many involuntary activities, including body temperature, blood volume, and fluid balance. It also has some control over appetite and emotional expression. Finally, and perhaps most importantly, it is the link between the nervous system and the endocrine system.

Located behind and beneath the cerebrum, the **cerebellum** ④ controls body coordination. Although it initiates no voluntary movements on its own, it monitors and adjusts activities and movements that are stimulated by other brain regions. When a movement occurs, the cerebellum regulates its quickness and force, ensuring that it goes where it should.

The **brain stem** ⑤ connects the rest of the brain to the spinal cord and controls involuntary respiration, blood vessel diameter (blood pressure), and heart rate. It also controls responses to sight and sound as well as eyeball movement. The brain stem controls body movements and posture; it controls but does not initiate sneezing, coughing, swallowing, and vomiting. Because many basic homeostatic processes are controlled by the brain stem, an injury to this part of the brain is often fatal.



EXPLORING THE CEREBRUM



The cerebrum is divided into lobes, each controlling different functions.

The *frontal lobe* **1** performs mental functions such as reasoning, planning, and memorizing. It also controls verbal communication and starts the commands for voluntary body movements.

The *parietal lobe* **2** receives sensations such as pain, pressure, touch, and temperature. It then directs this information to the frontal lobe, which determines what to do about it. The parietal lobe also uses muscle tension to maintain a sense of the position of the body.

The *occipital lobe* **3** is involved primarily in vision and memory of objects and symbols. A severe blow to the head may cause the sensation of “seeing stars” because it stimulates the neurons leading from the eyes to the occipital lobe. Nerve impulses from these fibers are interpreted as visual impulses by the occipital lobe.

The *temporal lobe* **4** perceives the sensations of hearing and smell. It also provides the ability to remember the pronunciation of words and the melody of songs and stores memories of both sight and sound.

The cerebrum is also divided longitudinally into two hemispheres. Because the nerves coming from the cerebrum cross to the opposite side of the body, the right hemisphere controls the left side of the body, and the left hemisphere the right side of the body.

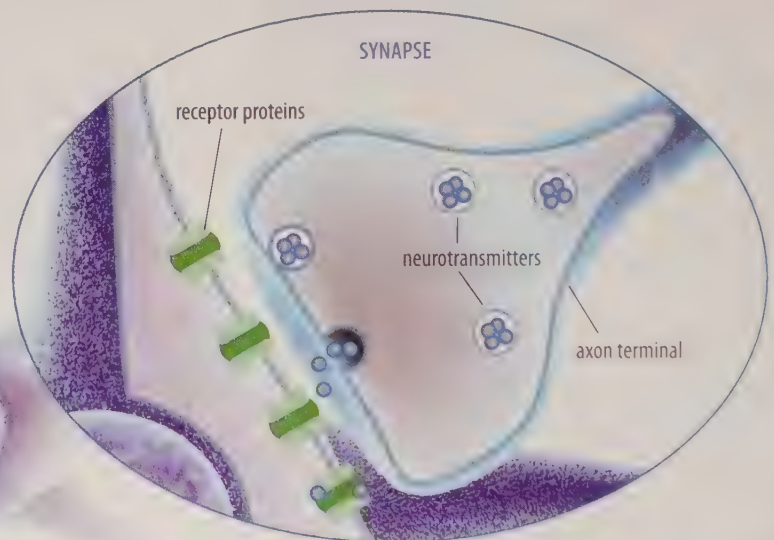


The spinal cord continues from the brain stem down most of the spinal column. It relays messages between the brain and the PNS, which relays messages to and from the rest of the body. The spinal cord is a cylindrical mass of nervous tissue composed of thirty-one segments with one pair of spinal nerves originating from each segment. The spinal cord is made of white matter in the outer regions and gray matter in the center. The neuron cell bodies that make up much of the central gray matter are connected primarily with the PNS, and the axons that form the outer white matter carry signals to and from the brain. Some axons carry messages to the brain; others carry messages only away from the brain. For example, pain signals pass along only certain axons, while signals to muscles pass along other axons.

24.2 THE FUNCTION OF THE NERVOUS SYSTEM

Neurons carry messages using electrochemical signals that travel down the length of the neuron. Neural cells have proteins in their membranes called *sodium-potassium pumps* that actively transport sodium cations out of the cell and potassium cations into the cytoplasm. The concentrations of several types of anions also build up inside the cell, so that the membrane has a net positive charge on the outside and a net negative charge on the inside. This difference in charge across the membrane forms the neuron's **resting potential**.

When a neuron receives a signal, protein channels in the membrane open, causing an influx of sodium ions into the cell, an event called an **action potential**. The action potential causes other protein channels to open, passing the action potential down the length of the neuron.



When the sodium ions rush in, other protein channels open, allowing potassium cations to rush out, reestablishing the resting potential. The sodium-potassium pumps then begin transporting sodium cations back out of the cell and potassium ions back into the cell.

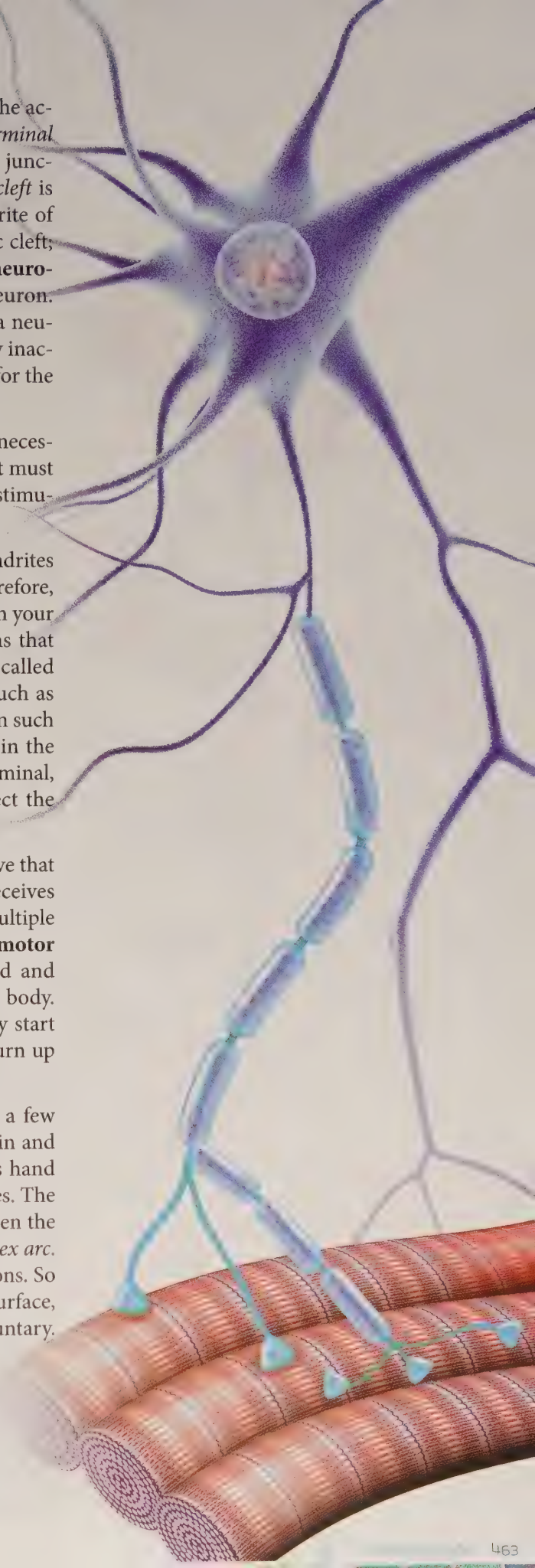
A neuron typically receives a signal at one of its dendrites, and the action potential moves down the axon until it reaches the *axon terminal* (see image on the facing page). The axon terminal is part of the junction between two neurons known as a **synapse**. The *synaptic cleft* is a gap between the axon terminal of one neuron and the dendrite of the next neuron. The action potential cannot cross the synaptic cleft; instead it causes the axon terminal to release molecules called **neurotransmitters** that stimulate receptor proteins in the other neuron. Neurotransmitters can also carry an action potential between a neuron and a muscle or gland. Enzymes in the synaptic cleft quickly inactivate the neurotransmitters so that receptor proteins are ready for the next action potential.

So how do your neurons avoid setting off action potentials unnecessarily? For a stimulus to cause an action potential in a neuron, it must be significantly strong enough. This level is called a **threshold**. A stimulus weaker than the threshold will not cause an action potential.

You may have noticed that an action potential starts at the dendrites and ends at the axon terminal. It never goes the other way. Therefore, you need nerves that go in both directions to take messages from your sensory organs to your brain and back to an effector. Neurons that carry information about your surroundings to the brain are called **sensory neurons**. Their dendrites may detect sensory input such as heat or cold, or they may be connected to a special sensory organ such as the eye. Sensory stimuli cause an action potential to begin in the dendrites and proceed up the axon until it reaches the axon terminal, which hands the signal to an **interneuron**. Interneurons direct the impulse to the brain where the impulse is interpreted.

Let's say that sensory nerves in your skin that detect cold perceive that the temperature in the house is too cold. When your brain receives the message, another signal is sent down the spinal cord to multiple interneurons in the spinal cord that then pass the impulse to **motor neurons**. Motor neurons have cell bodies in the spinal cord and axons that conduct the action potential to effectors all over the body. Depending on what you decide to do about the cold, you may start shivering, move to a warmer location, put on more clothing, turn up the thermostat, or perform all these actions.

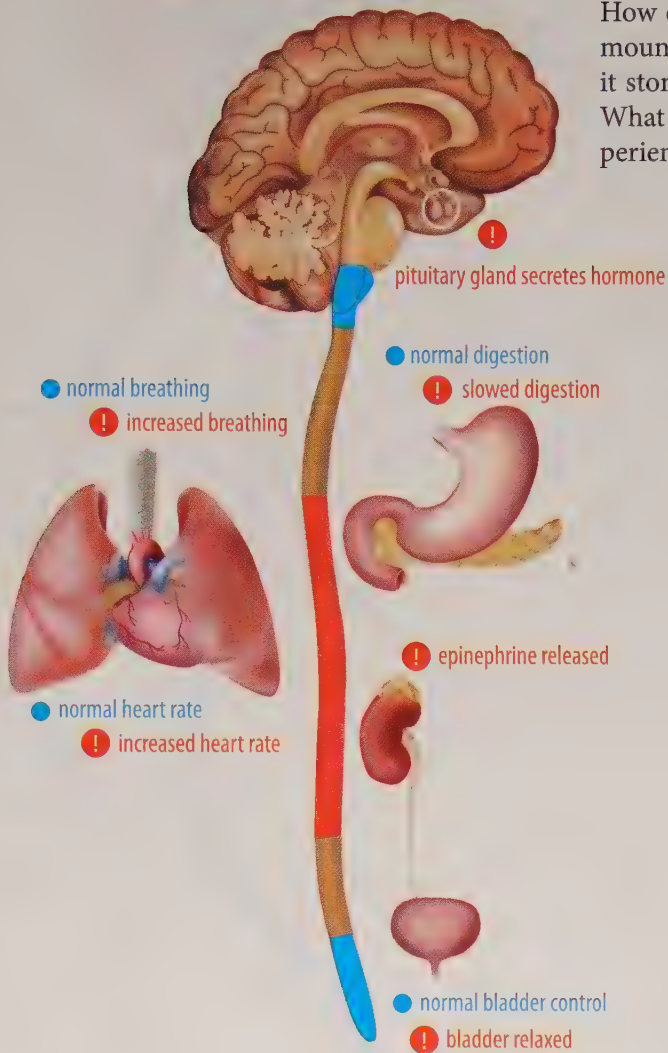
The speed of an action potential is incredibly fast. However, a few stimuli require action before a signal has time to reach the brain and return. A person who touches a hot object needs to move his hand away before thermal energy does too much damage to his tissues. The pain receptors send an action potential up a sensory nerve. When the impulse reaches the interneuron, it takes a shortcut called a *reflex arc*. The interneuron sends the impulse to one or more motor neurons. So by the time someone is even aware that he is touching a hot surface, his hand has already jerked back. This reflex is entirely involuntary. He doesn't have to think about it.



24.3 THE NERVOUS SYSTEM IN THE HUMAN BODY

● PARASYMPATHETIC NERVOUS SYSTEM

! SYMPATHETIC NERVOUS SYSTEM



The nervous system intricately controls the body, but even more amazingly, the nervous system performs tasks that we cannot explain. How does a cell or group of cells in the brain remember a beautiful mountain landscape seen two years ago? Or, for that matter, how does it store the concept and word *mountain*? How does a person think? What is a dream? What is an emotion? The brain controls all these experiences thousands of times each day. Scientists continue to explore these questions, and while we may never know for sure how the brain does all that it does, what we continue to learn fits much better with the worldview that says our brain was designed by God than with one that says our brains are products of time and chance.

So far we have discussed the nervous system under normal circumstances. During such times, the **parasympathetic nervous system**, part of the autonomic nervous system, is operating. The nerve impulses travel through neurons located in the brain stem and at the very bottom of the spinal cord. They stimulate proper digestion, absorption of food, and elimination of wastes. They also maintain normal heart and breathing rates as well as lower blood pressure. These functions are performed best when a person relaxes in a pleasant, peaceful environment. The parasympathetic system controls all your body functions while you sleep.

During times of danger, the other part of the autonomic nervous system, the **sympathetic nervous system**, takes over. Neural impulses pass through neurons located in the middle portions of the spinal cord. They help the body gear up in order to survive and be successful in stressful situations, such as a natural disaster. The impulses direct the adrenal glands, part of the endocrine system, to release a rapid surge of the hormone *epinephrine*, which stimulates a quick increase in heart and breathing rates and causes a rise in the blood sugar needed for muscle action. The pupils of the eyes dilate quickly so that the person can see where he is running. The digestive system is shut off, and the entire nervous system is put on emergency standby. This is often called the *fight-or-flight response*.



24A REVIEW QUESTIONS

1. Create a concept map using the following terms: autonomic nervous system, central nervous system, nervous system, parasympathetic nervous system, peripheral nervous system, somatic nervous system, and sympathetic nervous system.
2. Label each of the following structures as part of the central nervous system (CNS) or the peripheral nervous system (PNS).
 - a. cerebellum
 - b. axon connected to a pain receptor in the skin
 - c. interneuron
3. Which part of the brain is the link between the nervous system and the endocrine system?
4. Which cation is concentrated outside a neuron when it has a resting potential?
5. Explain how an action potential crosses a synaptic cleft.
6. List the three types of neurons involved in a reflex arc in the order in which an action potential travels during a reflex.
7. Which glands release epinephrine as part of the response when the sympathetic nervous system takes over?
8. Why might someone who is constantly overly excited have problems with high blood pressure and poor digestion?

24B

THE SENSORY ORGANS

How does the body observe the world around it?

24.4 THE STRUCTURE OF THE SENSORY ORGANS

The nervous system is an astonishing piece of divine engineering, but it would be severely handicapped without sensory organs to send messages to the brain about the body's surroundings. All known sensory organs contain **sensory receptors**, specialized dendrites of sensory neurons. Some receptors are little more than bare dendrites, but many have protein structures associated with them, and some are part of larger structures, most notably the eye and ear. Receptors are stimulated by various external and internal conditions and inform the body of changes. A single receptor is usually sensitive to only one type of stimulus. The sensory organs also contain structures and tissues that support and assist the receptors.

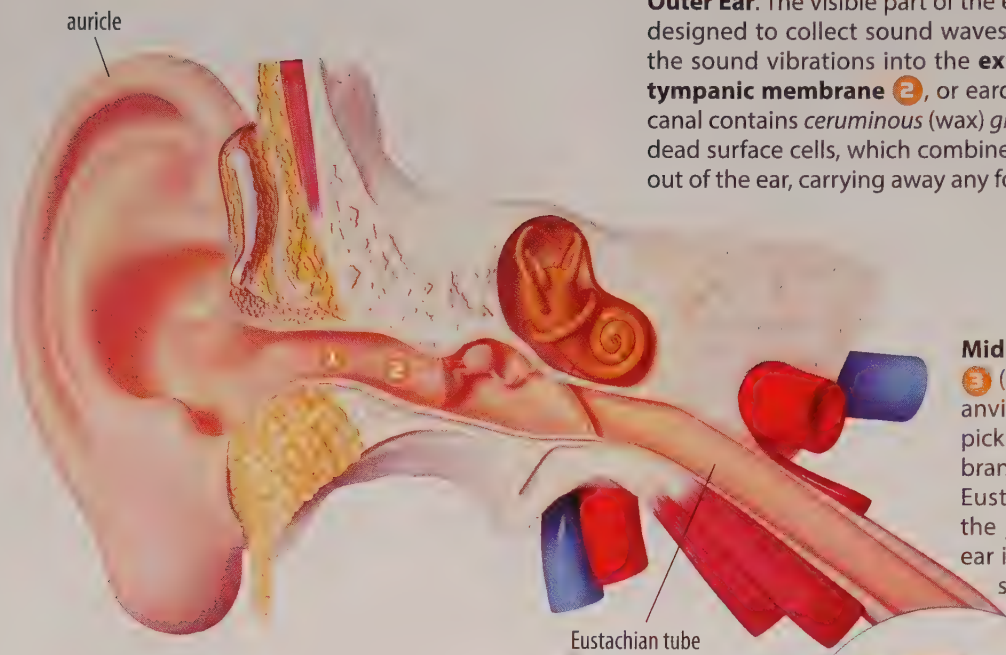
We perceive our world primarily aurally and visually, with sight being the predominant sense. Our sense of hearing allows others in close proximity to communicate verbally with us, and our eyes detect a host of color, distance, and texture variations in our surroundings. Let's take a closer look at these structures.

24B Questions

- » What are the major structures of the ear?
- » What are the major structures of the eye?
- » How do you sense your environment?
- » Why are senses important?



EXPLORING THE EAR



Outer Ear. The visible part of the ear is the *auricle*, a flap of cartilage designed to collect sound waves. The shape of the auricle directs the sound vibrations into the **external auditory canal** **1** to the **tympanic membrane** **2**, or eardrum. The skin lining the auditory canal contains *ceruminous* (wax) glands. The skin continuously sheds dead surface cells, which combine with earwax and gradually move out of the ear, carrying away any foreign matter.

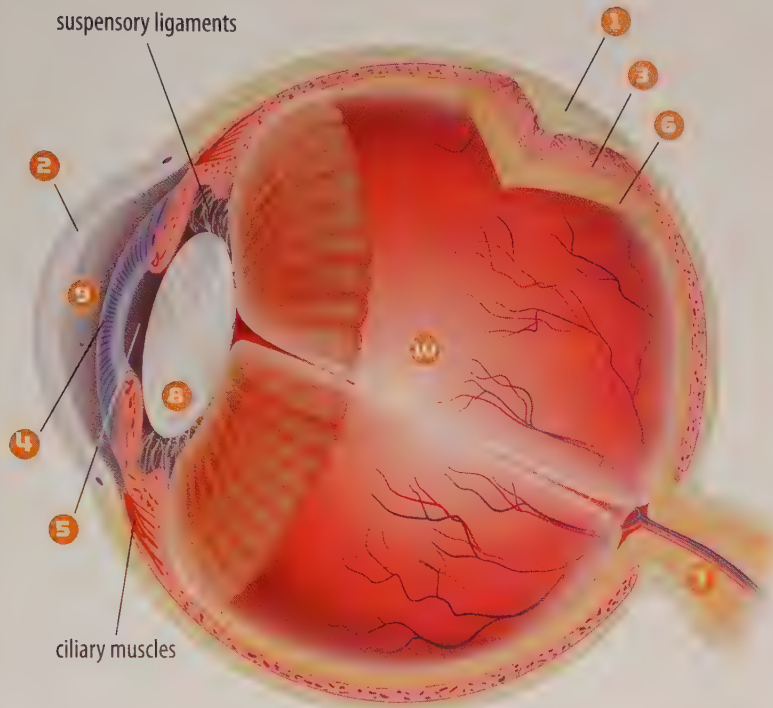
Middle Ear. Three tiny bones, the **malleus** **3** (MAL ee us; hammer), **incus** **4** (ING kus; anvil), and **stapes** **5** (STAY pee-z; stirrup), pick up vibrations from the tympanic membrane and carry them to the inner ear. The Eustachian tube allows air to enter from the pharynx. If the pressure in the middle ear is different from the atmospheric pressure, the difference causes the tympanic membrane to bulge outward or inward. This decreases the effectiveness of the eardrum and could even burst it if the pressure difference were to become too great.

Inner Ear. A series of channels and cavities within the skull form the *bony labyrinth* of the inner ear. The *membranous labyrinth* closely duplicates the shape of the bony channels in a tube-within-a-tube arrangement. The **cochlea** **6** receives vibrations from the stapes and transforms them into nerve impulses to be sent to the brain. The **semicircular canals** **7** along with the *utricle* and *sacculle* (both located between the semicircular canals and the cochlea) provide a sense of balance.



EXPLORING THE EYE

The outer layer of the eye, known as the **sclera** ①, is often called the *white of the eye*. This white, fibrous tissue maintains the shape of the eyeball. The **cornea** (KOHR nee uh) ② is a transparent portion of the sclera at the front of the eye that allows light to enter the eyeball.



The middle layer, the **choroid** (KOHR oyd) ③, is fragile and thin and contains many blood vessels for nourishing the innermost part of the eye. The pigmented **iris** ④, lying behind the cornea, is a muscular portion of the choroid that surrounds the **pupil** ⑤, which allows light into the eyeball. The muscles in the iris change the diameter of the pupil, regulating the amount of light entering the eye.

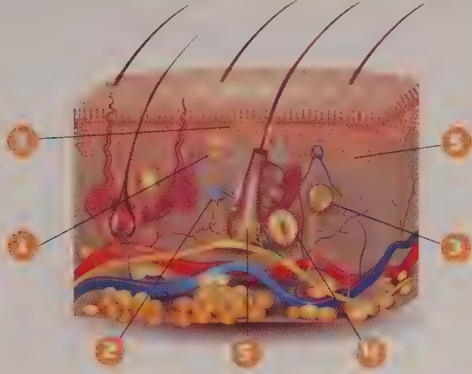
The third and innermost layer of the eye, the **retina** ⑥, contains thousands of specialized neurons and their fibers. These neurons are *photoreceptors* that can be stimulated by light. The impulses from the photoreceptors are transmitted to the **optic nerve** ⑦.

The **lens** ⑧ is a biconvex, semisolid structure supported by the *ciliary muscles* and *suspensory ligaments*, which can change the lens's shape.

The eye contains two cavities. The *aqueous humor* ⑨, a transparent, watery fluid, diffuses from blood vessels located near the ciliary muscles and fills the chamber between the lens and cornea. The larger chamber of the eyeball lies behind the lens and contains the *vitreous humor* ⑩, a clear, jellylike substance that provides support for the eye.

The *lacrimal* (tear) *gland* lies in the upper lateral region of each eyelid. Every day it secretes about 1 mL of fluid, which is spread evenly over the surface of the eyeball each time you blink. The fluid lubricates the eyelid and moistens and cleans the cornea. It also contains the enzyme *lysozyme*, which kills bacteria.



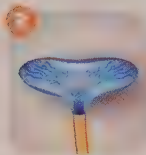


Because humans rely on their sight and hearing for most of their information, the other senses are often called *minor senses*. This is not to suggest that these are unimportant. Our chances of survival would be greatly reduced without our minor senses, and certainly life would be a lot less pleasant.

EXPLORING THE MINOR SENSES



TOUCH RECEPTOR



HEAT RECEPTOR



COLD RECEPTOR



PRESSURE RECEPTOR



PAIN RECEPTOR

Cutaneous receptors sense touch, cold, heat, pain, and pressure. Each sensation has different receptors, and certain receptors are more numerous in certain areas. Touch receptors lie near the skin's surface and are especially numerous in the fingertips and palms of your hands and the soles of your feet. Heat and cold

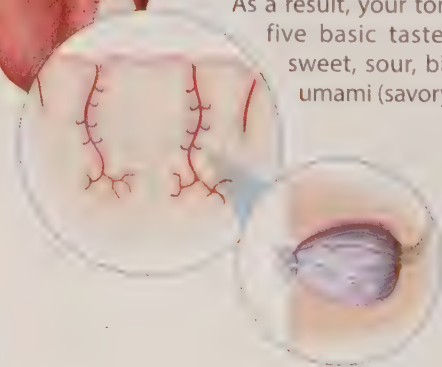
receptors are both buried deep in the dermis. Pressure receptors lie below the skin, and pain receptors can be found in nearly every tissue of the body. All the receptors create a nerve impulse that other nerves carry to the brain, which interprets the impulses and responds to them.

The sense of smell, or **olfactory sense**, is one of the least understood senses. Humans apparently can distinguish several thousand different odors. The molecules in the air stimulate *olfactory receptors*, which consist of numerous cells in the mucous membranes that line the upper region of the nasal cavities. After a short period of stimulation, the olfactory receptors become insensitive to that specific stimulus (smell). So you may notice a strong smell when you first walk into a room, but you will probably not notice it after several minutes. This is called *accommodation*, and while it occurs with most nerve sensations other than pain, it usually does not occur with these as quickly as with smell.



You have about 10,000 taste buds, primarily on the papillae of the tongue, but some are found on the inner surface of the cheek, roof of the mouth, and throat structures. Each taste bud holds numerous taste cells. These taste cells have chemoreceptors called *taste hairs* that stimulate a nerve impulse when they bind to one of five particular molecules or ions.

As a result, your tongue perceives five basic taste sensations—sweet, sour, bitter, salty, and umami (savory, meaty taste).



24.5 THE FUNCTION OF THE SENSORY ORGANS

Cutaneous, taste, and olfactory receptors all create nerve impulses that are carried along axons to the CNS. The photoreceptors in the eye and the auditory receptors in the ears send impulses in the same manner. Since the structures of the eyes and ears are better understood and are especially important to our existence, most of our discussion will concern sight and hearing.

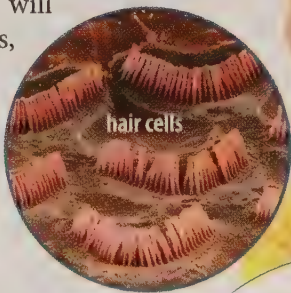
HEARING

Sound waves travel through the air and enter the external auditory canal. When the sound waves encounter the tympanic membrane, they cause it to start vibrating. The malleus, which is attached to the inside of the eardrum, carries those vibrations to the incus, which carries them to the stapes. The joints between these bones are flexible, and they greatly amplify the strength of sound vibrations as they carry them from the eardrum to the inner ear.

The stapes is attached to the inner ear through a membrane-covered hole in the bony labyrinth called the *oval window*. When the stapes vibrates the oval window, the fluid inside the cochlea vibrates along with it. Running the full length of the cochlea's inner surface, the *organ of Corti* contains thousands of receptor cells called **hair cells**. The vibrations in the cochlear fluid cause the cilia of the hair cells to bend as the fluid moves around them. Different hair-cell cilia will bend, depending on the frequency of the vibrations, allowing the cochlea to distinguish between different frequencies. The bending of the hair cells produces a nerve impulse that is transferred to nerve cells. These impulses are carried by the *auditory nerve* to the temporal lobe of the cerebrum, where they are perceived as different sounds.

BALANCE

While the cochlea is processing vibrations, the rest of the bony and membranous labyrinths are helping you keep your balance. The utricle and saccule control your sense of *static equilibrium*, your sense of body position when you're not moving. The utricle and saccule are lined with sensory hair cells embedded in a jellylike substance that contains crystals of calcium carbonate. When the head moves, the calcium carbonate crystals slide, pulling the jelly. This movement bends the hair cells, stimulating nerve impulses that are sent to the brain.



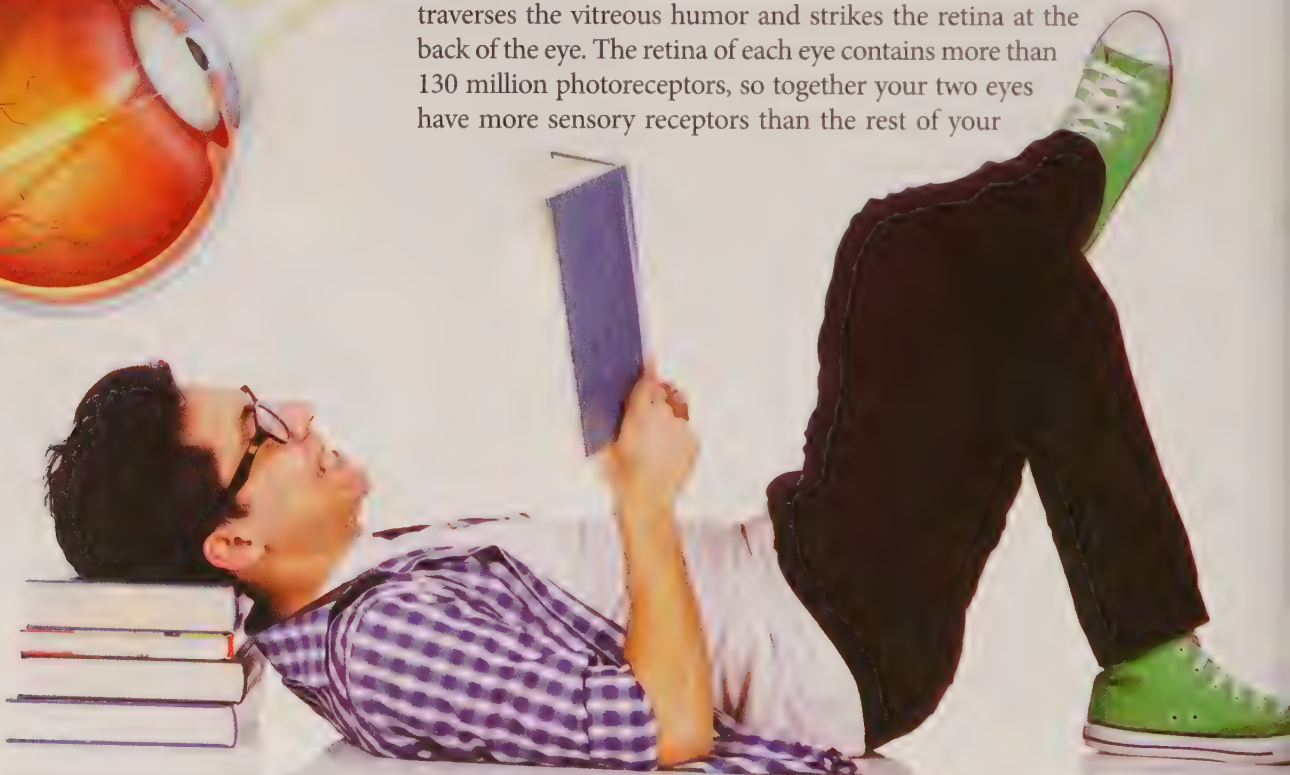
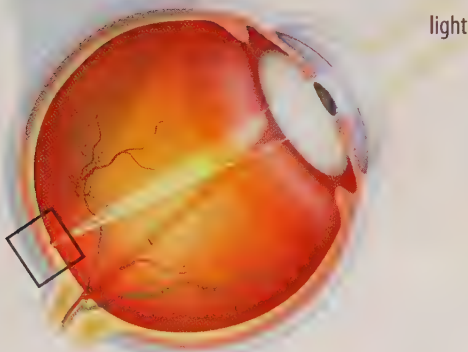
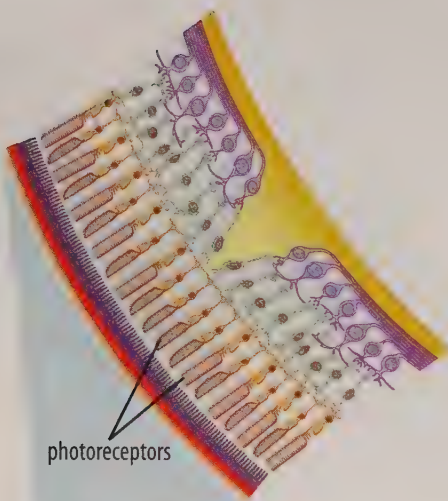
Your body's ability to respond automatically to positional changes when you are moving is called *dynamic equilibrium*. The three semicircular canals control this. Like the utricle and saccule, the semicircular canals are lined with hair cells embedded in a gelatinous layer, but they also contain fluid. During walking, running, and other dynamic activities, the fluid flows over the gelatinous material, bending the hair cells. The movement of the hairs stimulates nerve impulses that travel along a branch of the auditory nerve to the temporal lobe and cerebellum. Impulses from the cerebellum adjust muscle actions, producing coordinated movements for each position change.

SIGHT

Some objects, such as the sun and light bulbs, emit light. Most objects, including the moon, houses, and your body, reflect light. When light strikes an object, its atoms and molecules absorb certain wavelengths of light and reflect others. Our brain interprets different wavelengths as colors.

When light strikes your eye, it passes through the transparent cornea and aqueous humor and enters the pupil. It must then pass through the lens. By nature the lens is nearly spherical, but the suspensory ligaments attached at the upper and lower edge pull it nearly flat. The ciliary muscles contract to reduce the tension of the suspensory ligaments, allowing the lens to become more convex. A more convex lens focuses light from nearby objects on the retina, allowing you to clearly see the object. When focusing on distant objects, the ciliary muscles relax, allowing the suspensory ligaments to pull the lens into a flatter shape. The ability of your eyes to focus on objects at different distances is called *visual accommodation*.

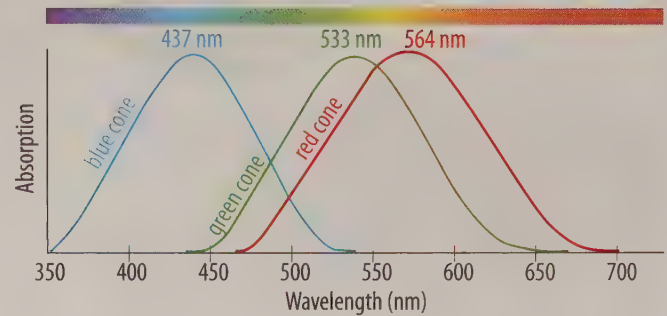
Once the now-focused light has passed through the lens, it traverses the vitreous humor and strikes the retina at the back of the eye. The retina of each eye contains more than 130 million photoreceptors, so together your two eyes have more sensory receptors than the rest of your



body put together. Most of these photoreceptors, called **rods**, are scattered over the retina. They are sensitive to low-intensity light but cannot distinguish color. They can rapidly discern movement, but produce only a shadowy image of light and dark. As a result, color is difficult to see in low-light situations.

The other type of photoreceptors, the **cones**, detect color. You actually have three types of cones. Each one detects a range of wavelengths of light, which our brain interprets as different colors, and each type of cone is most stimulated by the wavelengths we perceive as one of the primary colors. So one type of cone is most stimulated by the wavelengths we interpret as red, one is most stimulated by the wavelengths we interpret as green, and the third is most stimulated by the wavelengths we interpret as blue. Of course, we can see many more colors than just those three. When light waves such as those we see as yellow strike our retinas, they stimulate both red and green cones. The brain receives the signals from both of the stimulated types of cones and interprets the object as yellow. The exact shade of color depends on which type of cone is most stimulated by that particular wavelength. The cones are especially concentrated in the *fovea* (FOH vee uh), a small depression in the central region of your retina. As a result, you see the sharpest color image of an object when you are looking directly at it in a well-lit environment. In dim light, the image would be less clear because there are no rods at the fovea.

Both rods and cones contain light-sensitive pigments, and when the photoreceptors are stimulated by light, the pigments decompose. These substances initiate a complex biochemical pathway that changes light energy into a nerve impulse, which is carried to the cerebrum's occipital lobe by the optic nerve. The brain then interprets the sensory input as images and colors.

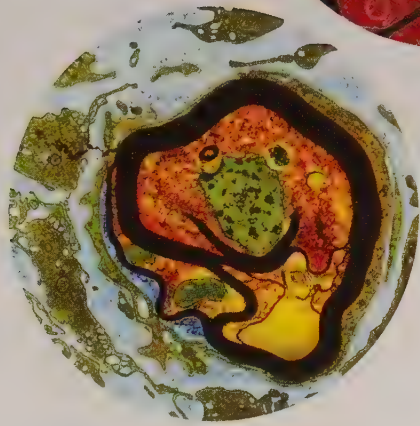
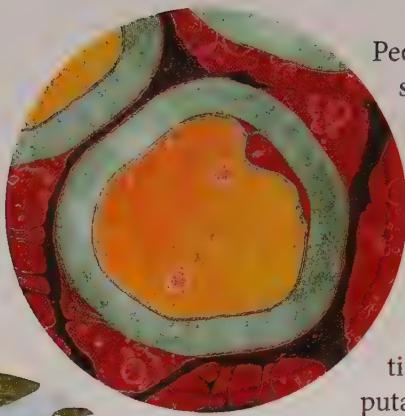


24.6 THE SENSORY ORGANS IN THE HUMAN BODY

Your sensory organs work with your nervous system to keep you aware of your surroundings. You can see potential danger, hear the voice of a family member, or feel if an object is hot or cold without actually touching it. Most of a baby's sensory organs are fully functional at birth, although eyesight continues to develop over the first five months of life. However, babies lack a framework to process data; this comes from experience. As a child grows, he learns to incorporate new information with previously learned information.

A newborn can feel pain, and while we often think of pain as a bad thing, it serves a very useful purpose. It alerts us when something is wrong. For this reason, pain receptors are located in nearly every tissue of the body, unlike other sensory organs, which are usually concentrated in a single organ. However, some tissues have more pain receptors than others.





24-1

A healthy axon (top) is surrounded by a thick myelin sheath (green). In an axon infected by leprosy (bottom), the myelin sheath (brown) disintegrates.

People who suffer neuropathy from a disease such as leprosy often suffer injuries or infection without realizing it. Even though antibiotics can cure leprosy, they cannot restore the function of the pain receptors destroyed by the leprosy bacteria. If any pain receptors survive the leprosy attack, they are usually located deep in the tissue. As a result, the person may not feel any pain from an infection until it has reached these deep tissues. This kind of infection is much harder to treat than one that is recognized quickly. Even though an injury may not cause pain, it still causes tissue damage, which can lead to infection, possibly requiring amputation of a limb.

Those living with neuropathy caused by conditions such as diabetes often suffer continual pain, tingling, and numbness. In addition to making life difficult, neuropathy can create the same problems as it does for leprosy sufferers. Injuries may go unnoticed, and infection may become very bad before the victim seeks treatment.

The main difficulty in treating neuropathy lies in the fact that nerve tissue, unlike other tissue, typically does not regenerate. Although learning to trick neurons into regenerating would be a great long-term goal, several strategies can now be used to limit the damage done by neuropathy.

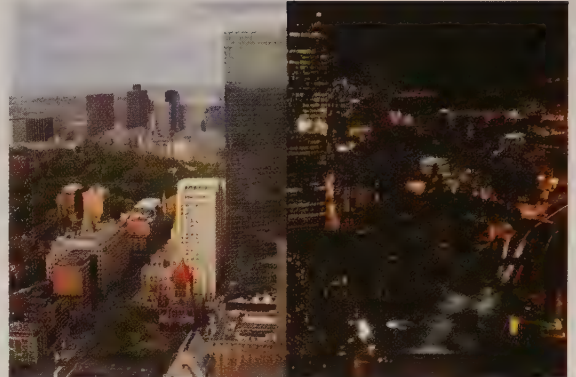
Currently, the best way to prevent neuropathy is to attack its root cause. For neuropathy caused by leprosy, this means diagnosing and treating leprosy quickly, before it has time to destroy the patient's neurons. However, this is often difficult since most cases of leprosy occur in places with little access to healthcare. The need for medical workers is often great. Several Christian organizations establish medical clinics that work with a local church or missionary, seeing to both the physical and spiritual needs of people.

This same *control-the-underlying-cause* approach also works best for treating neuropathy caused by diabetes or other noncontagious, chronic conditions. Diabetes can be controlled, though it cannot be cured. Pain relievers can also relieve some of the discomfort caused by neuropathy.

However, treating the underlying cause works only when you know what it is. Some neuropathy sufferers are diagnosed with *idiopathic neuropathy* because physicians cannot find a cause. In these cases, the only treatments currently available help the individual manage the symptoms.

24B REVIEW QUESTIONS

1. Indicate whether each of the following structures is part of the outer ear, middle ear, or inner ear.
 - a. incus
 - b. auricle
 - c. saccule
2. The cornea is a transparent section of what layer of the eye?
3. Order the names of the following structures from largest to smallest: taste bud, taste cell, taste hair.
4. List the following structures in the order that a vibration would pass through them: auditory nerve, cochlea, eardrum, external auditory canal, hair cells, stapes.
5. Which structures of the inner ear control your sense of dynamic equilibrium?
6. Visual accommodation describes the function of what structure of the eye?
7. You are walking after dark, and you see the silhouette of an object up ahead. Which type of photoreceptors are your eyes using? Explain.
8. Some people with leprosy-induced neuropathy can pick up a hot dish without feeling the heat. Why might this be dangerous to them?



24C

THE ENDOCRINE SYSTEM

How does the body tell cells when to grow and reproduce?

247 THE STRUCTURE OF THE ENDOCRINE SYSTEM

Remember the adrenal glands that are responsible for the fight-or-flight response? They are part of the endocrine system. Glands such as the salivary glands secrete their products through a duct, a tube that connects the gland to the organ where its product is needed. However, endocrine glands have no ducts. Instead, they release their products, chemical messengers called **hormones**, directly into the bloodstream. These hormones can affect multiple cells far away from the gland's location.

The nervous system can cause a change in the body very quickly, but its effect is usually short-lived. To even flex your arm requires many nerve impulses, one right after another. The endocrine system usually works more slowly, but its effects are longer lasting. You have eight major endocrine glands located throughout your body.

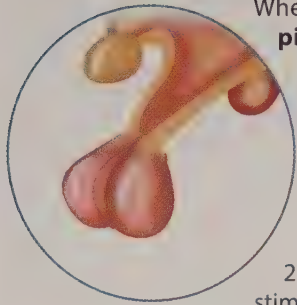
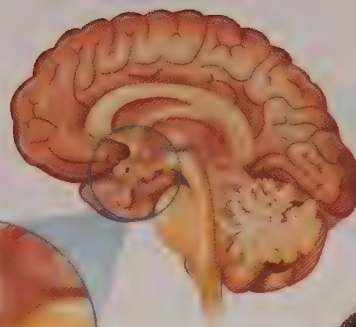
24C Questions

- » What's the difference between the nervous system and the endocrine system?
- » How do hormones tell the body what to do?
- » How does a gland know when to produce a hormone?
- » How do hormones help a child grow into an adult?



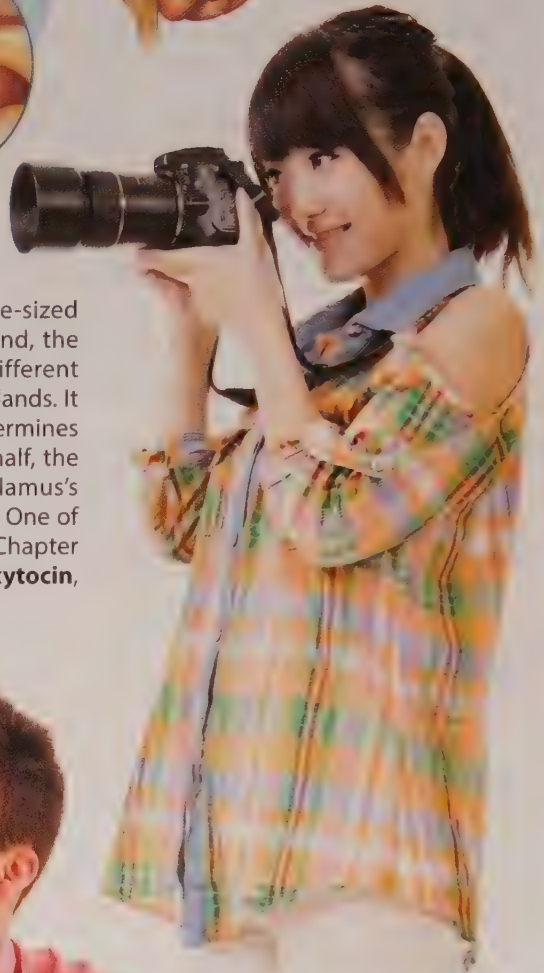
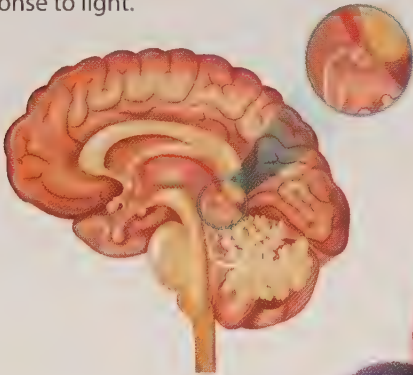
EXPLORING THE HUMAN ENDOCRINE GLANDS

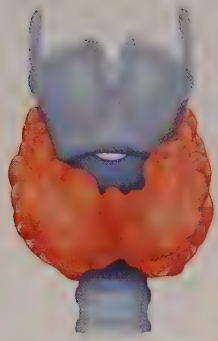
As you learned in Section 24A, the hypothalamus is the connection between the nervous system and the endocrine system. Its neurons produce hormones that are released at the ends of the axons in much the same way that neurotransmitters are released by most other neurons. Many of these hormones control the pituitary gland by functioning as *releasing hormones*, like a chemical green light, and *release-inhibiting hormones*, like a chemical red light.



When the hypothalamus's hormones reach the marble-sized **pituitary gland**, they affect the front half of the gland, the *anterior lobe*. The anterior lobe secretes several different groups of hormones that control other endocrine glands. It also releases **growth hormone**, which largely determines an individual's height and size. The gland's back half, the *posterior lobe*, provides a place for the hypothalamus's neurons to release two other important hormones. One of these, antidiuretic hormone, you learned about in Chapter 23 in connection with the urinary system. The other, **oxytocin**, stimulates smooth muscles to contract.

A small oval structure, the **pineal gland** lies deep in the brain between the cerebral hemispheres near the thalamus. The pineal gland secretes the hormone *melatonin*, which is believed to affect a person's circadian rhythms. The pineal gland releases melatonin in response to darkness and stops releasing it in response to light.





The **thyroid** sits in front of the trachea, just below the larynx, and produces **thyroxine** and **triiodothyronine**. These hormones essentially control the speed of the cells of the body. They increase oxygen use, stimulate heat production in most body tissues, and indirectly affect growth. The production of these two hormones is controlled by *thyroid-stimulating hormone* (TSH) from the anterior lobe of the pituitary gland. You remember from Chapter 21 that excess calcium can be stored in the bones. The hormone **calcitonin**, produced by the thyroid, is responsible for moving excess calcium from the blood to bones.

The four **parathyroid glands** are located in pairs on each side of the thyroid. They produce *parathyroid hormone*, which works in opposition to calcitonin. When parathyroid hormone is present, calcium moves from the bones to the blood and the kidneys reduce the amount of calcium excreted in urine.





Perched atop the kidneys, the **adrenal glands** have a two-layered structure similar to the structure of the kidneys. The inner *adrenal medulla* secretes **epinephrine** and **norepinephrine**, which produce the fight-or-flight response of the sympathetic nervous system that you learned about in Section 24A. The outer *medulla cortex* is influenced by *adrenocorticotropic hormone* (ACTH) from the anterior lobe of the pituitary gland. It secretes three primary groups of hormones. The first group, **cortisol**, helps regulate glucose metabolism during emergencies. The second group, **aldosterone**, regulates the concentration of minerals, ions, and water in the blood and urine. The third group, the *adrenal androgens*, are sex hormones (see the next paragraph). Although androgens are primarily male sex hormones, women do produce small amounts that are usually converted into female sex hormones.

From birth, the **gonads**, or reproductive organs, produce small amounts of sex hormones. In males, the testes produce hormones called **androgens**, the most familiar of which is **testosterone**. In females the ovaries produce hormones called **estrogens** and another hormone called **progesterone**. During the early teen years, the anterior lobe of the pituitary gland begins to produce *gonadotropins* that cause the gonads to begin producing sex hormones in far greater amounts.



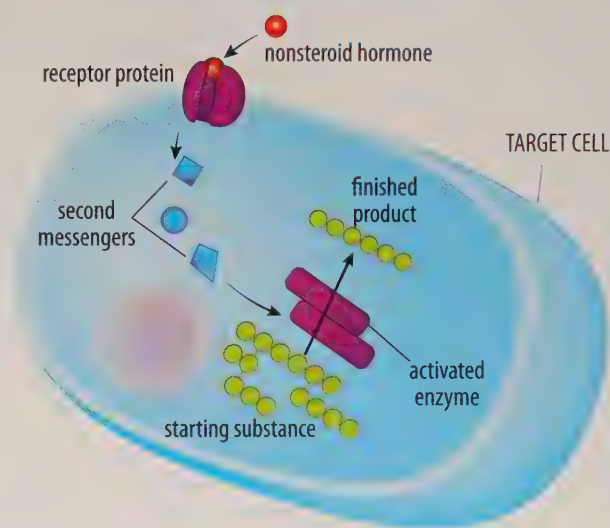
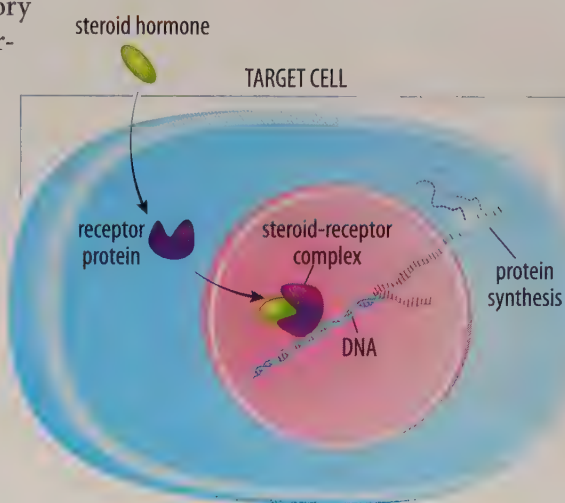
You learned in Chapter 23 that the pancreas releases all those different digestive enzymes in pancreatic juice. The pancreas also contains groups of cells called *islets of Langerhans*, which release two hormones into the blood stream, **insulin** and **glucagon**. When the blood glucose level rises, for instance after a meal, insulin causes the body cells to absorb glucose from the bloodstream and causes the liver to store glucose as glycogen. Both of these actions reduce the blood glucose level. When the blood glucose level drops, glucagon causes the liver to convert glycogen to glucose and causes fats to be converted to glucose, raising the blood glucose level.

24.8 THE FUNCTION OF THE ENDOCRINE SYSTEM

Unlike the nervous system, which directly connects to the organs and tissues that it controls, endocrine glands can control structures far away from their location. Once a hormone enters the circulatory system, it can travel to its **target cells** in any part of the body. Target cells have specific receptors that recognize and bind specific hormones. As a result, hormones pass by nontarget cells without affecting them.

Hormones come in two basic forms, and each type binds to the receptors in its target cell differently. **Steroid hormones** have a high lipid content and can easily diffuse through the target cell's cell membrane and enter the cytoplasm. Once inside the cell, the steroid hormone binds with one or more receptors to form a *hormone-receptor complex* that alters the cellular processes of the target cell. Often the hormone-receptor complex binds to the DNA and activates specific genes. The gene is then transcribed into mRNA, which is then translated into proteins that cause the desired effect in the target cell.

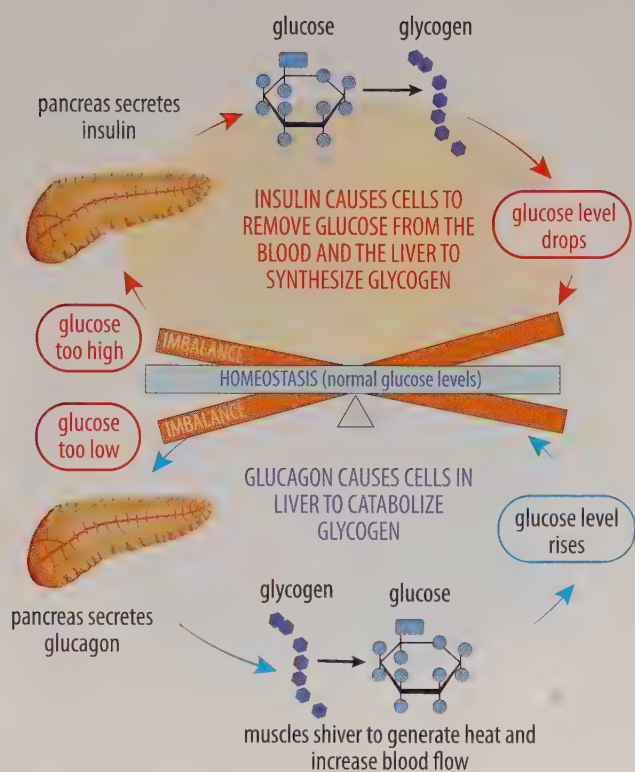
Nonsteroid hormones lack a high lipid content and cannot diffuse through the cell membrane of their target cells. Instead, they bind to receptors imbedded in the cell membrane of their target cells, causing the release of other chemicals, called *second messengers*, into the cytoplasm. These second messengers begin a chain of cellular processes that produce the desired changes in the target cell.



24.9 THE ENDOCRINE SYSTEM IN THE HUMAN BODY

Hormones influence or control many metabolic processes throughout the body, including the water balance in blood, reproduction, growth, and blood pressure. They also prepare the body for important life changes. The sex hormones are steroid hormones that, during *puberty* (see Chapter 25), activate genes that have been inactive since birth. As these genes produce proteins, major changes begin to happen. The reproductive organs begin to grow and the body begins to change.

As you can see, hormones are powerful. So how does the body control them? Hormone production is often controlled by negative feedback. For instance, the blood glucose level is part of the negative feedback loop for both insulin and glucagon. A low blood glucose level signals the pancreas to stop producing insulin, and a high blood glucose level halts glucagon production. This type of control allows the different hormones to maintain homeostasis, instead of disrupting it as they would do if they were allowed to operate unchecked. Additionally, many endocrine glands control or at least influence the production of others. The pituitary gland affects many of the other glands, and the adrenal glands initiate the production of sex hormones from the reproductive organs, to name just two examples.



If hormones remained in the bloodstream, they would build up until they caused all the different body processes to run out of control. Homeostasis would be destroyed, and we would all die very quickly. However, our loving Lord has designed our bodies to prevent this from occurring. The liver breaks down hormones, and many are removed by the kidneys to be excreted in urine.

The endocrine system seems to be interconnected with our thoughts and emotions. The exact relationship between these aspects of our minds is not known, but it is important to remember that humans are spiritual as well as physical creatures and that though the endocrine system is powerful, it is not all-powerful.

In spite of what is sometimes thought, Christians who are walking with God can feel depressed. Many people struggle with mood swings or just "feeling down," at least partially as a result of changes in their hormone levels. But while these types of mood changes are normal, we can easily fall into the trap of mistaking these feelings for reality. Even when Christians are feeling down, God's grace is sufficient to enable the believer to do what he should do. It's important to remember during dark times that Christ has redeemed all those who trust Him and has promised to always be with His people, even when they don't *feel* that it's true. He has not called us to always feel happy, but He has called us to trust and obey Him.

24C | REVIEW QUESTIONS

1. Which structure is part of both the nervous system and the endocrine system?
2. Which endocrine gland releases hormones that control several other endocrine glands?
3. Which part of the adrenal glands releases hormones in response to signals from the sympathetic nervous system?
4. Which structures in a male begin to increase hormone production in response to gonadotropins?
5. Explain why a steroid hormone does not need a membrane-bound receptor to influence its target cell.
6. A target cell is acted on by a hormone, but the mRNA levels in the cell remain the same. What type of hormone acted on this cell? Explain.
7. The sex hormones are steroid hormones. How do these hormones cause the physical changes of puberty?
8. What two organs are especially important in removing hormones from the bloodstream?
9. Human beings are both physical and spiritual beings. What does that tell us about our emotions and our responses?

REVIEW QUESTIONS

CONCEPT REVIEW

1. Which part of your brain handles activities such as deciding to go for a walk?
2. Having decided to go for a walk, you step outside and realize how hot it is. Which lobe of your cerebrum receives the nerve impulses from your temperature receptors?
3. Indicate whether each of these ions is inside or outside a neuron's cell membrane during a resting potential.
 - a. potassium cations
 - b. anions
 - c. sodium cations
4. Which part of a neuron typically receives an incoming nerve impulse?
5. A speck of dust strikes the skin of a person with normal sensory perception, but he does not feel it. What is the most likely explanation?
6. Jeff left school at 3:30, played basketball for a half-hour, showered, and walked home, arriving just before supper at 5:00. Which division of his autonomic nervous system was active during this time?
7. Rhonda is brought to an eye doctor. Her pupil is not changing size in response to changes in light intensity. It is determined that the issue is in a smooth muscle. What structure is likely at fault?
8. Describe olfactory accommodation.
9. Which structure of the cochlea contains the hair cells?
10. Which structures of the membranous labyrinth are not involved in hearing?
11. Curtis can see some colors but not all of them. The most likely cause is a mutation in one of the genes that code for what eye structure?
12. What is the main obstacle to treating neuropathy?
13. Which endocrine gland releases a hormone when the blood sugar is too high?
14. Hypoglycemia occurs when the blood glucose level becomes too low. Generally, it is caused when too little of a hormone is produced. Given what you have learned about hormones, which hormone does the body of a hypoglycemic person lack?
15. What would happen if the body accumulated too much parathyroid hormone?
16. Place the following terms in order of the sequence that steroid hormones effect change in a cell: cell membrane, DNA, hormone-receptor complex, protein synthesis.
17. A newly discovered hormone is isolated and discovered to be made almost entirely of amino acids. What type of hormone is it? Explain.

Key Terms

central nervous system	459
meninges	459
cerebrospinal fluid	459
peripheral nervous system	459
neuron	459
cell body	459
dendrite	459
axon	459
cerebrum	460
thalamus	460
hypothalamus	460
cerebellum	460
brain stem	460
resting potential	462
action potential	462
synapse	463
neurotransmitter	463
threshold	463
sensory neuron	463
interneuron	463
motor neuron	463
parasympathetic nervous system	464
sympathetic nervous system	464
sensory receptor	465
external auditory canal	466
tympanic membrane	466
malleus	466
incus	466
stapes	466
cochlea	466
semicircular canal	466
sclera	467
cornea	467
choroid	467
iris	467
pupil	467

(continued)

T Key Terms (continued)

retina	467
optic nerve	467
lens	467
olfactory sense	468
hair cell	469
rod	471
cone	471
hormone	473
pituitary gland	474
growth hormone	474
oxytocin	474
pineal gland	474
thyroid	475
thyroxine	475
calcitonin	475
parathyroid gland	475

(continued)

TRUE OR FALSE

18. A neuron's cell body always lies between its dendrites and its axon.
19. Most nerve impulses are sent directly to the brain and do not enter a reflex arc.
20. Scientists have a very good understanding of the nervous system.
21. The tympanic membrane creates a nerve impulse that the auditory nerve carries to the brain.
22. The vitreous humor is essentially empty space.
23. The rods and cones are embedded in the cornea.
24. The pineal gland controls the rest of the endocrine system.
25. Each hormone affects every cell of the body.
26. Because moods are at least partly caused by hormones, we have no real control over our behavior.

CRITICAL THINKING

27. A friend believes that humans are purely physical creatures. Explain why her thinking is wrong.

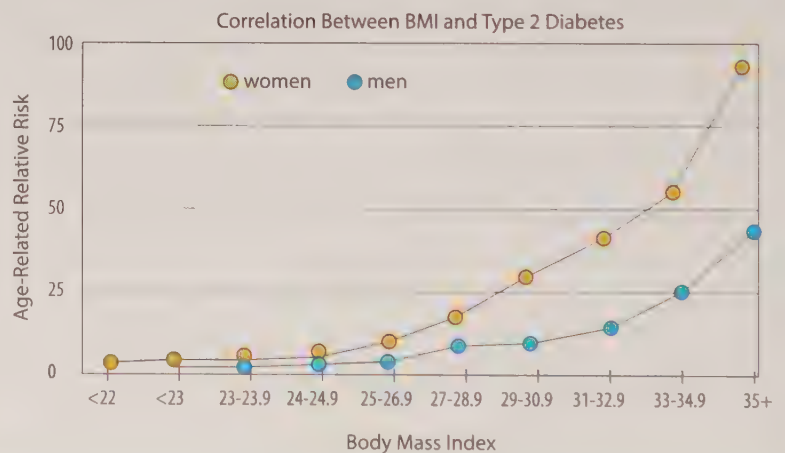
CASE STUDY: TYPE 2 DIABETES

Diabetes is a disease in which the blood glucose level is consistently too high but the cells do not receive enough glucose. There are several causes, but one of the common forms, Type 2, is caused by the cells becoming insensitive to insulin, a condition called *insulin resistance*. Although sufficient insulin is present, the target cells do not respond as they should.

Because the cells do not take in glucose, they cannot perform cellular respiration, and the blood glucose level continues to rise. Over time, the high concentration of glucose can damage many different organs, including the kidneys, heart, eyes, and nerves. Because the cells are starving, the body begins to break down fats for energy, but this doesn't really help either. Instead, the breakdown of fats lowers the blood pH, a potentially fatal condition known as *acidosis*.

People who have diabetes must manage their condition. Since being overweight makes diabetes worse, being careful to maintain a healthy body weight is important. Exercise also improves the blood glucose level, so a daily exercise routine will often help a diabetic

person manage the condition. Diet is probably the most important aspect of a diabetes management policy. A diet low in sugars and high in protein helps to keep blood glucose from spiking after each meal. Finally, some diabetics need to check their blood glucose level each day and give themselves injections of insulin.



Use the Case Study on the facing page to answer Questions 28–29.

- 28.** Given the data in the study's chart, what is something that teens can do to reduce their risk of developing Type 2 diabetes?
- 29.** While Type 2 diabetes often strikes in adulthood, Type 1 typically shows up early, often during childhood. In Type 1 diabetes, the pancreas reduces or even ceases producing insulin, often because the body's immune system mistakes the islets of Langerhans as foreign cells. Type 2 diabetes patients can sometimes manage their diabetes without insulin. Could Type 1 diabetes patients do the same?
- 30.** Many of the neurons in the CNS have myelin sheaths protecting the axons. In multiple sclerosis (MS), the immune system attacks the myelin sheaths and eventually destroys the nerves. What symptoms is MS likely to cause?
- 31.** Although there is no cure for MS, sometimes there are ways to slow its progress. One of the most common classes of MS medicine is beta interferons, which are thought to inhibit some aspects of the immune system. How might this help?

Key Terms *(continued)*

adrenal gland	476
epinephrine	476
norepinephrine	476
cortisol	476
gonad	476
androgen	476
testosterone	476
estrogen	476
progesterone	476
insulin	476
glucagon	476
target cell	477
steroid hormone	477
nonsteroid hormone	477



CHAPTER 25

REPRODUCTION, GROWTH, AND HEALTH

25A THE REPRODUCTIVE SYSTEM 483

25B HUMAN GROWTH AND DEVELOPMENT 491

25C BALANCED LIVING 497

MISSING BABIES

For many people, the birth of a child is a celebration of life. But for others, a child is unfashionable, a burden, and even illegal. Countries in Europe and Asia have seen their populations flat line or shrink as people stop having children. In places like China, people are concerned about overpopulation and view children as a drain on precious natural resources. Abortions of baby girls are very common in China and India. Because of this, there is an increasing gender gap in several countries that favors male babies. But care and provision for the elderly depends on a growing, balanced population. When families stop having children or abort the ones they do conceive, society suffers.

But why is having children a good thing? Modern culture is questioning the very basics of family, gender, and sexuality. Who decides what is good for society?

THE REPRODUCTIVE SYSTEM

How does the body produce new life?

25.1 THE STRUCTURE OF THE REPRODUCTIVE SYSTEM

The reproductive system is different from every other system that we've studied in the human body: *you can live without it*. In fact, the reproductive system works *against* all the other systems. Reproduction actually upsets rather than supports homeostasis. Just ask any pregnant mom—reproduction really does make life processes harder. An expectant mom has to breathe, eat, excrete, and drink for her growing baby, putting increased demands on her respiratory, digestive, excretory, and circulatory systems. However, though an *individual* can live without the reproductive system, the *human race* can't continue to exist without reproduction.

Reproduction involves one aspect of the Creation Mandate that we haven't actually mentioned: the command to have children (Gen. 1:28). Reproduction is part of God's good and wise command for all of creation, and it extends up to His highest creation—mankind. God made sex something that people can enjoy within God's design for the family, but He also made it something productive for society. He is the only one who can determine what is ultimately good for our families, culture, society, and mankind.

Because of the Fall, reproduction is harder, just as the work of exercising good and wise dominion is. But that doesn't mean we shouldn't reproduce. In fact, one part of having good and wise dominion means having children. Society and the world will bear the consequences if we do otherwise. On the other hand, we can enjoy the blessings of sex and children within the context of the biblical family. Let's take a professional look at the male and female organs that God has given us for our blessing and for the benefit of mankind. Follow the numbers in the diagrams that follow to see where sperm in a male and eggs in a female come from and how they unite to produce a baby.

25A Questions

- » What is the purpose of the reproductive system?
- » How do an egg and sperm unite to become a new person?
- » What does the Bible say about sex?



THE MALE REPRODUCTIVE SYSTEM

1 The testes (s. **testis**) are the most significant organs of the male reproductive system—the organs that produce tadpole-like sperm to fertilize the female's eggs. Males have two testes.

2 **Seminiferous tubules.** Cells lining these tiny tubes in the testes undergo meiosis to produce millions of haploid sperm.

3 The **scrotum** is the sac of skin that contains the testes. It keeps the sperm at just the right temperature, about 2°C lower than body temperature. The testes in a baby boy gradually descend from the pelvis into the scrotum during development before birth.

4 **Epididymis.** Sperm migrate to this tightly coiled tube to mature.

5 **Vas deferens.** Sperm travels to the prostate gland through this tube.

6 **Prostate gland.** This walnut-sized gland produces **semen**, a fluid that surrounds, protects, and nourishes sperm migrating from the testes. Sperm now in semen migrates to the urethra.

7 The **penis** is the male appendage that deposits sperm. The penis also contains the urethra, as well as muscles, ligaments, and spongy material that control the angle of the penis. The muscles relax and blood flows into the spongy material when the male is sexually aroused, causing an *erection*. Sperm in semen are deposited in a process known as *ejaculation*, which takes place at the peak of a man's sexual experience, called an *orgasm*. If ejaculation happens during *sexual intercourse*, it may produce a fertilized egg.

8 The urethra conducts both urine from the urinary system and sperm-containing semen from the prostate gland.

9 Urinary bladder. A male's urinary and reproductive systems use many of the same vessels.



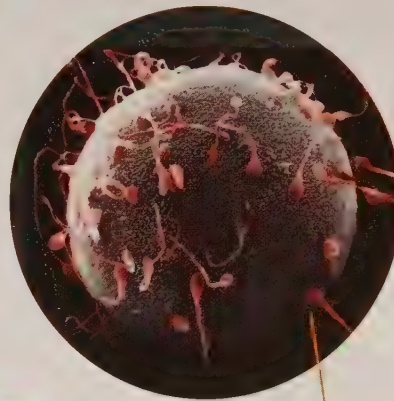
THE FEMALE REPRODUCTIVE SYSTEM



1 The **ovaries** are the most significant organs of the female reproductive system; they produce the female's haploid eggs, called ova (s. **ovum**). Females have two almond-sized ovaries with thousands of immature ova. However, a sexually mature woman's ovaries usually release only one ovum each month. A developing ovum is nourished by surrounding cells called *follicles*.

2 **Vagina.** Sperm from the male enter the female's body during sexual intercourse at the vagina, an elastic tube that leads from outside the woman's body to the cervix.

3 **Cervix.** Sperm migrate up the vagina through this narrow opening into the uterus.



unfertilized egg

sperm attempting to fertilize egg



4 **Fallopian tubes.** These ducts, also called *oviducts*, carry the single, mature ovum away from the ovaries toward the uterus. This is where the male's sperm and the female's ovum unite to form a zygote, which develops into a human being.

5 **Uterus.** This pear-shaped organ is where a fertilized ovum ends its trip if the timing is right. Here a new life receives nourishment and develops. The uterus's epithelial lining, called the *endometrium*, thickens every month to prepare to nourish a fertilized ovum.

6 **Urinary bladder.** Unlike in a male, the female's urinary and reproductive systems do not use the same vessels and are kept separate.

25.2 THE FUNCTION OF THE REPRODUCTIVE SYSTEM

THE MENSTRUAL CYCLE

- 1 Hormones stimulate a follicle to grow around an immature ovum.
- 2 The follicle and ovum continue to grow and mature.

God's purpose for the function of the human reproductive system is to produce children within the context of a biblical family. But how does the woman's body prepare for and provide for a developing baby? It begins with the **menstrual cycle**, the cycle of changes that happen to a woman's uterus to prepare to nurture a developing baby in the event that one of her ova is fertilized by the man's sperm.

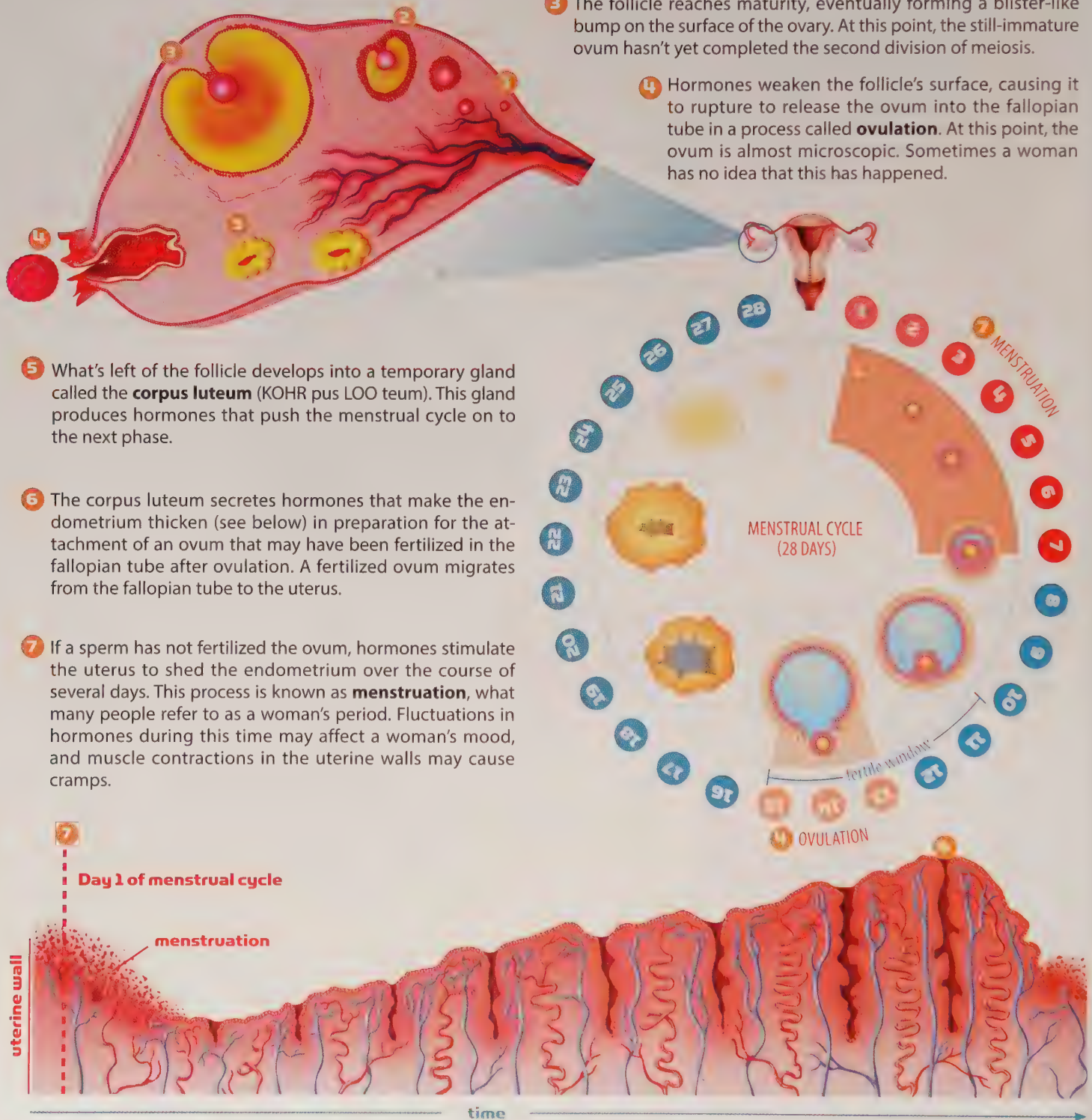
- 3 The follicle reaches maturity, eventually forming a blister-like bump on the surface of the ovary. At this point, the still-immature ovum hasn't yet completed the second division of meiosis.

- 4 Hormones weaken the follicle's surface, causing it to rupture to release the ovum into the fallopian tube in a process called **ovulation**. At this point, the ovum is almost microscopic. Sometimes a woman has no idea that this has happened.

- 5 What's left of the follicle develops into a temporary gland called the **corpus luteum** (KOHR pus LOO teum). This gland produces hormones that push the menstrual cycle on to the next phase.

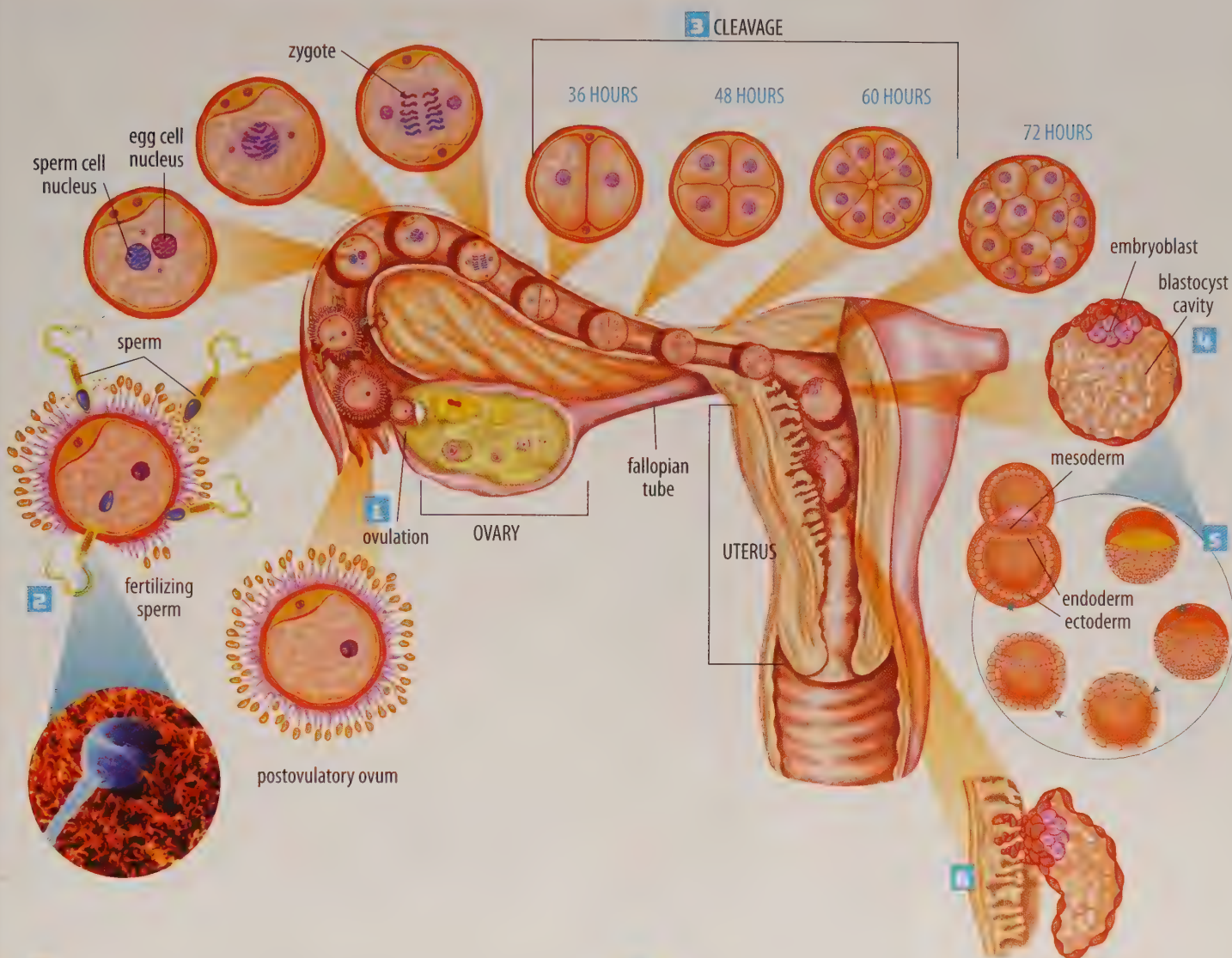
- 6 The corpus luteum secretes hormones that make the endometrium thicken (see below) in preparation for the attachment of an ovum that may have been fertilized in the fallopian tube after ovulation. A fertilized ovum migrates from the fallopian tube to the uterus.

- 7 If a sperm has not fertilized the ovum, hormones stimulate the uterus to shed the endometrium over the course of several days. This process is known as **menstruation**, what many people refer to as a woman's period. Fluctuations in hormones during this time may affect a woman's mood, and muscle contractions in the uterine walls may cause cramps.



What happens if an ovum is fertilized during intercourse by one of millions of sperm? How would a woman's menstrual cycle be changed? A fertilized ovum sets in motion a whole series of events that ends with a baby being born after about nine months.

FERTILIZATION AND IMPLANTATION



1 Ovulation. During ovulation, the mature ovum moves to the fallopian tube, surrounded by a few follicle cells for protection and nourishment.

2 Fertilization. A male's sperm must migrate up the female's reproductive system within a few days after ovulation for the ovum to be fertilized. At *fertilization*, the immature ovum nucleus divides, completing the second phase of meiosis to form a zygote. A new life has just begun.

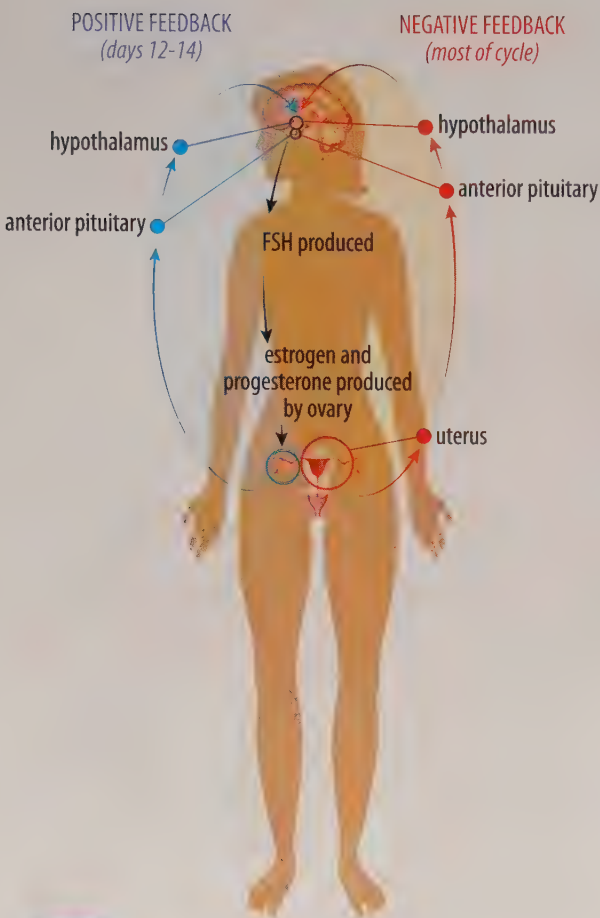
3 Cleavage. The zygote undergoes mitosis to produce daughter cells in a phase of embryo development called **cleavage**.

4 Blastocyst formation. The rapidly dividing embryo takes three days to migrate to the uterus, and then floats free in the uterus for another three days. Cell division continues, producing a mass of cells in a fluid-filled sphere called a **blastocyst**.

5 Gastrulation. During **gastrulation**, the blastocyst forms the three germ layers that you learned about earlier—the ectoderm, mesoderm, and endoderm.

6 Implantation. The blastocyst uses up its reserves of nutrients and attaches to the thickened endometrium in the uterus for nourishment—we call this **implantation**. From here, the baby's development takes off.

25.3 THE REPRODUCTIVE SYSTEM IN THE HUMAN BODY



25-1

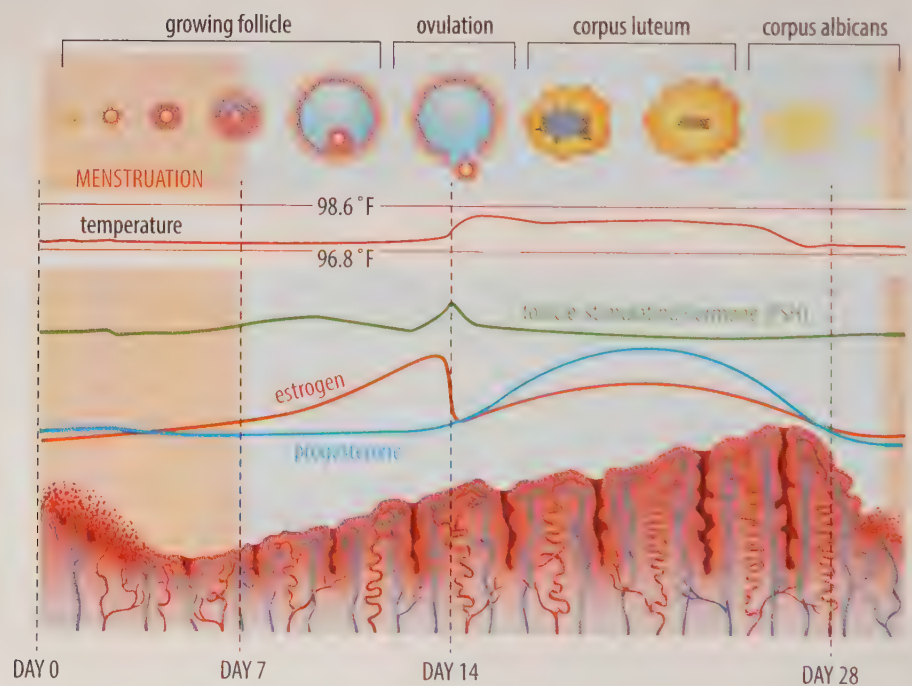
The feedback system for the female's reproductive cycles

The other body systems are deeply affected by the reproductive system, heightening the senses during sexual intercourse and involving the respiratory, circulatory, nervous, and integumentary systems. However, as mentioned above, the reproductive system disrupts homeostasis.

A woman's organ systems maintain homeostasis by accommodating stresses on her body. To avoid attacking the man's sperm during intercourse, her immune system is temporarily switched off. If she becomes pregnant, her immune system is kept from attacking a developing embryo. The respiratory system carries oxygen and carbon dioxide for both mom and baby. The circulatory system transports nutrients to the baby and wastes from the baby through the placenta.

The endocrine system works especially closely with the reproductive system to manage the menstrual cycle in a woman. The ovaries produce a female hormone called *estrogen* in the greatest amounts leading up to and resulting in ovulation. They also produce the female hormone *progesterone* in the greatest amounts after ovulation to thicken the uterus. Hormones offer a negative feedback mechanism similar to the way that your body monitors your temperature. This negative feedback mechanism depends on whether an ovum is fertilized.

But the ovaries are not the only organs that produce hormones controlling the reproductive system. When a girl reaches sexual maturity, the hypothalamus signals the pituitary gland to begin secreting a gonadotropin called *follicle-stimulating hormone (FSH)*. This hormone stimulates several follicles to develop each month to nourish a developing ovum in the ovaries. The pituitary gland is involved in pro-



ducing the hormones which cause the corpus luteum to form in the ovaries.

When a boy reaches sexual maturity, the hypothalamus signals his pituitary gland to produce FSH to stimulate the development and nourishment of sperm in the seminiferous tubules of the testes.

25.4 SEXUALITY, FAMILY, AND A BIBLICAL WORLDVIEW

The world is fascinated with sex, but God created sex, marriage, and the family. He created Adam and Eve as male and female and brought them together to experience union without shame (Gen. 2:24–25). The Bible uses the marriage relationship to illustrate Christ's love and care for the church (Eph. 5:23–27). Children are the natural and beautiful result of God's plan for marriage and the family.

The Fall has led to the perversion of God's good design, and modern society increasingly undermines the basics of sexuality. Not only do husbands and wives forsake their God-ordained roles, but they break their marriage union through adultery and divorce. It is commonplace for unmarried couples to be immoral and even live together. Pornography is a thriving industry. Sexual abuse and rape threaten people's well-being. Homosexual marriage has even been declared legitimate in the US Supreme Court. Our culture continues to wrestle with the basic question of gender identity. These things are not part of God's good and original plan for humanity, and they have the potential to unravel the fabric of society.

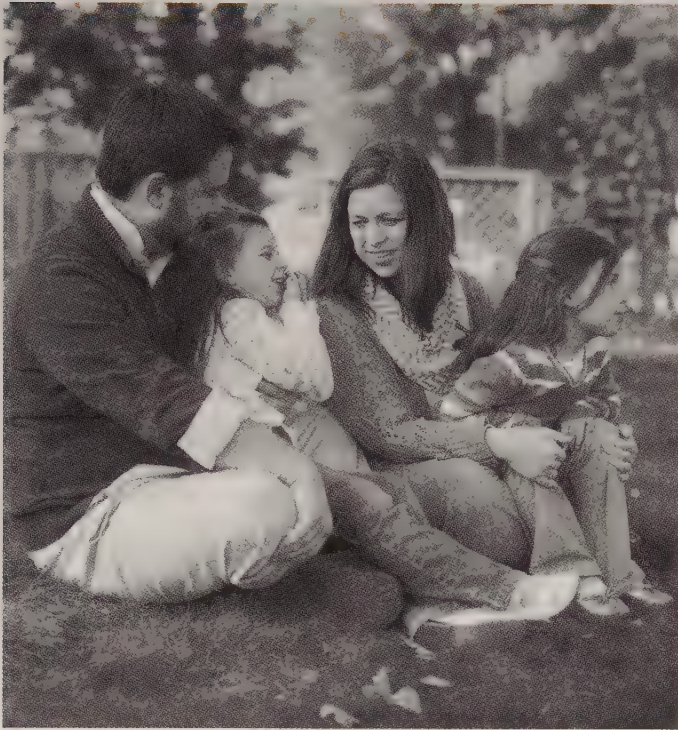
But God is working His grand plan of Redemption for the human race. He preserves society in spite of its fallen condition. When we live out God's good and perfect plan for the family, we can be salt and light in a dark world. At the end of all things we will see God's perfect plan revealed in the complete redemption of His bride, the church.

You can make decisions *right now* that show that you believe God's way is best. You can avoid behaviors like homosexuality and sexual immorality that fall outside God's design (Heb. 13:4). You can refuse to look at things that lead you to



sin and that God calls wicked (Job 31:1). You can refuse to fantasize about sin (Matt. 5:28). Moral purity is not easy in our fallen world. But by God's grace it is achievable (2 Cor. 9:8). God's restoration of the human race needs to begin with the choices that we make every day. When we make choices that please and honor Him, our lives can be light in a dark world.

KYLE'S STORY



Kim and Chris Rackley were expecting their third child. Already parents of two girls, they were thrilled to learn that they were expecting a boy. But then the news came that Kyle, their unborn son, had trisomy 18, with the 18th of his 23 sets of chromosomes being in a triplet rather than a pair. This condition usually causes miscarriage within the first 13 weeks of pregnancy. Kyle had only weeks to live.

Kim, who had a cooking blog with thousands of followers, began to blog about their family experiences. She began to hear from other mothers who were identifying with her struggles. Kim's doctor told her that there was only one thing he could do to help her: offer her unlimited 3D ultrasounds so that she could get to know Kyle before the Lord took him.

Kyle lived longer than anyone expected, within 10 weeks of his due date. Chris and Kim were forced to make hard decisions. One day, Kyle stopped moving. Two days later, after a stillbirth, Kim and Chris kissed their little boy goodbye with faith that they would see him again someday.

Kim's doctor has told Kyle's story to other medical professionals to show how choosing to continue a difficult pregnancy rather than abort the baby can bring healing to a family. Kyle's story has brought hope to women considering abortion. It is a wonderful testimony of how God can give grace to a suffering family that chooses to live by faith.

25A REVIEW QUESTIONS

1. How does the function of the reproductive system fit with God's commands to mankind?
2. State the most significant organ of both the male and female reproductive systems and describe the purpose of each.
3. List the following organs of the male reproductive system in order on the basis of where sperm form and pass through as they mature.
epididymis, penis, prostate gland, seminiferous tubules, vas deferens
4. What additional purpose does the female reproductive system have that the male's does not possess?

5. Arrange the following events in chronological order to describe how a woman's body prepares for and releases an ovum to be fertilized and nourished.
- 1 An ovum is released to the fallopian tube during ovulation.
 - 2 A blastocyst attaches to the uterine wall during implantation.
 - 3 A fertilized ovum divides to form germ layers during gastrulation.
 - 4 A fertilized ovum migrates down the fallopian tube to the uterus.
 - 5 An ovum to be fertilized is nourished by developing follicles in the ovaries.
 - 6 An ovum unites with sperm in the fallopian tube to form a zygote.
6. Give an example not mentioned in the text of how the Fall affected God's command to have children.
7. Give an example of how you can make decisions right now that show that you believe God's plan for the family is best.

25B

HUMAN GROWTH AND DEVELOPMENT

How does a person's body change over the course of his or her life?

25B Questions

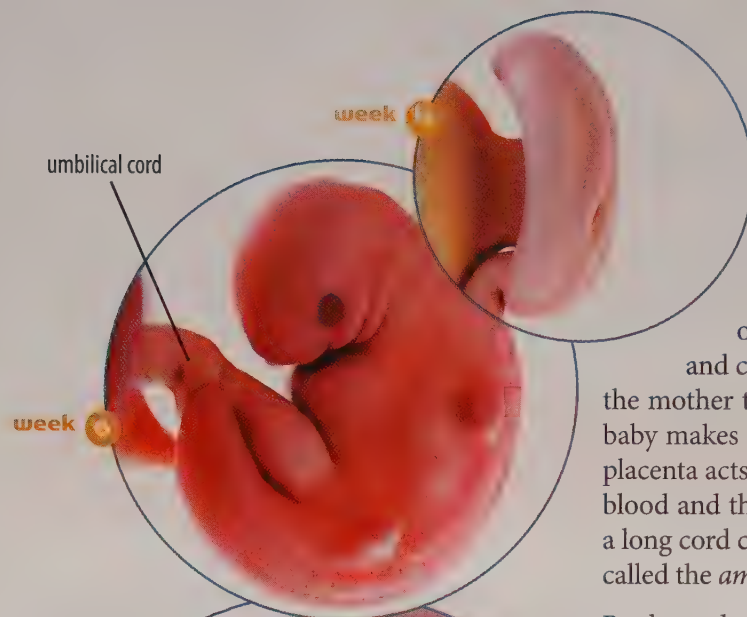
- » How does a baby develop and grow in the womb?
- » How does a child change as he or she gets older?
- » How is a teen's body different from that of a child?
- » How does an adult change as he or she ages?



25.5 | PRENATAL DEVELOPMENT AND BIRTH

Do you know a woman who is pregnant? If so, you can see her eager sense of expectation to see the baby forming inside her.

We've tracked how a woman's body produces an ovum that is fertilized in the fallopian tubes and implanted in the uterus where it is nourished. But what happens after that? It takes about 40 weeks, or 9 months, for a baby to mature from a fertilized egg into a squealing newborn. Doctors divide this time into three parts, called *trimesters*.



THE FIRST TRIMESTER

The first trimester, weeks 1–13, is the most crucial stage of a baby's development for his long-term health. During this time, the rapidly dividing blastocyst implants in the uterus as its outer cells work with the lining of the uterus to form a placenta. This organ links mother and child, transferring nutrients, such as food and oxygen, from the mother to the baby, and wastes from the baby to the mother. The baby makes his own blood, which doesn't mix with mom's blood. The placenta acts as the "station" to exchange substances between the baby's blood and the mother's blood. The baby is attached to the placenta by a long cord called the **umbilical cord** and is also surrounded with a sac called the *amnion* (amniotic sac), which eventually fills with fluid.

By the end of the first trimester, the baby has gone from a few cells to an embryo about 2 inches long that weighs about 28 grams (1 ounce).

His heart and nervous system are the first organs to form, but by the end of the trimester all major internal organs are present.

After 11 weeks he is considered a **fetus** because the way that he is developing changes. All the parts are there and are functioning; now they just get bigger. And he is starting to look like the little person that he has been since conception!



THE SECOND TRIMESTER

During the second trimester, weeks 14–27, the baby develops facial features and muscle tissues. His cartilage skeleton converts to bone, and his brain begins to send signals to control his organs. He can suck his thumb and get the hiccups. He is practicing how to breathe and suck by taking in **amniotic fluid**, the fluid filling the amniotic sac that surrounds and cushions the baby. His reproductive organs also begin to develop. During this trimester, many parents will have an ultrasound done and receive a sonogram to find out whether they are having a girl or a boy.



THE THIRD TRIMESTER

The baby grows quickly now. He is moving so much that he can make mom uncomfortable! He can cry and open and close his eyelids—he's practicing for after he is born! Fuzz on his head is the beginning of hair. If he is born during the third trimester, he has a possibility of survival with close medical supervision. However, the longer he stays inside mom's womb, the better his chances to be born healthy.

BIRTH

It's getting close to the time that baby sees the world. Mom's uterus is stretched to its maximum size, and the fetus is too big for his cozy home. This stretching makes the muscles in the uterus start to contract. Contractions become stronger and more frequent until they peak and occur at regular intervals. Mom is in labor! Quick, to the hospital!

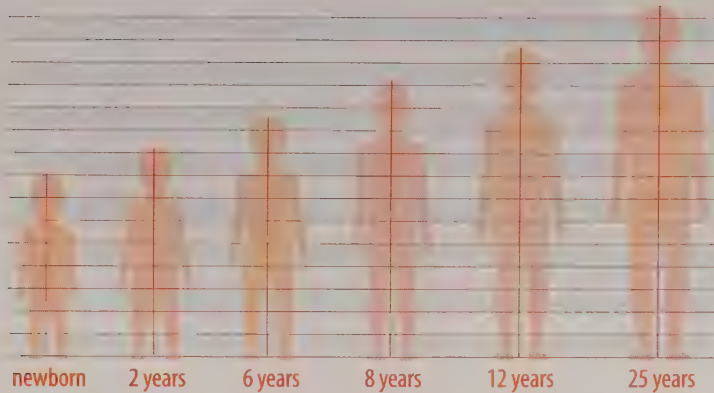
The mother's cervix becomes thin and releases a hormone that strengthens contractions. The amniotic sac breaks **1**, releasing a gush of amniotic fluid. Eventually, these contractions push the baby's head into the vagina, or *birth canal*. Both mom's pelvic area and the baby's head flex to allow it to push through the vagina.

Then the baby's head crowns **2** (i.e., the top or "crown" becomes visible) and completely emerges, and his body follows. However, he's still attached to the placenta by the umbilical cord. This cord is pinched and cut within the first ten minutes after the baby is born. It's time for him to breathe on his own! After baby is born, the placenta and the rest of the umbilical cord, called the *afterbirth* **3**, is delivered. This normally happens within about 20 minutes after a baby is born.

It will take mom about 4–6 weeks to recover from childbirth. In the meantime, the baby can get his nourishment from her in an entirely new way—by nursing from her breasts, which produce milk in a process called *lactation*. Hormones have already triggered her body to produce this supply.



25.6 CHILDHOOD



If you've had a baby born in your family, you know he doesn't stay little long! During the first year, he changes dramatically, learning how to communicate, make decisions, and move about—perhaps even walk.

His development continues after his first year as he grows more teeth and learns how to regulate his body's functions. His body's proportions change as he matures, his head forming a smaller percentage of his body as he ages. A child has significant nutritional needs to fuel his growing body, such as calcium for his quickly growing bones and muscles.

25.7 ADOLESCENCE

As a child grows to become a teen, his body begins to dramatically change as the hypothalamus signals the pituitary gland in the endocrine system to produce a whole new batch of hormones. These hormones cause the child to begin to develop the *secondary sex characteristics*. Guys begin to look more trim as they lose the body fat of childhood and develop muscles. Vocal folds get larger, making both male and female voices deeper. External sex organs, or *genitals*, enlarge. Hair begins to grow in places other than on the head, such as under the arms, on the legs, and in the *pubic region*, the area of the body near the genitals. Teen girls begin the menstrual cycle. This dramatic time of life in which a person physically transitions to adulthood is called **puberty**.

However, the changes in a person's body during adolescence don't just involve their reproductive and endocrine systems. Huge swings in hormones also affect a person's nervous system, influencing his emotions and sense of balance as his brain tries to keep up with his quickly growing body. This can also affect a teen in social and spiritual ways.

Often people struggle with their sexuality during adolescence. Many teens in this stage of life experiment with pornography, heterosexual immorality, and homosexuality. Some experiment with all of them, searching for fulfillment. Occasionally teens struggle with gender identity. In fact, some professionals make a distinction between *sex*, as determined by one's reproductive organs and secondary sex characteristics, and *gender*, one's masculinity or femininity as communicated in his or her social interactions.



God's Word tells all of us how to think about ourselves and sexuality. The Bible prohibits all sexual activity outside of marriage (Exod. 20:14), and it limits marriage to one man with one woman (Gen. 2:18, 24). The Bible teaches that a person's sex and gender should align (Matt. 19:4). While it is true that the Fall has affected every part of man, it does not follow that gender is undetermined and can be chosen by an individual. Men and women should accept their sex as God's will for them and should seek to act in keeping with that determination.

You are in this stage of life. Your body is approaching *physical* maturity, but you will spend the rest of your life acquiring wisdom and maturing *spiritually*. That process can occur only one way—by living in biblical wisdom and choosing God's way as the best way. A relationship with Jesus Christ is the only path to fulfillment.

25.8 ADULTHOOD

So what comes next after adolescence? When you reach your twenties, you will most likely experience your peak physical condition. It is at this stage of life that you have the potential to be strongest and most capable of procreating. Men begin to produce sperm only after puberty. The ova have been present in a woman's body since birth but now regularly mature to allow her to become pregnant. Women experience an entirely different range of hormones during pregnancy, birth, and while nursing a baby.

After their twenties, however, both men and women begin to experience more changes. In their thirties and forties they begin to lose muscle strength and ligament elasticity and hair eventually begins to turn grey as melanin production is diminished. As we age, all life processes begin to slow down and become more inefficient. The amount of energy the body uses during resting, called the **basal metabolic rate**, changes as we grow older. This rate starts to decrease significantly in the thirties and forties, and weight gain may result. We also tend to get slightly shorter as we age. By the time a woman reaches her fifties, her hormone production has changed dramatically, and her menstrual cycle and ovum production stops during what is known as *menopause*. Men continue to produce sperm for the rest of their lives, though the number produced decreases.

The average life expectancy of an American is about age 80, and during later years people can still have rich experiences, investing in their families and the people around them. We can have a meaningful life especially as we invest in younger people. Take a moment and think—what older people have invested themselves in you?



God knows, even if you don't, how many days He will give you in this life (Ps. 90:10). If He gives you seventy or even eighty years of life, you still will eventually die, and the wise thing to do is to make choices in light of that reality (Ps. 90:12). Death is not the end. The Bible teaches us that our bodies will be raised and that we will spend an eternity in the presence of God or in the place of judgment. For Christians, the hope of resurrection is the hope of going to be with Jesus. Though Christians are temporarily separated from believing loved ones, death is only the beginning of an eternity in heaven.

END-OF-LIFE DECISIONS

Imagine that you were diagnosed with a disease that will take your life in less than a year. What kind of decisions would you have to make? What would you do with the time you had left to live?

Brittany Maynard was faced with this decision. When she was 29, a year after she was married, she found out that she had terminal brain cancer. She began undergoing treatments, but the cancer continued to grow. She began to form a plan for the time when her health would degenerate and death would come, but she decided that she wasn't interested in care that would simply make her comfortable while she was dying. She left California with her husband and moved to Oregon. Why? Oregon law provides for *death with dignity*, or assisted suicide, which allows doctors to prescribe a medication to a terminally ill patient that will end her life. She could choose when she would die. There would be no surprises, no suffering, and a quiet death surrounded by her loved ones. She shared her story with the world to help get death-with-dignity legislation passed elsewhere. Her husband approved of her decision and has, since her death, been instrumental in getting such legislation passed in several states. But was it really Brittany's right to choose to die?

For people dealing with diseases and aging loved ones, end-of-life decisions can be tough, but the Bible gives us guidance in difficult situations like this. Brittany's life didn't belong to her, nor does your life belong to you. A person does not have the right to take his or anyone else's life, or that of an unborn child. Our lives are gifts from God. Sometimes God allows people to suffer, but He can also give us the grace to bear it.

A Christian genuinely holds something that Brittany did not—hope. Believers can cling to the hope that Jesus' resurrection gives to suffering Christians. Suffering will not last forever, and

death is not the end. Believers wait expectantly for the time when they will exchange these decaying bodies for ones that live forever. Jesus has forever robbed death of its sting and its victory (1 Cor. 15:54–55).



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Brittany Maynard's family, including her mother shown here, is using Brittany's story to push for death with dignity legislation.

25B REVIEW QUESTIONS

1. What is the difference between an embryo and a fetus?
2. What are the three stages of pregnancy? Describe the baby's development in each stage.
3. How is a child's body different from that of a baby?
4. List three of the secondary sex characteristics that develop with puberty.
5. What organ and organ system is responsible for the changes that happen to a person during puberty?
6. Describe three ways that a person's body changes as he or she reaches and passes the thirties.
7. How should you view death from a biblical worldview?

25C

BALANCED LIVING

How can you keep your body healthy?

25.9 WHAT YOU TAKE IN

Up to this point in life, you have had many of your decisions made for you. But as you get older, you will become more independent. You'll need to make life decisions that affect your body. We need to consider what we take into and do with our bodies, recognizing that a person is more than just a body.

NUTRITION

We have already considered the kinds of nutrients your body needs to be healthy. There is a lot of disagreement over what the healthiest lifestyle is, and scientific research is beginning to indicate that what works well for one person may not work well for another. However, just about everyone agrees that we all need to drink adequate water, limit the amount of added sugars and processed foods in our diets, and increase the amount of time we spend exercising. This doesn't mean that a person can never have dessert again—just not at every meal!

To be healthy, people need certain amounts of nutrients from the food they eat, including water, carbohydrates, fats, proteins, minerals, and vitamins. But many Americans are overeating. Additionally, many Americans are not nearly active enough, so they are consuming far more calories than they need. Many people think that they need to increase their vitamin intake when what they really need is to consume more water. Unwisely, we often replace water with sugary drinks such as sodas.

25B Questions

- » What outside factors affect the body's homeostasis?
- » How can what you do help your body maintain homeostasis?
- » How do your mind and spirit affect your body?



25-3

Healthy eating is both a matter of what you eat and of how much you eat.

Although people have been dieting for years, many still struggle with being overweight. Those who lose weight while dieting often gain it back again soon after going off the diet. Dieting is often an attempted quick fix to the underlying problem of an unhealthy lifestyle.

While it's a good idea to keep your weight in check to avoid the problems that come with being overweight, there's an even better reason. God lives in the bodies of believers, and it is our responsibility to maintain these bodies as the Holy Spirit's temple (I Cor. 6:19–20). It's easy to think about this when considering drinking alcohol, taking drugs, or smoking cigarettes, but it applies to eating too. Being healthier can make a believer more useful for God's glory.

DRUGS

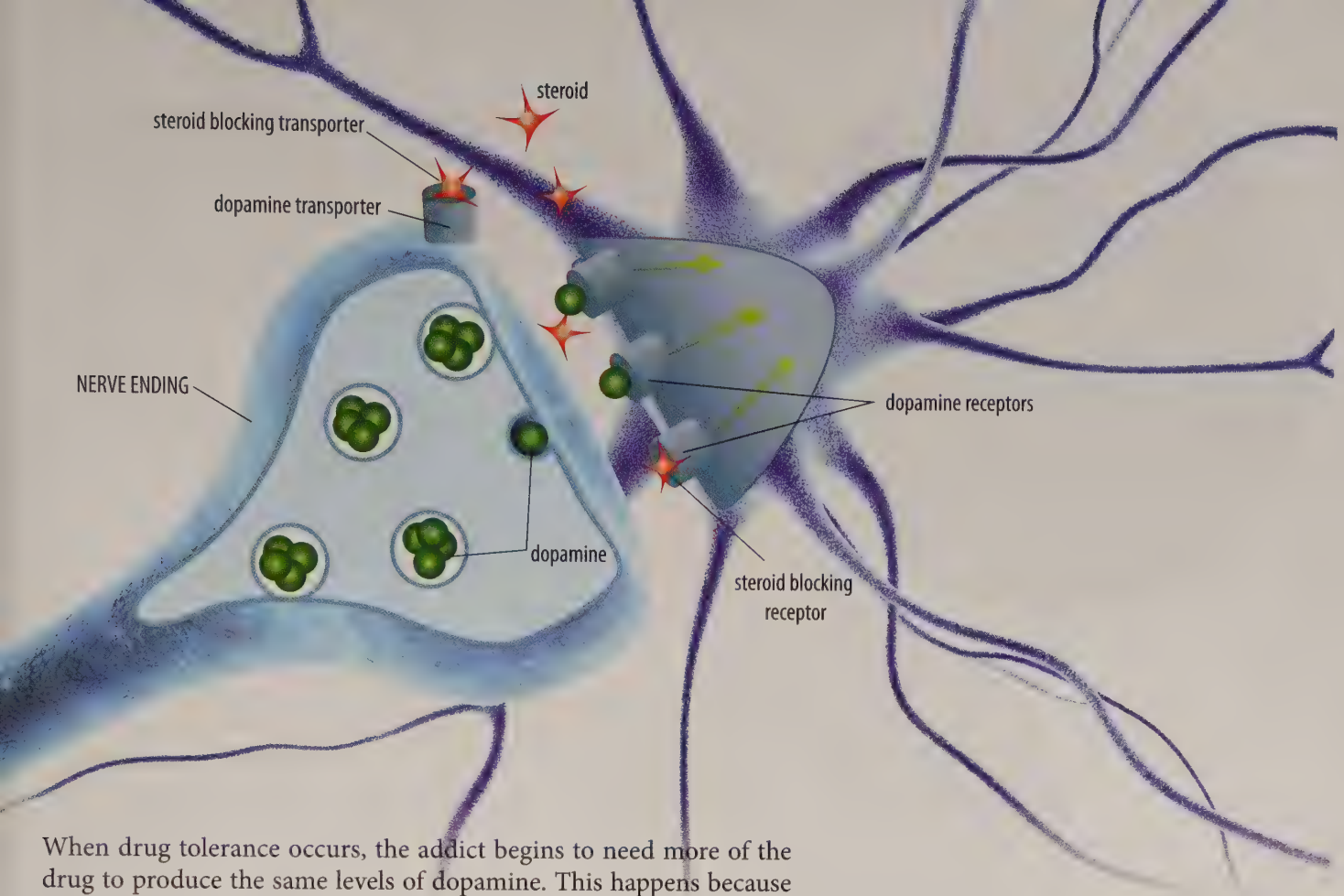


Drugs are another group of substances that we take into our bodies. A **drug** is any chemical that changes the function or structure of a living tissue. A drug can be good or bad, depending on how much you take.

People use drugs as medicines to prevent, treat, or cure a disease. Certain drugs, such as sleeping pills, affect body function. Aspirin and ibuprofen act as inhibitors to enzymes that cause us to feel pain. Vaccines give us immunity and antibiotics fight infections. Some substances, like antidepressants, can even affect our emotional state.

With some drugs, a person can gradually respond less to the same amount of a drug in an effect called *drug tolerance*. An increased dosage is required to achieve the desired physical response. For some drugs like alcohol, caffeine, and morphine, a person can form a physical or emotional addiction. If he doesn't have the drug, he experiences **withdrawal**, a series of physical consequences that make it very difficult to be without it.

Why does this happen? Drugs that cause addictions affect neural synapses by producing a neurotransmitter called **dopamine**. Dopamine is one of several chemicals that help your brain feel happy. For example, when you sit in the sunshine or exercise, your body naturally releases dopamine to produce a "high." Substances as innocent as caffeine or as sinister as heroin work by producing dopamine.



When drug tolerance occurs, the addict begins to need more of the drug to produce the same levels of dopamine. This happens because the brain naturally reduces the number of dopamine receptors in the nervous system when there is an abundance of the substance. The body also produces much less dopamine. When a person experiences withdrawal, he feels depressed and can undergo significant symptoms, such as chills, vomiting, insomnia, and pain.

Medicines are good and useful for bringing people healing, but because we are sinners we can use good things in evil ways. Many of the people who develop addictions to drugs are desperately seeking some kind of happiness, some kind of satisfaction that will last. Jesus Christ is the only one who can fill our greatest need and bring healing that lasts for eternity. For centuries, people with addiction problems have found lasting freedom, joy, and satisfaction in life through Christ. That opportunity still exists for people today.

25.10 WHAT YOU DO

EXERCISE

Though you're probably not too worried about your health right now, the decisions you make today can set you up for a healthy lifestyle. You can actually raise your basal metabolic rate and reduce your risk of cancer, heart disease, diabetes, arthritis, and depression in one fell swoop. And, by the way, you could also have a more trim body. Sound like a miracle pill? You just need to get moving and keep going! Exercising is a healthy way to naturally increase your dopamine, and your body needs it to stay balanced.



Almost any movement will do—stretching, walking, gardening, bicycling, even doing chores around the house (won't your mom like that?). You don't have to hit the gym to get and keep moving. Consider taking up a sport, whether an individual or team sport. Whatever you do, make it fun so that you will be more likely to keep doing it. Start slow and enjoy the outdoors while you're at it. You can focus on *aerobic exercises*, which increase your rate of breathing, or focus on getting stronger with strength, weight, or resistance training. You can work on flexibility. Or you could do all of these. There's almost no bad way to exercise if you start slow and work up gradually.

SLEEP

You probably like to stay up late and enjoy texting or chatting on social media; just make sure that you don't have to get up at 6:00 the next morning! Your body needs sleep to refresh all your organ systems, especially your brain. During a research study, 16-year-old Randy Gardner went without sleep for a record-breaking 11 days. He experienced hallucinations, short term memory loss, and mood swings. Even though he completely recovered without any problems, it's clear that people need sleep!

There are two types of sleep—**REM** (rapid eye movement) **sleep** and **NREM** (non-REM) **sleep**. REM sleep is the sleep of dreams during which the mind rejuvenates. NREM sleep is a deep, dreamless sleep during which the body physically rests. You could think of REM as active sleep for the brain, while NREM is quiet sleep for the brain. During the night, your body naturally goes through cycles of these two types of sleep. If your sleep gets disturbed, your whole body suffers!



25-31

Though different people at different ages have different sleep needs, right now you need about 8½ to 10 hours of sleep each day. Newborns can sleep up to 18 hours a day!

HYGIENE

High in the mountains of Papua New Guinea, the natives scramble all over the mountains, raising coffee beans and dining on chicken and vegetables in their thatched huts. In many ways they have very healthy lifestyles, but their life expectancy is a mere 56 years. Why do the people of the Eastern Highlands die so young? It's because of poor hygiene.

You're probably used to wearing clean clothes, taking a shower every day, brushing your teeth, and using deodorant so that you don't repulse everyone in your school! But there are other reasons for good hygiene beyond being socially acceptable. Good hygiene can help keep you and the people around you healthy by maintaining your body's homeostasis.

DAILY PERSONAL HYGIENE

1 Showering every day and washing your hair at least a few times a week helps to keep harmful bacteria at bay.

2 Brushing your teeth twice a day and flossing daily prevents tooth decay. You might not realize it, but cavities are contagious! There are even some scientific studies that link gum disease to heart problems and strokes.

3 Keeping your skin clean can also help prevent rashes and acne. Wear sunglasses on sunny days and sunscreen every day to protect your eyes and skin from the sun. Exposure to the sun over the course of your life can lead to skin cancers and speed up aging in your skin.

4 Washing your hands, especially before meals, protects your body from antigens that could cause infections and disease. Keeping your fingernails trimmed helps the skin in this high-traffic area of your body do its job to keep out invaders.



25.11 WHO YOU ARE

What makes a living, healthy person? It isn't just breathing and eating, though these things are necessary for life. You are not just a body—you are a rational, emotional, and social being made in God's image. Part of being alive and healthy is having healthy thoughts, emotions, and relationships.

Many people struggle with their mental health. In one year, 8 million Americans will go to their doctors to get help with depression. Mental problems incapacitate 11 million Americans each year, causing them to flounder in their work and relationships. When people are stressed and depressed, it affects their bodies. They don't do what they should with nutrition, exercise, hygiene, and sleep. Some even take their own lives, despite the fact that help is available. We live in a world where people have no hope.



Many people struggle with their relationships. Up to 50% of married American couples divorce. Almost 300,000 Americans experience some kind of sexual abuse every year, sometimes affecting their physical health as well as their emotional health. The abortion of about 1 million babies every year in America places mothers under an incredible burden of guilt. Divorce, abuse, and guilt bring stress and plunge people into depression that affects their bodies, despite having the best psychologists at their disposal. We live in a world where people are insecure.

Science can't give us hope, and it can't give us security. God wants us to have abundant life, and that comes through one Man—Jesus (John 10:10). So we end where we began: the one who created the world and watched it fall became a man who brings us true, eternal life. Only Jesus restores the hope and security that was present in Eden and robbed from mankind at the Fall. When believers live in obedience to God's commands, they live out the work of redemption that Christ has begun in them. And He will bring it to completion one day, rising as the Sun of Righteousness with healing in His wings for those who fear Him (Mal. 4:2).

25C | REVIEW QUESTIONS

1. What substances, when ingested, affect your body's homeostasis?
2. When considering calories, what must a person do to lose weight?
3. Give an example of a drug and explain why your example is considered a drug.
4. When does a drug become harmful?
5. Give an example of an aerobic exercise.
6. During which type of sleep does the brain use the most oxygen and glucose from the body (see Figure 25-5)? Explain your answer.

25-5 |

The brain waves that a person demonstrates during the different stages of sleep are displayed to the right. The tighter the waves, the more active the sleeper is. Compare REM brain waves with the ones a person has when he is awake.



7. How does good hygiene help your body maintain homeostasis?
8. How do mental health and relationships affect the body's homeostasis?
9. How can a Christian enjoy a healthy mind and healthy relationships?

REVIEW QUESTIONS

CONCEPT REVIEW

1. Where are the seminiferous tubules located in the male reproductive system?
2. How does a man's body keep sperm alive as long as possible?
3. How many ova does a woman's two ovaries produce each month?
4. Which organ of the woman's reproductive system nourishes the developing embryo?
5. List the following events in chronological order: blastocyst formation, cleavage, fertilization, gastrulation, implantation, ovulation.
6. How does a woman's reproductive system work with her endocrine system?
7. In one or two sentences, describe a biblical view of sex.
8. Place the following events in the life of a baby in chronological order.
 - 1 The baby is considered a fetus, with all organs present.
 - 2 The baby's cells begins to divide, and this blastocyst implants in the uterus.
 - 3 The baby can open and close his eyes and is growing hair on his head.
 - 4 The baby forms a placenta and an umbilical cord.
 - 5 The baby's reproductive organs move into place.
 - 6 The baby's heart and nervous system form.
9. How does puberty start?
10. Though we live in a fallen world where anyone can get sick, who is ultimately responsible that you be healthy?
11. What happens when a person stops using a drug that he's become addicted to? Why does this happen?
12. How does exercise affect the body's homeostasis?
13. How is a person more than a body?

TRUE OR FALSE

14. A man will stop producing haploid cells for fertilization at some point in his old age.
15. Both male and female reproductive organs are located close to organs of the urinary system.
16. A man's sperm and a woman's ovum unite to form an embryo in the uterus.
17. God makes no allowance for sex before marriage, for adultery, or for homosexuality.
18. A baby is *not* considered a fetus until the end of the second trimester.
19. A person's body proportions change as he matures.
20. A person is typically in his peak physical condition in his thirties.

Key Terms

testis	484
seminiferous tubule	484
scrotum	484
epididymis	484
vas deferens	484
prostate gland	484
semen	484
penis	484
ovary	485
ovum	485
vagina	485
cervix	485
fallopian tube	485
uterus	485
menstrual cycle	486
ovulation	486
corpus luteum	486
menstruation	486
cleavage	487
blastocyst	487
gastrulation	487
implantation	487
umbilical cord	492
fetus	492
amniotic fluid	492
puberty	494
basal metabolic rate	495
drug	498
withdrawal	498
dopamine	498
REM sleep	500



21. A person's basal metabolic rate decreases as he ages past his twenties.
22. Any kind of sustained physical movement can be considered exercise.

CRITICAL THINKING

23. In a tubal pregnancy, an embryo fails to migrate from the fallopian tube to the uterus and implants in the fallopian tube instead; this is known as an *ectopic pregnancy*. Why is this problematic?
24. Calculate your basal metabolic rate using the equations below.

Women

$$\text{BMR} = 655 + 4.35 \times (\text{weight in lb}) + 4.7 \times (\text{height in in.}) - 4.7 \times (\text{age in years})$$

Men

$$\text{BMR} = 66 + 6.23 \times (\text{weight in lb.}) + 12.7 \times (\text{height in in.}) - 6.8 \times (\text{age in years})$$

25. Now multiply your BMR by the appropriate ratio below based on your level of activity to calculate how many calories you need each day to provide the energy that your body uses.

I almost never exercise. ($\text{BMR} \times 1.2$)

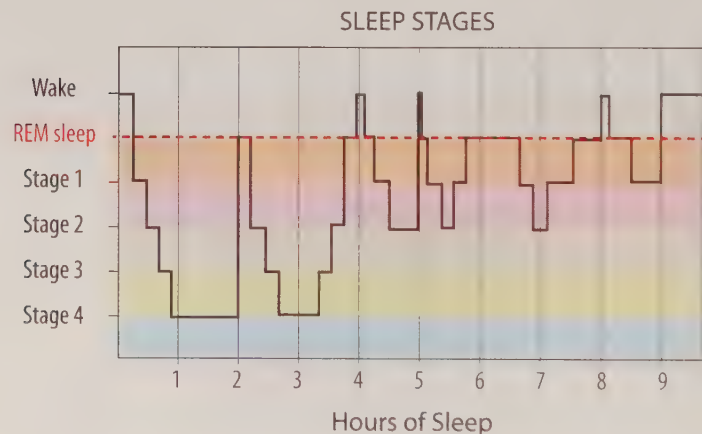
I exercise 1–3 days per week. ($\text{BMR} \times 1.375$)

I exercise 3–5 days per week. ($\text{BMR} \times 1.55$)

I exercise 5–7 days per week. ($\text{BMR} \times 1.725$)

I am undergoing intense physical training. ($\text{BMR} \times 1.9$)

Use the graph below to answer Questions 26–29.



26. Compare the various cycles of sleep each night.
27. After what type of sleep do people usually wake?
28. Which cycle of sleep is usually the longest?
29. What do you notice about Stage 4 NREM sleep?

Use the Case Study and the circle graph below to answer Questions 30–32.

CASE STUDY: STDs

Teens who don't feel the need for abstinence are vulnerable to two dangers: an out-of-wedlock pregnancy and *sexually transmitted diseases (STDs)*. STDs spread almost exclusively through sexual intercourse when one participant is infected. Sometimes a person doesn't know that he is infected, but even if he does, he may not tell his sexual partner. If a woman gets an STD, she can pass it along to any children she conceives.

STDs include the AIDS virus and other viruses including the *herpes virus*. Some STDs, such as *syphilis* and *gonorrhea*, are bacterial infections that can be treated with antibiotics. STDs can cause some symptoms (e.g., genital warts and fevers), but left

untreated, these diseases can spread to internal organs and even cause cervical cancer. Some remain in a person's body for the rest of his or her life, even after treatment. Some have no known cure.

Sex education courses in public schools assume that teens will experiment with sex. For this reason, they teach teens about how a person can contract STDs, STD symptoms, and how to prevent STDs and pregnancy by using contraceptives such as condoms. Condoms are anywhere between 50% and 100% effective in preventing AIDS and gonorrhea. Some schools even pass them out to students. However, more high schoolers are choosing to abstain from sexual activity altogether.

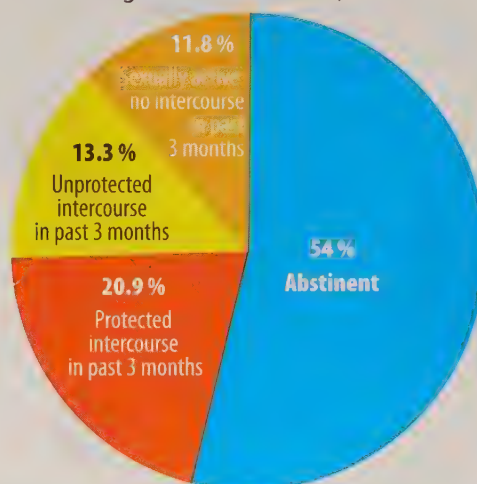
30. Why are STDs so dangerous?
31. What is the best way to prevent STDs?
32. Why should a Christian practice abstinence before marriage?

Read the Case Study below. Then answer Questions 33–36.

This Case Study is based on a true story.

33. Should Katja feel that the rape was her fault? Should she remain silent?
34. Is rape the only way a person can experience sexual abuse? Explain.
35. What can Katja do now to make decisions that honor God?
36. Sexual abuse doesn't affect just girls. In 1990, the first national study on sexual abuse showed that 27% of women and 16% of men reported having been abused as children. Suggest how hard it might be for men to deal with and get help.

Sexual Activity Among American High-School Students, 2009



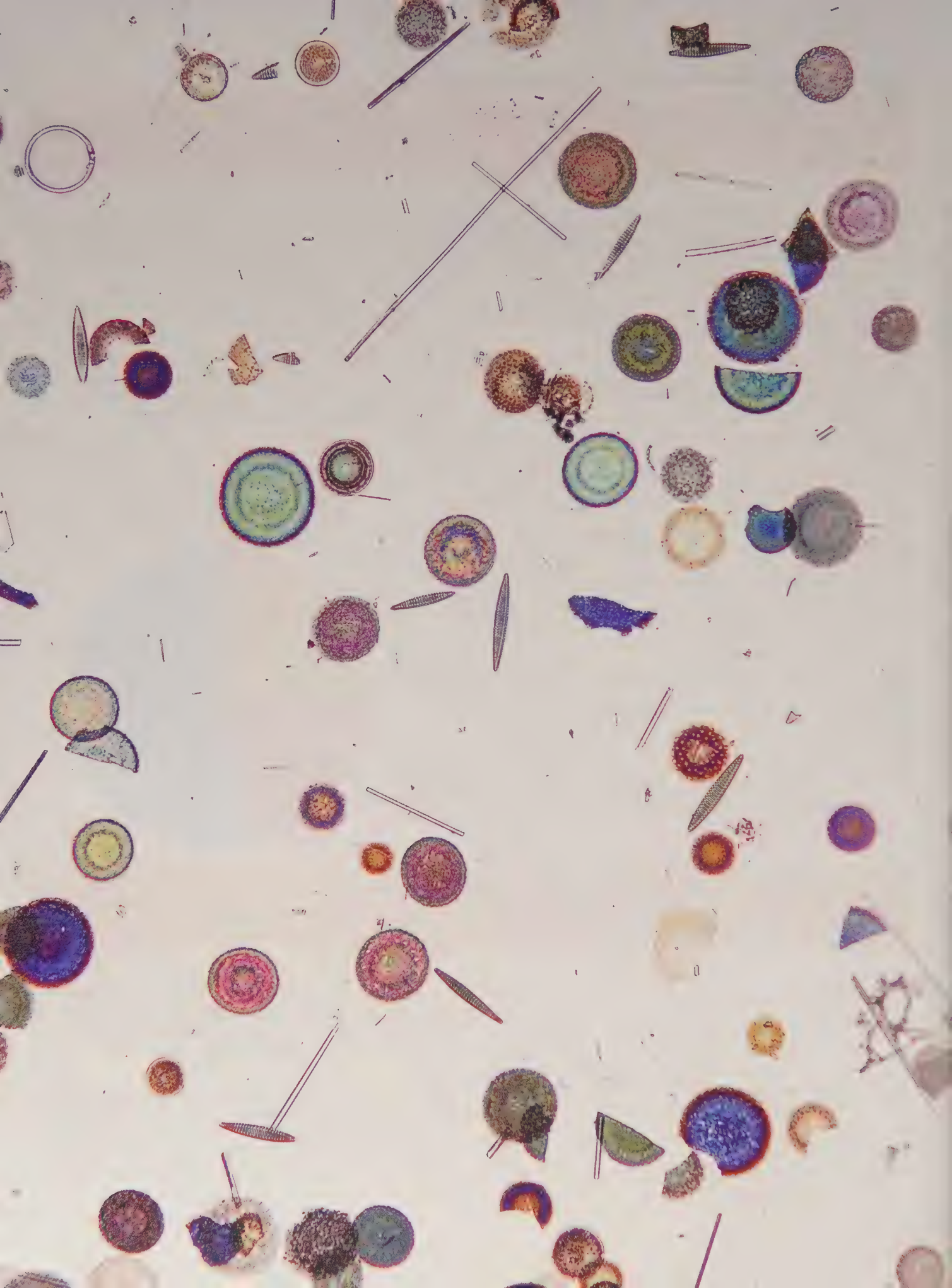
CASE STUDY: SEXUAL ABUSE

Katja had just graduated from high school. She was a Christian student attending a summer orientation for the state college she was planning to attend. She enjoyed touring the campus, and when her roommates invited her to a party, she decided to go. However, when she got there, alcohol and drugs were everywhere. Katja knew better than to try any of it but she also had no way of getting back to campus, which was miles away.

Then a guy came over to her and started talking. Surprisingly, Roger wasn't drunk or high. He said that he was a Christian too. When he offered to get her a soda, she thought nothing of it.

But soon, Katja became very drowsy. Before she knew what had happened, Roger had taken her to another room and raped her. He had used a date-rape drug to weaken her resistance. A few months later, Katja found that she was pregnant. What should she do?

Sadly, rape—when one person forces another to have sexual intercourse—is a common and devastating occurrence in our world. When someone forces or tricks someone to satisfy his sexual desires, it is just another type of sexual abuse. About 20% of women are sexually abused at some point in their lives.



APOLOGETICS AND EVIDENCE

CHRISTIAN APOLOGETICS

Differences in worldviews between people can dissolve into heated arguments. But should Christians involve themselves in such disputes? The apostle Peter reminds us that we should always be ready to give a reason for our faith with respect and gentleness (1 Pet. 3:15). The formal word for the act of giving an account or explanation of the Christian faith is *apologetics* (from the Greek word for “speaking in defense”).

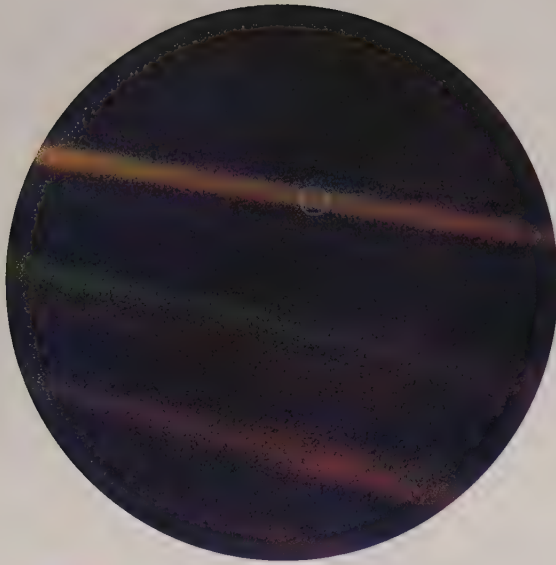
Christians have often used apologetics

- » to explain to others the reasons for their beliefs and practices, as the apostles did through their epistles and when standing before various authority figures;
- » to try to persuade an unbeliever to become a Christian;
- » to try to persuade another person who holds to a non-biblical position to change his mind; and
- » to encourage believers that their beliefs are reasonable.

Like any kind of effective argumentation, apologetics relies on presenting credible evidence, building a logical presentation, and making a persuasive defense. Christian apologetics draws mainly from

- » biblical evidence that comes from properly interpreted scriptural passages;
- » non-biblical evidence (historical, scientific, etc.);
- » a well-constructed argument that follows accepted rules of logic and avoids logical fallacies; and
- » a respectful and loving appeal to understand, to change one’s belief, or to be strengthened in one’s faith.





A-1

This famous photo from *Voyager 1* shows Earth from the edge of the solar system. It is called the "Pale Blue Dot" photo, part of the first mosaic of images taken of our entire solar system from four billion miles away.

A key part of convincing someone that your position is correct is presenting evidence to support your position. But this is where worldview comes into the picture. All evidence is filtered and interpreted through one's worldview. With the exception of evidence from the Bible, which Christians hold to be perfect and without error, no other kind of evidence is truly objective or certain, not even scientific evidence! However, even Biblical evidence, while perfect, is subject to interpretation by the reader.

Each person's worldview will guide his interpretation of the significance, or even in some cases, the validity, of the evidence. And no one is absolutely logical or flawless in his reasoning. Our fallen minds can misinterpret, misunderstand, or draw illogical conclusions from evidence. Normally, if evidence doesn't fit into our view of things or makes us uncomfortable at some deep level in our minds, we either reject it or explain it away.

When using non-biblical evidence to present arguments for what we believe, we must be careful about its quality. Some non-biblical evidence that we might have used at one time is no longer considered valid. For example, many Bible believers, including Martin Luther, believed that the earth was the center of the solar system. When Copernicus, Galileo, and Kepler built evidence for a heliocentric theory, many Christians rejected the idea as unbiblical. Some still do! But the Bible is written in a way that doesn't necessarily support a geocentric or a heliocentric theory. Today, we can send probes out to the edge of the solar system to observe that our solar system is, in fact, best modeled by the heliocentric theory.

On the other hand, high-quality, non-biblical evidence can be effective in helping unbelievers question their presuppositions. For instance, geologists can describe a single stratum of sedimentary rock at least 1000 miles across covering portions of the central United States. It is distinctive because it's mostly sandstone and shows evidence of deposition under rapidly flowing water (cross-bedding). Most geologists interpret this feature as sediments gradually deposited by a large system of meandering rivers during a vast period of time, but the evidence better fits deposition by a broad, fast-moving flood all at once in a short period of time.

Some disagreements resulting from differences between Christian and secular worldviews don't have clear non-biblical answers. The "starlight and time" problem in cosmology is an excellent example of this. If the universe is only 7000 years old, then how can we see light from objects that are more than 13 billion light-years away if the speed of light is unchanging?

When trying to change the heart of an unbeliever through apologetics, the most concrete, impressive evidence will not work on its own (Luke 16:27–31). Only the Holy Spirit through the presentation of Scripture convinces and persuades (Rom. 10:8–17). Piling up non-biblical evidence will save no one, and the unbeliever can make his own pile of

evidence to counter yours. The relative heights of the piles cannot determine truth!

Even a believer who bases some of his convictions on non-biblical evidence may be on shaky ground. A Christian's life ultimately must rest on faith, not sight (2 Cor. 5:7). Belief based on non-biblical evidence or improperly interpreted biblical evidence is unstable because the view of such evidence changes with time. For example, since the 1900s, many Christians believed that the canopy theory was true. But recent atmospheric modeling and evaluation of the theory by qualified creationist atmospheric scientists have concluded that a vapor canopy could not possibly have been the source for the rains during the Flood and would have made life on Earth impossible before that event. If a person bases his faith on evidences such as these, he could easily become disillusioned and perhaps bitter if the evidence is later shown to be invalid. This is particularly true for professing believers who have no root of faith (see Mark 4:16–17). Only sound biblical evidence obtained from proper hermeneutics (methods of interpreting the Bible) and accompanied by the ministry of the Holy Spirit will convince and persuade.

A PROPER VIEW OF EVIDENCE AS AN APOLOGETIC

God is able to use all sorts of means to convince an unbeliever. And evidence and logical argument are two of those potential means, which Paul himself employed. He pointed to eyewitnesses (1 Cor. 15:5–6), and he used reason and persuasion (Acts 19:8–9).

But Paul knew, as we should, that no amount of evidence, on its own, is sufficient to convert someone. Only God's powerful Holy Spirit can do that, because man's ultimate problem is not in his brain or in his science textbook. Humanity's shared problem is that we are all born loving all sorts of things other than God.

Even when you do appeal to evidence, don't let your debate stay there. Use evidence as a shovel to dig deeper, to question the other person's presuppositions. The moral law is a good way to do that. Secular scientists have recently claimed that evolution can account for the rise of love, justice, and self-sacrifice as important emotions that help the species survive. But how do these work with the underlying evolutionary assumption that natural selection acts through untold millennia of survival of the fittest? This contradiction isn't easily explained, but the evolutionist will come up with an explanation because he looks around him and sees that love, justice, and self-sacrifice exist. They must be useful for survival. The only real way to compare worldviews is to ask, "Which one has the greater explaining power?" Which worldview better accounts for morality and the existence of life?

So graciously push back: "Can you really live as if love and justice aren't right—just useful for preserving the species? How can a worldview based on natural selection and random chance account for our shared human conviction that some things are right and others wrong?"

ST. MATTHEW 7

eye, but considerest not the beam that is in thine own eye?

4 Or how wilt thou say to thy brother, Let me pull out the mote out of thine eye; and, behold, a beam is in thine own eye?

5 Thou hypocrite, first cast out the beam out of thine own eye; and then shalt thou see clearly to cast out the mote out of thy brother's eye.

6 ¶ Give not that which is holy unto the dogs, neither cast ye your pearls before swine, lest they trample them under their feet, and turn again and rend you.

7 ¶ Ask, and it shall be given you; seek, and ye shall find; knock, and it shall be opened unto you:

8 For every one that asketh receiveth; and he that seeketh findeth; and to him that knocketh it shall be opened.

9 Or what man is there of you, whom if his son ask bread, will he give him a stone?

10 Or if he ask a fish, will he give him a serpent?

11 If ye then, being evil, know how to give good gifts unto your children, how much more shall your Father which is in heaven give good things to them that ask him?

12 Therefore all things whatsoever ye would that men should do to you, do ye even so to them: for this is the law and the prophets.

13 ¶ Enter ye in at the strait gate: for wide is the gate, and broad is the way, that leadeth to destruction, and many there be which go in thereat:

14 Because strait is the gate, and narrow is the way, which leadeth unto life, and few there be that find it.

15 ¶ Beware of false prophets, which come to you in sheep's clothing, but inwardly they are ravening wolves.

16 Ye shall know them by their fruits. Do men gather

a Jer. 23
ch. 12

b ch. 3
Luke
John

c Prov. 9
& 23
Acts

d Hos. 12
ch. 22
Luke
& 13

e ch. 21
Mark
Luke
& 18

f John
& 15
& 16
Jas. 1
1 John

g Num.
John
1 Cor.

h Jer. 2
Luke

i Luke
2 Tim.

k Ps. 5
& 6
1 Luke

l Luke
Acts
& 8

m Gen.
& 8

n Luke

o Lev. 19
ch. 22
Rom.

p Luke
1 Tim.

q Or, H
Deut.
Jer. 2
ch. 24
Rom.
Eph.

r Mic. 3
2 Tim.
s ch. 13
Mark
& 6
Luke

t Acts
1 John
x ver. 8
y Luke

A Christian worldview accounts for love and justice because their source is an absolute, personal, triune God. Love exists because it is part of God's nature as a triune Being to love—the Father loved the Son and the Spirit, the Son loved the Father and the Spirit, and the Spirit loved the Son and the Father, from eternity past.

All of life is a journey of discovery. You're always learning and growing—or you should be! You may grow to find that some of your understanding of Scripture was wrong or, perhaps, incomplete. This is part of life in a fallen world. Even dedicated Christians are still fallible. They can't assume that they understand the Bible perfectly. But you can, with the Spirit's help, obey what you do understand and seek to refine that obedience and understanding over time.

When building up a believer's faith and tearing down strongholds of unbelief (2 Cor. 10:4–5), begin with careful, consistent interpretations of Scripture. Then show how careful, consistent interpretations of scientific or cultural evidence can be understood in light of these biblical truths. Remember, however, that presuppositions play a role in everyone's evaluation of the evidence. You can't test the big bang or a 7000-year-old earth with the scientific method. So biblical presuppositions must interpret all the evidence you encounter. Science and human reasoning must never be your starting point; the fear of the Lord is the beginning of knowledge.

CREATING GRAPHIC ORGANIZERS

There will be several times in this textbook when you will be asked to demonstrate that you understand a concept or a group of concepts by creating a *graphic organizer*. A graphic organizer is just a visual way to represent data. Use this appendix as a guide to help you create different kinds of graphic organizers to show how concepts in biology compare, how they are structured, or how they move through a process.

TABLE/T-CHART

A table is often used in science to organize data, but it can also be used to organize descriptions and other information. A table can be a helpful way to compare two or more concepts in biology. For example, the three classes of levers are compared in Table 1 below. If you are comparing only two concepts, this kind of table with only two columns can be called a *T-chart* because of its shape.

Table 1

Comparing Classes of Levers

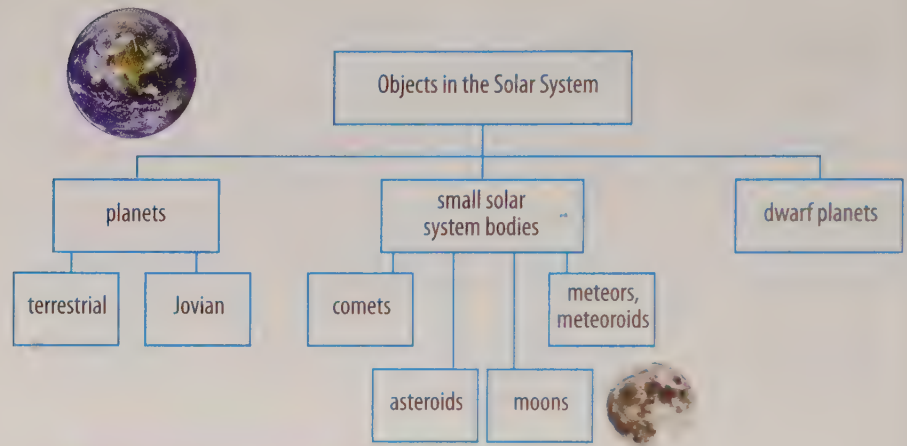
	First-class lever	Second-class lever	Third-class lever
Order of parts	resistance, fulcrum, effort	fulcrum, resistance, effort	fulcrum, effort, resistance
Comparing lengths of effort arm (EA) and resistance arm (RA)	$EA = RA$	$EA > RA$	$EA < RA$
Mechanical advantage	$= 1$	> 1	< 1

When you create a table, put the concepts that you are comparing in the top row. Put the characteristics under consideration in the left-most column. Fill in the cells, considering how each characteristic or category differs for the concepts that you are comparing.

HIERARCHY CHART

A *hierarchy chart* is one that shows the relationships between several concepts. For example, a company has an organizational chart that shows the relationships of employees and managers. Hierarchy charts are especially useful in biology when studying classification.

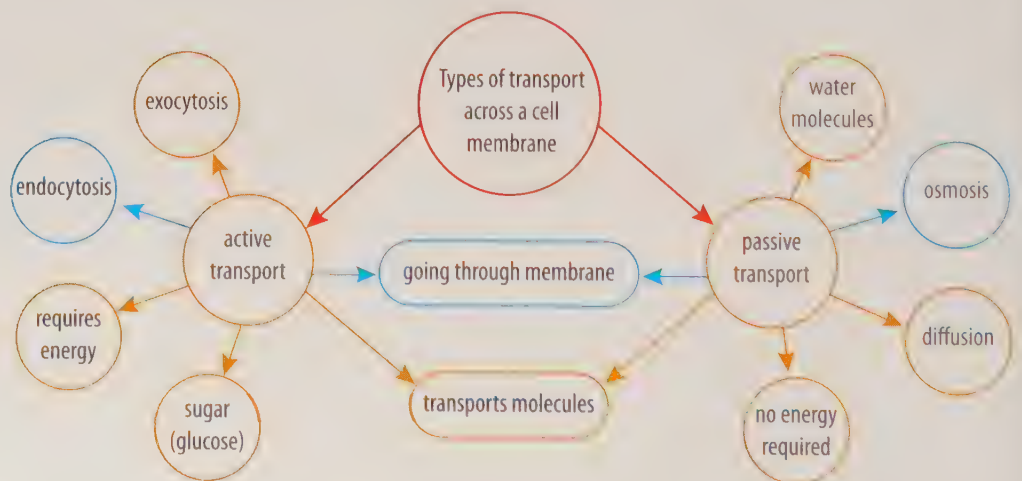
When you create a hierarchy chart, think of the different categories that a larger category includes. The example below shows how all the objects in the solar system can be classified as dwarf planets, planets, or small solar system bodies.



CONCEPT MAP

A *concept map* is a free-form graphic organizer that relates concepts, sub-concepts, and their related characteristics. It's similar to an outline in visual form. Because concept maps are so flexible, they can be more difficult to create.

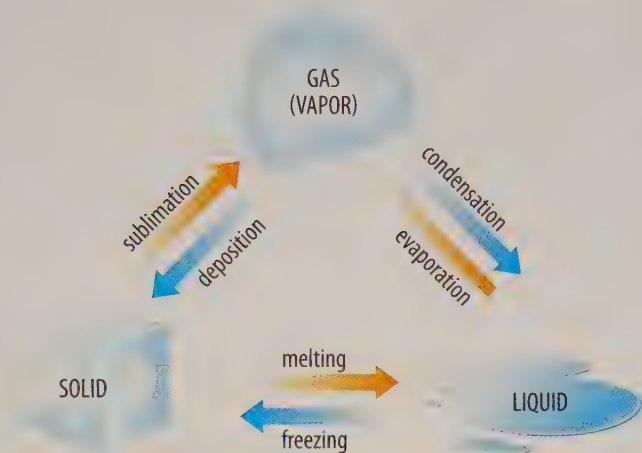
To make a concept map, start with the biggest concept and put it in a circle. Use lines or arrows to connect this main concept with smaller concepts. You can use linking words to help a viewer see the connection between two concepts and read the concept map like a sentence. The further you get from the main idea, the more specific the information should become.



PROCESS MAP/FLOWCHART

A *process map* illustrates a specific chain of events in a process. Because of its purpose, it almost always includes arrows to indicate the direction of the process.

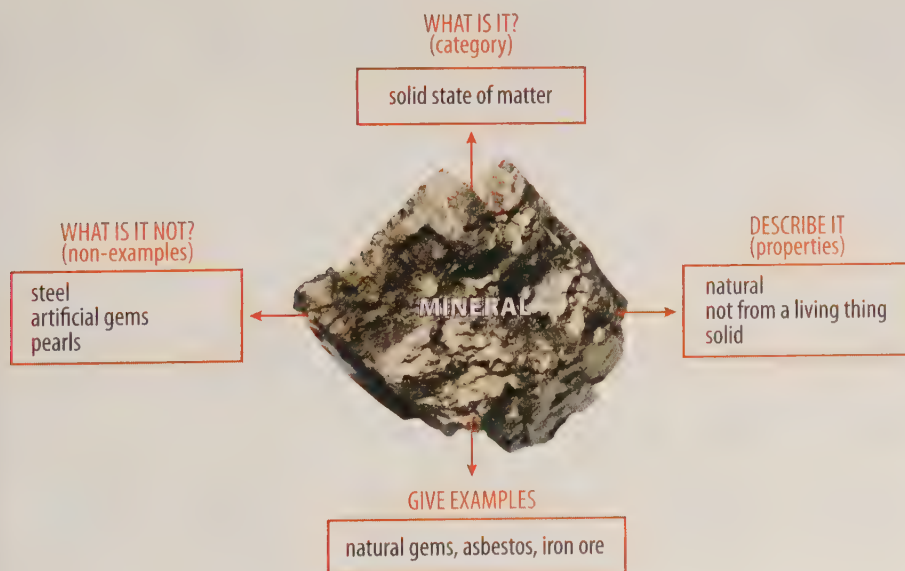
When you create a process map, think of the process that you are illustrating and the different steps that are part of this process. Make sure that you put them in chronological order! You can show a process in a line of events such as a timeline, or, if the process repeats itself, you can show it in a circle as a cyclical process that doesn't have a beginning or an end.



CONCEPT DEFINITION MAP

The last type of graphic organizer is a *concept definition map*. This graphic organizer takes a concept and considers four questions: What is it? What is it not? What are its properties? What are some examples?

Think through these four questions for a concept when you create a concept definition map. Then put the concept in the middle of the map and organize these four questions in boxes labeled with these questions around the concept.



APPENDIX C

PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9
IA								
1 H Hydrogen 1.008 1								
	2A							
3 Li Lithium 6.941 2, 1	4 Be Beryllium 9.012 2, 2							
11 Na Sodium 22.99 2, 8, 1	12 Mg Magnesium 24.31 2, 8, 2							
		3B	4B	5B	6B	7B		8B
19 K Potassium 39.10 2, 8, 8, 1	20 Ca Calcium 40.08 2, 8, 8, 2	21 Sc Scandium 44.96 2, 8, 9, 2	22 Ti Titanium 48.87 2, 8, 10, 2	23 V Vanadium 50.94 2, 8, 11, 2	24 Cr Chromium 52.00 2, 8, 13, 1	25 Mn Manganese 54.94 2, 8, 13, 2	26 Fe Iron 55.85 2, 8, 14, 2	27 Co Cobalt 58.93 2, 8, 15, 2
37 Rb Rubidium 85.47 2, 8, 18, 8, 1	38 Sr Strontium 87.62 2, 8, 18, 8, 2	39 Y Yttrium 88.91 2, 8, 18, 9, 2	40 Zr Zirconium 91.22 2, 8, 18, 10, 2	41 Nb Niobium 92.91 2, 8, 18, 12, 1	42 Mo Molybdenum 95.95 2, 8, 18, 13, 1	43 Tc Technetium (97.91) 2, 8, 18, 13, 2	44 Ru Ruthenium 101.1 2, 8, 18, 15, 1	45 Rh Rhodium 102.9 2, 8, 18, 16, 1
55 Cs Cesium 132.9 2, 8, 18, 18, 8, 1	56 Ba Barium 137.3 2, 8, 18, 18, 8, 2	57 La Lanthanum 138.9 2, 8, 18, 18, 9, 2	72 Hf Hafnium 178.5 2, 8, 18, 32, 10, 2	73 Ta Tantalum 180.9 2, 8, 18, 32, 11, 2	74 W Tungsten 183.8 2, 8, 18, 32, 12, 2	75 Re Rhenium 186.2 2, 8, 18, 32, 13, 2	76 Os Osmium 190.2 2, 8, 18, 32, 14, 2	77 Ir Iridium 192.2 2, 8, 18, 32, 15, 2
87 Fr Francium (223) 2, 8, 18, 32, 18, 8, 1	88 Ra Radium (226) 2, 8, 18, 32, 18, 8, 2	89 Ac Actinium (227) 2, 8, 18, 32, 18, 9, 2	104 Rf Rutherfordium (261)	105 Db Dubnium (268)	106 Sg Seaborgium (271)	107 Bh Bohrium (270)	108 Hs Hassium (277.2)	109 Mt Meitnerium (276.2)

92
U
Uranium
238.0
2, 8, 18, 32, 18, 8, 2

- Radioactive
- Atomic number
- Name
- Symbol
- Atomic mass
 - rounded to four significant digits
 - mass number of isotope with longest known half-life indicated by ()
- Electron structure by energy level

- Alkali metals
- Alkaline-earth metals
- Transition metals
- Post-transition metals
- Metalloids
- Nonmetals
- Halogens (also nonmetals)
- Noble gases
- Radioactive isotopes

Lanthanide series

58 Ce Cerium 140.1 2, 8, 18, 19, 9, 2	59 Pr Praseodymium 140.9 2, 8, 18, 21, 8, 2	60 Nd Neodymium 144.2 2, 8, 18, 22, 8, 2	61 Pm Promethium (144.9) 2, 8, 18, 23, 8, 2	62 Sm Samarium 150.4 2, 8, 18, 24, 8, 2
90 Th Thorium 232.0 2, 8, 18, 32, 18, 10, 2	91 Pa Protactinium 231.0 2, 8, 18, 32, 20, 9, 2	92 U Uranium 238.0 2, 8, 18, 32, 21, 9, 2	93 Np Neptunium (237.1) 2, 8, 18, 32, 22, 9, 2	94 Pu Plutonium (244.1) 2, 8, 18, 32, 24, 8, 2

Actinide series

10	11	12	13	14	15	16	17	18	8A
									2 Helium He 4.003 2
			3A	4A	5A	6A	7A		
			5 Boron B 10.81 2, 3	6 Carbon C 12.01 2, 4	7 Nitrogen N 14.01 2, 5	8 Oxygen O 16.00 2, 6	9 Fluorine F 19.00 2, 7	10 Neon Ne 20.18 2, 8	
			13 Aluminum Al 26.98 2, 8, 3	14 Silicon Si 28.09 2, 8, 4	15 Phosphorus P 30.97 2, 8, 5	16 Sulfur S 32.07 2, 8, 6	17 Chlorine Cl 35.45 2, 8, 7	18 Argon Ar 39.95 2, 8, 8	
	1B	2B							
28 Nickel Ni 58.69 2, 8, 16, 2	29 Copper Cu 63.55 2, 8, 18, 1	30 Zinc Zn 65.38 2, 8, 18, 2	31 Gallium Ga 69.72 2, 8, 18, 3	32 Germanium Ge 72.63 2, 8, 18, 4	33 Arsenic As 74.92 2, 8, 18, 5	34 Selenium Se 78.97 2, 8, 18, 6	35 Bromine Br 79.90 2, 8, 18, 7	36 Krypton Kr 83.80 2, 8, 18, 8	
46 Palladium Pd 106.4 2, 8, 18, 18	47 Silver Ag 107.9 2, 8, 18, 18, 1	48 Cadmium Cd 112.4 2, 8, 18, 18, 2	49 Indium In 114.8 2, 8, 18, 18, 3	50 Tin Sn 118.7 2, 8, 18, 18, 4	51 Antimony Sb 121.8 2, 8, 18, 18, 5	52 Tellurium Te 127.6 2, 8, 18, 18, 6	53 Iodine I 126.9 2, 8, 18, 18, 7	54 Xenon Xe 131.3 2, 8, 18, 18, 8	
78 Platinum Pt 195.1 2, 8, 18, 32, 17, 1	79 Gold Au 197.0 2, 8, 18, 32, 18, 1	80 Mercury Hg 200.6 2, 8, 18, 32, 18, 2	81 Thallium Tl 204.4 2, 8, 18, 32, 18, 3	82 Lead Pb 207.2 2, 8, 18, 32, 18, 4	83 Bismuth Bi 209.0 2, 8, 18, 32, 18, 5	84 Polonium Po (209) 2, 8, 18, 32, 18, 6	85 Astatine At (210.0) 2, 8, 18, 32, 18, 7	86 Radon Rn (222.0) 2, 8, 18, 32, 18, 8	
110 Darmstadtium Ds (281.2)	111 Roentgenium Rg (280.2)	112 Copernicium Cn (285.2)	113 Ununtrium Uut (284.2)	114 Flerovium Fl (289.2)	115 Ununpentium Uup (288.2)	116 Livermorium Lv (293)	117 Ununseptium Uus (294)	118 Ununoctium Uuo (294)	

The names given to elements 113, 115, 117, and 118 represent the Latin and Greek names for their arabic numbers.

As of 2016, the following proposed names were awaiting approval by the International Union of Pure and Applied Chemistry: 113—nihonium (Nh), 115—moscovium (Mc), 116—tennessine (Ts), and 117—oganesson (Og).

63 Europium Eu 152.0 2, 8, 18, 25, 8, 2	64 Gadolinium Gd 157.3 2, 8, 18, 25, 9, 2	65 Terbium Tb 158.9 2, 8, 18, 27, 8, 2	66 Dysprosium Dy 162.5 2, 8, 18, 28, 8, 2	67 Holmium Ho 164.9 2, 8, 18, 29, 8, 2	68 Erbium Er 167.3 2, 8, 18, 30, 8, 2	69 Thulium Tm 168.9 2, 8, 18, 31, 8, 2	70 Ytterbium Yb 173.0 2, 8, 18, 32, 8, 2	71 Lutetium Lu 175.0 2, 8, 18, 32, 9, 2
95 Americium Am (243.1) 2, 8, 18, 32, 25, 8, 2	96 Curium Cm (247.1) 2, 8, 18, 32, 25, 9, 2	97 Berkelium Bk (247) 2, 8, 18, 32, 27, 8, 2	98 Californium Cf (251.1) 2, 8, 18, 32, 28, 8, 2	99 Einsteinium Es (252.1) 2, 8, 18, 32, 29, 8, 2	100 Fermium Fm (257.1) 2, 8, 18, 32, 30, 8, 2	101 Mendelevium Md (258.1) 2, 8, 18, 32, 31, 8, 2	102 Nobelium No (259.1) 2, 8, 18, 32, 32, 8, 2	103 Lawrencium Lr (262) 2, 8, 18, 32, 32, 9, 2

COMBINING FORMS

You may find science a little intimidating because of all the long, unfamiliar words that scientists use. However, you can figure these terms out by breaking them down into simple parts that have meaning to you. When you see a difficult scientific word, look at the entries in this appendix to help you understand its meaning. These word parts may come at the beginning, end, or in the middle of the term, depending on the meaning.

For example, if you ran into the word “aerophyte,” you could separate this word into two parts, *aero-* and *-phyte*. *Aero-* means air, and *-phyte* means plant. So an aerophyte is an air plant, or a plant that is able to pull water out of the air and doesn’t have roots embedded in the soil.

Some word roots can be used only as prefixes, others only as suffixes. Still others can be used as either. For example, *cardiologist* is the name of a heart doctor, while *tachycardia* refers to a rapid heart rate. In the list below, a hyphen (-) indicates roots that are normally used as suffixes.

D-1

An aerophyte



a (Gk.)—not, without
ac, ad, ag (L.)—to, toward
acanth, acantha, acantho (Gk.)—spine, thorn
aer, aero (Gk.)—air
alb, albi, albid (L.)—white
allelo (Gk.)—one another, pair
amph, amphi, ampho (Gk.)—on both sides
an (Gk.)—without
ana (Gk.)—up, throughout, again
ant, anti (Gk.)—opposite, against
ante (L.)—before
ap, apic (L.)—tip, extremity
aqua, aquari (L.)—water
arthr, arthro (Gk.)—joint
-ase—suffix forming enzyme names
aster, astero, astr (Gk.)—star
aur, aure (L.)—gold, golden
aut, auto (Gk.)—self



bact, bacter, bacr (Gk.)—a rod
bacteri, bacterio (Gk.)—bacteria

bi (L.)—two, twice, double
bio, bios, biot (Gk.)—life
bol, bola, bole, bolo, bolus (Gk.)—a throw; clod, lump



card, cardi, cardia, cardio (Gk.)—heart
carn, carneo, carni (L.)—flesh
cat, cata, cato (Gk.)—down, downward
caud, cauda (L.)—tail
cell, cella, celli (L.)—chamber, cell
cent, centi (L.)—a hundred
centr, centri, centro (Gk.)—center
cephal, cephal, cephalo (Gk.)—head, brain
cereb, cerebell, cerebr, cerebro (L.)—brain
chem, chemo (Gk.)—juice; pour; chemistry
chlor, chloro (Gk.)—green
chondr, chondro (Gk.)—grain, corn; cartilage
chord, chorda (L.)—string, cord

chrom, chroma, chromato, chromo (Gk.)—color

chrys, chryso (Gk.)—gold
cide, cis, cision (L.)—to kill; cut
cili, cilia, cilio, cilium (L.)—eyelash, eyelid, small hair
co, com, con (L.)—with, together
coagul (L.)—drive together, curdle
crani, crania, cranio, cranium (Gk.)—skull
cret, creta (L.)—to separate
cris, crista (L.)—crest, tuft
cut, cutane, cuti, cutic (L.)—skin
cyan, cyane, cyani, cyano (Gk.)—dark blue
cycl, cycle, cyclo (Gk.)—circle, wheel
cyst, cystis, cysto (Gk.)—bladder, pouch
cyt, cyte, cytic, cyto, cytus (Gk.)—hollow place, cell



dactyl, dactylo, dactylus (Gk.)—finger, toe
derm, derma, dermi, dermis, dermo (Gk.)—skin

detrit (L.)—to wear off
di, dis (Gk.)—separate, apart; two, double
dia (Gk.)—across, through
dipl, diplo (Gk.)—double, two
dors, dors, dorso, dorsum (L.)—back
dyn, dynam, dynamo, dynast (Gk.)—be able; power, energy

E

e (L.)—out, without, from
echin, echino, echinus (Gk.)—spiny, sea urchin
eco (Gk.)—house
ecto (Gk.)—outside, outer, external
-ell, -elle (L.)—small
em (L.)—in, into
-emia (Gk.)—blood
en, end, endo (Gk.)—within, inner
epi (Gk.)—upon, over, beside
equ, equa, equi (L.)—equal
erythr, erythro (Gk.)—red
eu (Gk.)—good, true, well
ex (L.)—out, off, from, beyond
exo (Gk.)—out, outside, without
extra (L.)—outside, more, beyond, besides

F

fasci, fascia (L.)—a bundle
fer, fera (L.)—to bear. *See also* phor
fibr, fibril, fibrin, fibro (L.)—fiber
flagell, flagellum (L.)—whip
foli, folia, folium (L.)—leaf

G

gamet, gamete, gameto (Gk.)—marriage, spouse
gast, gaster, gastero, gastr, gastri, gastro (Gk.)—stomach, belly
gene, genea, geneo, genesis, geno (Gk.)—birth, origin, family, beginning
-genic, -genous (Gk.)—producing
genus (L.)—race, sort, kind
geo (Gk.)—earth
germ (L.)—bud, sprout, seed
gest (L.)—to carry

gli, glia, glio (Gk.)—glue
glob, globo, globus (L.)—ball, globe
gluc, gluco (Gk.)—sweet
glutin (L.)—glue
glyc, glycer, glyco (Gk.)—sweet
gon, gone, gonia, gonidi, gonium, gono, -gony (Gk.)—seed, generation, offspring
gran, grani, grano, granum (L.)—grain
graph, grapho, graphy (Gk.)—to write
gymn, gymno (Gk.)—naked, bare

H

halo (Gk.)—salt, sea
hapl, haplo (Gk.)—single
hem, hema, hemato, hemia, hemo (Gk.)—blood. *See also* -emia
herb, herba, herbi, herbo (L.)—grass
hered (L.)—heir
heter, hetero (Gk.)—other, different
hist, histo (Gk.)—web, tissue
homo (L.)—man
homo, homeo, homio (Gk.)—like, same, resemble
hybrid (L.)—offspring of different parents
hydr, hydra, hydri, hydro (Gk.)—water
hyper (Gk.)—over, beyond
hypo (Gk.)—under, beneath

I

ichthy, ichthyo, ichthys (Gk.)—fish
il, im, in, ir (L.)—into, in; not
intr, intra (L.)—within
is, iso (Gk.)—equal

J

jug, jugo (L.)—*See* zygo

K

kary, karyo (Gk.)—nut, nucleus
kine, kinema, kinemato, kines, kinesi, kinet, kineto (Gk.)—move, moving, movement

L

lampr, lampro (Gk.)—shining, clear
later, lateral, latero (L.)—side
leuco, leuko (Gk.)—clear, white
libra (L.)—a balance, scales
liga, ligam, ligat (L.)—bound; a band
lip, lipo (Gk.)—fat
log, logo, logus, logy (Gk.)—word, study of
lun, luna (L.)—moon
lys, lysi, lysio, lysis, lytic (Gk.)—loosening, break apart

M

macr, macro (Gk.)—large
matr, matri, matro (L.)—mother
medi, media, medio (L.)—middle
mei, meio (Gk.)—less
melan, melano (Gk.)—black
mens, mensa (L.)—table
mer, mere, meri, mero (Gk.)—a part
mes, meso (Gk.)—middle
met, meta (Gk.)—between, with, after, change
meter, metr, metra, metri, metro, -metry (Gk.)—measure
micro (Gk.)—small
mill, mille, milli, millo (L.)—one thousand
mito (Gk.)—thread
mono (Gk.)—one
morph, morpha, morpho (Gk.)—form, shape
mult, multi (L.)—many
muta (L.)—change
myc, myce, mycet, myceto, myco (Gk.)—fungus
my, myo, mys (Gk.)—muscle

N

nan, nani, nano, nanus (Gk.)—dwarf
nast, nasto (Gk.)—pressed closed, solid
nem, nema, nemato, nemo (Gk.)—thread
neph, nephri, nephron, nephrus (Gk.)—kidney
neur, neura, neuro (Gk.)—nerve

-nomy (Gk.)—the science of
nuc, nucle, nucleo (L.)—central part



ocul, oculi, oculo, oculus (Gk.)—eye
-oid (Gk.)—like, form
omni (L.)—all
oo (Gk.); **ov, ovi, ovo, ovum** (L.)—egg
opt, opti, opto (Gk.)—eye, vision
ora (L.)—mouth
orth, ortho (Gk.)—straight, correct,
upright
os, oss, osse, ossi (L.); **ost, oste, osteo,**
osteum (Gk.)—bone
-ose—suffix forming sugar names
osmo (Gk.)—pushing



par, para (Gk.)—beside
-parous (L.)—to give birth
ped, peda, pede, pedi, pedo (L.)—
foot
per (L.)—through, by means of
peri (Gk.)—around
phag, phage, phago, -phagy (Gk.)—
to eat
pharm, pharmac (Gk.)—drug, poison
pheno (Gk.)—show, seem, appear
phil, phila, phile, phili, philo (Gk.)—
beloved, loving
phob, phobia, phobo (Gk.)—fear
phor, phora, phore, phori, phoro
(Gk.)—to bear
phos, phot, phota, photi, photo
(Gk.)—light
phyll, phyllo, phylum (Gk.)—leaf
physis (Gk.)—growth
phyt, phyto, phytum (Gk.)—plant
plan, plani (L.); **plat, plate, plati,**
platy (Gk.)—broad, flat
plasm, plasma, plasmato, plasmo
(Gk.)—something molded
plast, plasto (Gk.)—formed, molded
plur, pluri (L.)—more, several
pneumo, pneumon, pneumonia
(Gk.)—lungs
pod, podo, pody (Gk.)—foot
poly (Gk.)—many
poten, potent (L.)—powerful

pro (Gk.)—before, in front of
prot, prote, proto (Gk.)—first, original
pter, ptero, pterum, ptery (Gk.)—
wing, feather, fin
pulmo, pulmon, pulmono (L.)—lung
purpur, purple (L.)—purple
-pus (Gk.)—foot



radi, radia, radiat, radio (L.)—spoke,
ray
re (L.)—back, again
ren, rena, reni, reno (L.)—kidney
reticul (L.)—network
rhiz, rhiza, rhizo (Gk.)—root



sacchar, saccharo (Gk.)—sugar
sarc, sarci, sarco (Gk.)—flesh
scop, scope, scopo, -scopy (Gk.)—to
see; watch
scri, scribe, script (L.)—to write
secret (L.)—set apart
semi (L.)—half
semen, semin (L.)—seed
sexu (L.)—sex
-sis (Gk.)—the act of
soma, somat, somato, -some (Gk.)—
a body
sperm, sperma, spermato, spermi
(Gk.)—seed
spir, spira, spiro (L.)—coil; twist
-spire (L.)—to breathe
spor, spora, -spore, spori, sporo
(Gk.)—seed
stas, stasi, stasis (Gk.)—standing,
posture
stat, stati, stato (Gk.)—standing,
placed
stoichi, stoicho (Gk.)—element
stom, stoma, stomato, stomo (Gk.)—
mouth
stria, striat (L.)—furrow, streak
stroma, stromato (Gk.)—anything
spread out, coverlet
sy, syg, syl, sym, syn, sys (Gk.)—with,
together



tel, teleo, telo (Gk.)—end, complete,
far
tetr, tetra (Gk.)—four
therm, thermos (Gk.)—heat
thesis (Gk.)—an arranging
thigm, thigma, thigmato, thigmo
(Gk.)—touch
thora, thoraco, thorax (Gk.)—breast-
plate
thylac, thylaco (Gk.)—sack, pouch
tom, tome, tomi, tomo, tomy (Gk.)—
to cut
ton, tono (Gk.)—tone; tension
top, topo, topus, topy (Gk.)—place
tot, tota, toti (L.)—all
toxic, toxicum (L.)—poison
tran, trans (L.)—across, through
tri (L.)—three
trop, tropae, trope, tropo (Gk.)—
turn, change
troph, trophi, tropho (Gk.)—food,
nourishment
turg (L.)—swell
typ, -type, typi, typo (Gk.)—blow,
strike; impression



uni (L.)—one
ur, ura, uro (Gk.)—tail



vacu (L.)—empty
valen, valent (L.)—strength; be worth
vas, vasa, vaso (L.)—vessel, duct
vent, venter, ventr, ventro (L.)—bel-
ly, underside
vert, verta, verte (L.)—to turn
vor, vora, -vore (L.)—to devour, eat



xanth, xantho (Gk.)—yellow



zo, zoa, zoi, zoo, zoon (Gk.)—animal
zyg, zygo, zygos (Gk.)—yoke
zym, zyma, zymo (Gk.)—yeast, leaven,
ferment

READING TABLES, GRAPHS, AND SCIENTIFIC DIAGRAMS

Scientists often like to compare two or more groups of observations to see whether they are related in some way. Doing so is a type of *analysis*, the process of looking for patterns and relationships within sets of data. These patterns and relationships can often be better understood by presenting them in a visual form, such as a table, graph, or diagram. Not surprisingly, then, science textbooks normally contain many tables, graphs, and diagrams too. Knowing how to read them will greatly enhance your learning experience.

TABLES

One of the simplest means of organizing data is to use a *table*. A table arranges data into rows and columns. Each row or column corresponds to a defined set of data or variable. For example, the table below shows the results of a stream survey conducted by fisheries biologists. The table has been set up to show at a glance *what kind* of fish were observed during the survey (row headings), as well as *how many* of each sex were observed (column headings).

Table 1

Stream Survey

Species	Male	Female	Unknown
Chinook	3	5	1
coho	11	9	2
steelhead	1	0	0

Data tables are usually read from left to right across the table, but may also be designed to include useful information if read in another direction as well. Reading from left to right, we can see that the biologists observed three male Chinook salmon, five female Chinook salmon, and one Chinook salmon whose sex could not be determined. Reading from top to bottom reveals that the biologists observed a total of fifteen male fish of all species. If you wanted to know how many female coho salmon were observed, you would first find the row with the coho heading, then scan over to where that row intersects the column for female fish. Doing so shows that nine female coho salmon were observed.

III

A Chinook salmon

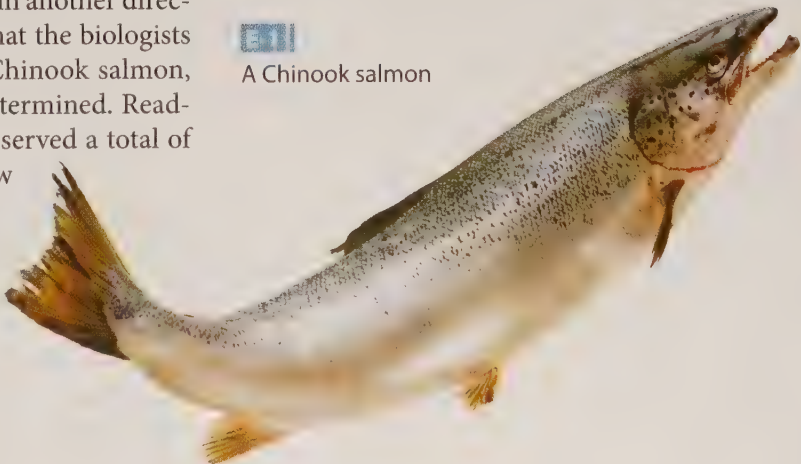


Table 1 displayed the results of a *survey*, but tables are often used to record the results of *experiments* as well. A group of students used Table 2 to record the results of an experiment to test the relationship between the time needed for a car to travel a certain distance down a slant track and the angle at which the track was set.

Table 2

Car Track Slope and Time of Travel

Track angle (°)	Trial 1 (s)	Trial 2 (s)	Trial 3 (s)	Average (s)
10	3.25	3.10	3.30	3.22
20	2.75	2.60	2.55	2.63
30	2.25	2.30	2.20	2.25

The two changing quantities, track angle and time, are called *variables*. Track angle, recorded in the first column, is the *independent variable* of the experiment since the angle of the track is set by the experimenters and does not depend on the values for time. The time to travel down the track, measured in the next three columns, is the *dependent variable*, because its value changes depending on the angle of the track. Notice that in each column heading, the units used to make each measurement are given (degrees for track angle and seconds for time). When the units are given in the heading, it means that all the measurements in that column are in those units; for example, every trial time is measured in seconds.

Table 2 displays the results of three trials done at each of three track settings, for a total of nine trials. The students also calculated the average speed at each track setting and recorded the result in a fourth column. Can you find the result for the second trial at a 20° track setting?

GRAPHS

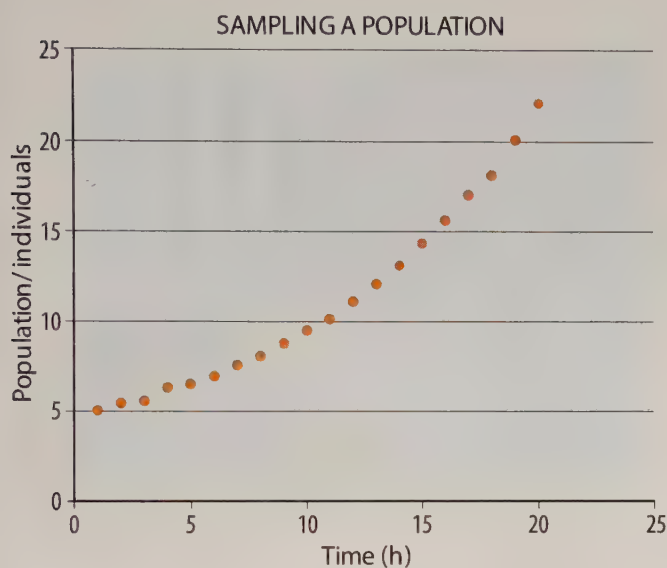
Another way to graphically display the relationship between two variables is to plot their values on a *graph*. The values of the independent and dependent variables are called the *coordinates* of the data. Each point plotted on a graph represents an *ordered pair* of coordinates, where the first number in the pair is the independent data coordinate and the second is the dependent data coordinate. You may have graphed ordered pairs in the form (x, y) in a math class.

Useful graphs include a title describing the graph's purpose, and labels identifying the quantities and units used on each axis. Numbered scales and a grid are usually included to help you estimate values of the variables plotted on the graph.

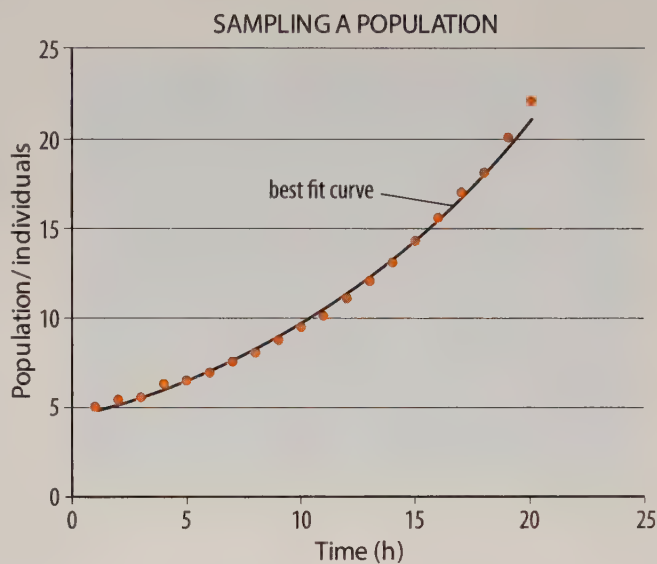
Scientists usually plot the independent variable on the horizontal axis of a graph, also known as the *x-axis*, with increasing values to the right. The dependent variables are plotted on the *y-axis*, the vertical axis, with the values increasing upward. These are not hard and fast

rules, and many graphs are arranged differently to improve the clarity of the plot. One of the first rules of reading graphs is to notice what the two variables are.

Graphs come in different forms. A simple plot of points on a graph is called a *scatter plot*. This is the starting point for many graphs. Scientists like to detect trends in the data and to create an equation that describes the trend. They draw a straight or curved line through the pattern of dots. The kind of line depends on how the pattern changes. We call the trend line a *line of best fit*. Graphs whose line of best fit is a straight line are said to show *linear relationships*. These are fairly rare in nature. Most trends in nature are slightly curved to really wavy! These graphs, logically enough, show *nonlinear relationships*.



A scatter plot

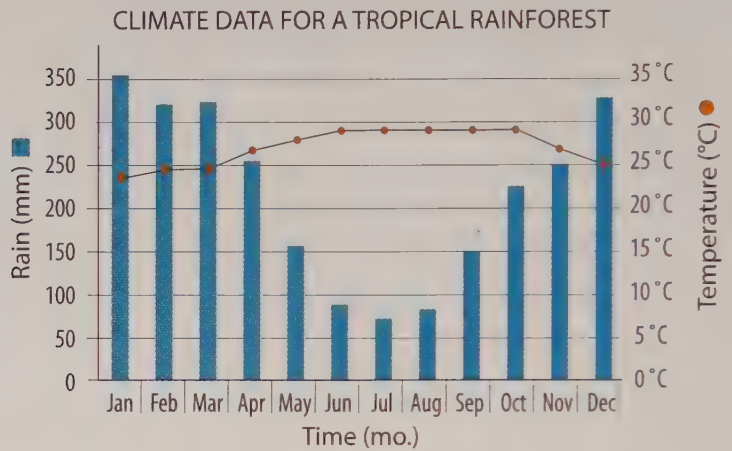


A scatter plot with a trendline

One of the most important things to learn from a graph is the rate at which the dependent variable changes in comparison to the independent variable. This rate is shown by the *slope* of the graph. A rising, or *positive*, slope shows that each increase in the independent variable produces an increase in the dependent variable. A horizontal slope shows that there is no relationship between the variables—a change in one does not produce a change in the other. A dropping curve has a *negative slope*, meaning that each increase in the independent variable produces a decrease in the dependent variable.

Scatter plots and trend lines can be read to obtain information not directly measured in the data set. The trend line connecting two data points represents values that are estimated—not measured. Obtaining unmeasured data this way is called *interpolation*. In addition, scientists often try to predict the values of the dependent variable if the independent variable continues to change beyond the range of the measured data. This method of analysis is called *extrapolation*. Extrapolating data depends heavily on assuming that the trend will continue as it has in the actual measured data.

Another common kind of graph is a *bar graph*. A bar graph depicts the value of the dependent variable of a data set in the form of a bar whose height (or length, depending on how the graph is set up) is determined by the variable's value. In the following graph, for example, the total rainfall for each month of the year in a rainforest can easily be seen. The shorter the bar, the less the amount of rainfall for a particular month. If you were asked to pick which months are the wettest in a rainforest, your eyes would quickly be drawn to the tallest bars on the graph. As this example shows, bar graphs are a good way to present data in which the independent variable has a nonnumerical value.



You will get to practice reading graphs in the chapter reviews of many chapters in this textbook. You will also have a few opportunities to *make* graphs in exercises in this textbook and even more in the Lab Manual.

SCIENTIFIC DIAGRAMS

Although biologists do make measurements during their investigations and present their findings in graphs, much of the content of this textbook is *conceptual*, meaning that ideas, facts, principles, and models are presented without using a lot of mathematics (perhaps this is a relief to you!). Biological processes and models are frequently illustrated by *diagrams*. These are visual aids whose purpose is to help make a concept more clearly understood. Diagrams are usually intended to help clarify something presented in the text, meaning that the text and diagram should be studied together in order to best understand the idea being presented. Diagrams are used in this textbook mainly to illustrate two things: structures and processes. Let's take a look at what to expect in each type of diagram.

STRUCTURAL DIAGRAMS

A structural diagram is intended to help you identify the parts of an organism. Keep in mind that the primary purpose of a structural diagram is to *inform* the reader, not to be an *exact representation* of the structure being discussed. Structural diagrams often make use of certain enhancements to make something clearer.

Structural diagrams can enhance color, zoom in on a structure, or cut away the exterior so that we can see inside. *Color coding* is often used to make the parts of a diagram more distinct, and in many cases makes use of colors not found in the original structure. *Exploded diagrams* separate the parts of a structure so that each individual piece can be clearly defined. A *zoom-out* is a close-up view of one portion of a diagram, giving more focus and detail to that portion. A *cutaway* shows how a structure might look if we could see into its interior. Structure diagrams will use call-outs or numbered bullets to label parts of the diagram. Each of these is designed to make a diagram more information-rich. In the diagram below, notice the use of both the cutaway and zoom-out features to help you better understand the structure of a mushroom.

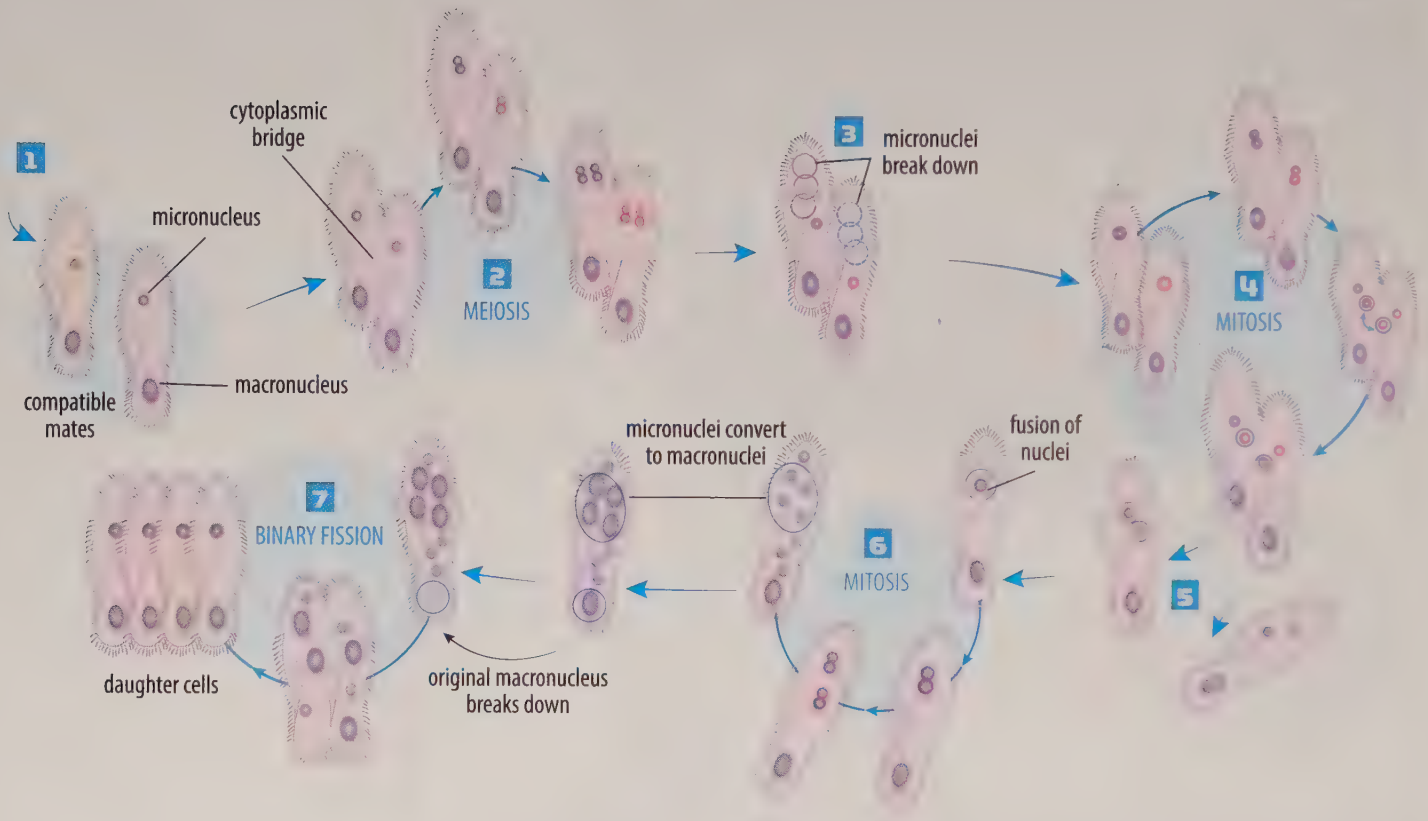


PROCESS DIAGRAMS

A process diagram is intended to show not how something *looks*, but how it *works*. Because some biological processes are very complex, diagrams of those processes can seem overwhelming at first glance. By definition, a process has a beginning and an end—it starts with something and ends up with something else. So process diagrams, unlike structural diagrams, normally have a part that should be looked at first, followed by other parts that are viewed in an orderly progression.

Process diagrams usually give visual clues about where to begin viewing the diagram. There may be *arrows* leading from the start of the

process to its end, or the steps of the process may be indicated by *numbered bullets*. Many diagrams make use of both arrows and bulleted items. Color coding is frequently used to help distinguish the parts of a process. Use the arrows and/or numbered bullets to guide you to the first step in the process, then read each step of the process along with the relevant text. Don't be concerned if you have to look at a process diagram several times to get the main ideas of what it teaches.



MATH PRINCIPLES

METRIC SYSTEM

Scientists frequently use very large and very small numbers. They prefer to write these numbers as concisely as possible, especially if they are round numbers. So they developed a system of unit prefixes that indicate which factor of ten should be multiplied by the base unit in the measurement.

Example: 1 kilometer = 1 km = 1000 × 1 m

Table 1

Metric Prefixes

Prefix	Symbol	Factor	Power of 10	Example
giga-	G-	× 1,000,000,000	10 ⁹	gigabyte (GB); used for measuring digital data
mega-	M-	× 1,000,000	10 ⁶	megajoule (MJ); work done by a bulldozer
kilo-	k-	× 1000	10 ³	kilometer (km); distance on Earth's surface
hect-	h-	× 100	10 ²	hectare (ha); measure of land area
deka-	da-	× 10	10 ¹	dekapoise (daP); a unit of viscosity or thickness of a fluid
(base)	—	× 1	10 ⁰	gram; a standard unit of mass
deci-	d-	× 1/10	10 ⁻¹	decibel (dB); sound loudness
centi-	c-	× 1/100	10 ⁻²	centimeter (cm); distances in a laboratory
milli-	m-	× 1/1000	10 ⁻³	millivolt (mV); heart pacemaker signal
micro-	μ-	× 1/1,000,000	10 ⁻⁶	micropascal (μPa); sound wave pressure
nano-	n-	× 1/1,000,000,000	10 ⁻⁹	nanometer (nm); the size of atoms

CALCULATIONS

Don't tell your math teacher this, but math is for science! Here are some math concepts you'll need in your science class.

RATIOS

It's really helpful to be able to compare the sizes or numbers of things in science. One way to do this is to find the ratio of one quantity to another.

Let's do an example: Find the ratio of girls to the total number of people in a group, maybe your class or family. To do this, take the number of girls and divide that by the number of everyone in the group. If there are 6 girls and 9 people total, then you divide 6 by 9. You get $6/9$, or $2/3$ after reducing. So the ratio of girls to everyone in the group is 2 to 3, or 2:3. In other words, there are two girls for every three people in the group.

AVERAGING

You and your friends discovered one day that the number of candies in each bag of M&Ms isn't the same. You want to know how many candies you should expect to be in a bag. You need to find the average number of M&Ms per bag. An average value falls somewhere in the middle of the group of values. It's a value *typical* of the group.

Averaging is straightforward. Just add together all the values in the group—the number of candies in each bag of M&Ms, for instance. Then divide the sum by the total number of values. Suppose you and your four friends counted 38, 42, 40, 37, and 40 M&Ms in the bags in your group. To find the average of these, you add the numbers together and divide by 5, the number of bags.

$$38 + 42 + 40 + 37 + 40 = 197$$

$$197 \text{ candies (total)} \div 5 \text{ bags} = 39.4 \text{ candies per bag (average)}$$

So, you should expect 39.4 candies per bag. But there aren't fractions of a candy in a bag! What do we do now?

ROUNDING

The solution to our averaging dilemma is called *rounding*. Since there are only whole candies in a bag, it makes sense to round the number to the one's place. Look at the first decimal place to the right, the tenth's place. If that number is 5 or larger, then add 1 to the one's place and drop all decimal numbers. If the tenth's place value is 0 to 4, just drop the decimal number and leave the one's place unchanged; in this case, we round 39.4 M&Ms to 39.

So you should expect about 39 candies per bag of M&Ms. The greater the number of bags you check, the more likely your average will represent a typical value of M&Ms.

GLOSSARY

A

abdomen A body region posterior to the thorax.

abiotic Nonliving; not derived from living things.

abscisic acid A plant hormone that acts as an inhibitor of other hormones and causes dormancy in buds and seeds.

accessory organ Of the digestive system, any organ that aids in digestion but is not part of the digestive tract.

acid A substance that can produce hydrogen ions (H^+) in solution.

acidophile An organism in kingdom Archaea that thrives in very acidic environments, such as acidic hot springs.

actin One of the two types of protein along with myosin responsible for muscle fiber contraction.

action potential The rapid change in charge difference across the cell membrane of a neuron that carries a nerve impulse along the axon of the neuron.

active immunity An immunity in which the body makes its own antibodies or has activated T cells for a particular antigen.

active transport The movement of substances across a cell membrane from regions of low concentration to regions of high concentration by any means that requires the use of energy.

adaptation Inheritable traits that improve the reproductive success of an organism.

adenosine diphosphate (ADP) The molecule produced when ATP is used for energy.

adenosine triphosphate (ATP) A molecule used within all cells for temporary energy storage.

adhesion The attraction of particles in one substance for particles in a different substance.

adrenal gland Either of the endocrine glands located on each kidney that produce several different hormones, including epinephrine and norepinephrine.

aerobic Describes any chemical process that requires oxygen.

air sac One of a series of hollow chambers that form part of the respiratory system of birds.

albumen The white of an egg.

alga A general term used for many autotrophic organisms, including members of the kingdom Chromista.

algal bloom A local surge in an algae population produced by very favorable environmental conditions.

alimentary canal The tubular passageway from mouth to anus that functions in the intake and digestion of food, the absorption of nutrients, and the elimination of residual waste; also, *digestive tract*.

allele One of a pair of genes that have the same position on homologous chromosomes and code for the same trait, though each may code for a different form of the trait.

allele frequency A measurement of how often an allele occurs in a population of organisms.

alternation of generations A plant reproductive strategy that includes alternating spore-forming and gamete-forming stages.

alveolus A small sac within the lung where gas exchange with air takes place.

amensalism A symbiotic relationship between two organisms that is injurious to one organism without affecting the other organism.

amino acid A class of organic compounds that serve as the building blocks of proteins.

amniote An animal whose embryonic development takes place inside a close-fitting membrane (amnion). The group includes reptiles, birds, and mammals.

amniotic fluid The protective fluid that surrounds an embryo within the amniotic sac.

amphibian An animal in the class Amphibia, such as a frog.

amplexus The physical contact of a male and female amphibian that stimulates the female to release eggs into the water.

amylase An enzyme secreted by the salivary glands and pancreas that breaks down starches into simple sugars.

anabolism The phase of metabolism that builds molecules and stores energy.

anaerobic Describes any chemical process that does *not* require oxygen.

anaphase The phase of mitosis during which chromosomes are separated into chromatids, and the chromatids are separated and sorted into daughter cells by the mitotic spindle.

anatomy The science that deals with the structure of the body.

androgen A male sex hormone produced by the testes.

angiosperm A vascular plant that produces flowers and fruits with seeds.

annual ring A visible ring caused by yearly growth in the vascular cambium; seen in a cross-section of a woody stem.

antagonistic pair A pair of muscles that work together to produce a motion and its opposite motion.

antenna An elongated, movable sensory appendage on the head of many invertebrates.

antibody A protein substance produced to eliminate antigens that have entered the body.

anticodon The set of three bases on a molecule of tRNA that correspond to a complementary codon on an mRNA molecule.

antigen Foreign material in the body that stimulates antibody production or begins cell-mediated immunity.

anus The opening at the end of the alimentary canal through which solid waste is eliminated.

aorta The large artery that carries blood from the left ventricle of the heart out to the body.

appendicular skeleton The bones of the pelvic and pectoral girdles and their appendages.

appendix A short, blind-ended tube attached to the large intestine near the juncture with the small intestine. Its exact function has not been positively determined.

aquifer An underground layer of water-bearing rock or sediment from which groundwater can be extracted.

Archaea A domain containing certain kinds of prokaryotic organisms, many of which are extremophiles.

artery Any vessel that carries blood away from the heart.

arthropod A member of the phylum Arthropoda, including chelicerates and insects.

artificial selection The human practice of breeding organisms that have desirable traits and variations.

asexual reproduction A type of reproduction in which new organisms are produced by a single parent and receive only the genes of that parent, producing, in effect, genetic clones of the original organism.

atom The building block of matter; the smallest possible particle of an element.

atrium A chamber through which blood enters the heart.

autoimmune disease A disease in which the body's immune system cannot distinguish between body cells and pathogens.

autosome A chromosome other than a sex chromosome.

auxin A plant hormone that promotes cell elongation and lateral root development.

axial skeleton The portion of the skeleton that supports and protects the organs of the head, neck, and trunk.

axon The portion of a neuron that carries impulses away from the cell body.

B

Bacteria A large domain of prokaryotic organisms.

bacteriophage A virus that infects bacteria.

bacterium An organism in either of the domains Archaea or Bacteria.

basal metabolic rate The amount of energy expended to maintain normal body functions while at rest.

base A substance that can produce hydroxide ions (OH^-) or accept hydrogen ions (H^+) in solution.

base pair The complementary nitrogenous bases that connect the two halves of a DNA molecule.

B cell A type of lymphocyte that functions in humoral immunity.

behavior The way an animal responds to its environment.

behavioral ecology The study of changes in animal behavior due to ecological pressures.

big bang The event described by the Big Bang theory, which states that the universe began in a very dense and very hot state and then rapidly expanded.

bilateral symmetry A type of symmetry in animals in which an imaginary plane through the centerline of the organism divides it into mirror-image halves.

bile A greenish fluid produced by the liver necessary for the digestion of fats.

binary fission A type of asexual reproduction used by all prokaryotes in which an organism divides to produce two identical organisms.

binomial nomenclature A system of naming organisms in which each organism is given a genus and species name.

biodiversity A measurement of the variety of life in a particular ecosystem.

bioethics The study of often-controversial ethical issues that arise as the result of new advances in biology and medicine.

biogeochemical cycle The movement of a specific chemical through the living and nonliving components of the biosphere.

biological evolution The idea that organisms can slowly change over time into other kinds of organisms.

biology The study of life.

biome The set of plants and animals that are adapted for life in those parts of Earth characterized by a particular climate.

bioremediation A technique that uses organisms to remove or neutralize hazardous wastes in the environment, such as oil spills.

biosphere The sum of all the habitable ecosystems on the earth.

biotechnology The use of living systems and organisms to produce new products and technologies, often by manipulating cells or cellular components.

biotic Living or derived from living things.

blade The broad part of a plant leaf.

blastocyst A fluid-filled sphere of embryonic cells.

blastula An early stage of embryonic development consisting of a hollow, fluid-filled ball of cells.

blood The liquid carrier of nutrients, hormones, and gases that moves through the circulatory system.

blubber A layer of insulating fat beneath the skin of marine mammals.

body plan The arrangement of physical features in an organism that contribute to its structure and form.

bolus A small mass of chewed food.

bond An attraction between two atoms as a result of sharing or transferring valence electrons.

bony fishes A group of fishes whose skeletons and fin rays are made of bone rather than cartilage.

book lung The plate-like respiratory structure found in arachnids.

bottleneck effect Term used to describe the situation in which the allele frequency in a population is drastically altered due to a sharp reduction in the size of the population.

Bowman's capsule The sac that encloses a glomerulus and collects filtrate from the blood. The filtrate is processed to produce urine.

brain stem The part of the brain that connects to the spinal cord and controls body movements and posture.

bronchiole The passageway in a lung through which air flows to an alveolus.

bronchus One of the two branches of the trachea that carry air to the lungs.

bryophyte A nonvascular plant in the group that includes mosses, hornworts, and liverworts.

bud An undeveloped shoot located at a node on a plant stem.

budding A type of asexual reproduction (e.g., in yeast) in which part of a cell is pinched off to form a new cell.



caecilian A legless amphibian belonging to the order Gymnophiona.

calcitonin The thyroid hormone that lowers the blood calcium level by causing the calcium to be moved to the bones.

Calvin cycle The portion of photosynthesis that uses energy captured during the light-dependent phase to convert carbon dioxide and water into sugars; also known as the *light-independent phase*.

cancer An unrestrained growth of abnormal cells with the potential to spread to other parts of the body.

cap The top of a club fungus's fruiting body containing the gills and spores.

capillary The smallest vessel of the circulatory system, where diffusion of nutrients and gas exchange occur.

capillary action The rising of a fluid within a tube due to adhesion between the molecules of the fluid and the tube.

capsid A protein coat that surrounds the nucleic acid of a virus.

capsule A protective coating found outside the cell walls of many bacteria.

carapace The portion of the exoskeleton that covers the cephalothorax in some arthropods.

carbohydrate An organic compound comprised of the elements carbon, hydrogen, and oxygen; includes sugars, starch and cellulose.

carcinogen A substance that increases the risk of cancer.

cardiac muscle Striated, involuntary muscle tissue found only in the heart.

carpel The female reproductive structure of a flower.

carrier A heterozygous organism that expresses the normal form of a trait but carries the recessive gene for an undesirable form of the trait and can pass it on to its offspring.

carrying capacity The maximum population size that a particular geographic area can support.

cartilage A firm but flexible form of connective tissue.

cartilaginous fishes A group of fishes, such as sharks and rays, whose skeletons are composed of cartilage rather than bone.

catabolism The phase of metabolism that breaks down molecules and releases energy.

catalyst A substance that changes the rate of a chemical reaction but is not itself used up or affected by the reaction.

cell The basic unit of structure in living things. All organisms are made of one or more cells.

cell body The part of a neuron containing the nucleus and cytoplasmic organelles.

cell cycle The series of events, including duplication of DNA, leading to the division of a cell into two daughter cells.

cell differentiation In multicellular organisms, the process of cells changing in order to perform specialized tasks.

cell-mediated immunity An immunity to disease involving activated cells, mainly T cells.

cell membrane A thin layer of phospholipids and proteins that defines the boundary of a cell.

cell theory One of the fundamental models of biology that states that cells are the smallest form of life, come from pre-existing cells, are the basic building block of all life forms, and carry out life processes to maintain homeostasis.

cell wall A rigid structure made by cells of plants, fungi, and most bacteria to surround the cell membrane.

cellular respiration The process by which cells break down glucose or other nutrients to produce usable energy.

cellulose The primary structural compound in plant cell walls, composed of long chains of glucose molecules.

central nervous system The portion of the nervous system consisting of the brain and spinal cord.

central vacuole An organelle in plant cells that holds materials and helps maintain the cell's shape through turgor pressure.

centromere The attachment point of the two chromatids in a chromosome.

centrosome A cellular organelle that functions in the organization of microtubules.

cephalization The concentration of sensory organs around one end of an organism.

cephalothorax A body region in some arthropods consisting of a fused head and thorax.

cerebellum The part of the brain that controls body coordination and monitors and adjusts body activities involving muscle tone, body posture, and equilibrium.

cerebrospinal fluid The fluid that nourishes and protects the brain and spinal cord and that flows between the two inner meninges.

cerebrum The part of the brain responsible for voluntary muscle activity and conscious activity.

cervix The neck of the uterus where it narrows and joins the vagina.

chelicerae The mouthparts of animals in the subphylum Chelicerata.

cheliped A crustacean walking leg bearing a small claw at its end.

chemical change A change in a substance that results in one or more new substances being formed that have different physical and chemical properties than those of the original substance.

chitin An organic substance, derived from glucose, found in the cell walls of fungi and the exoskeletons of invertebrates.

chlorophyll The green pigment of plant cells that is necessary for photosynthesis.

chloroplast A cellular organelle found in plant cells that contains the pigment chlorophyll and is the site where photosynthesis takes place.

chordate An organism in the phylum Chordata with a dorsal notochord, a nerve cord, pharyngeal pouches, and a post-anal tail at some stage in its life history.

choroid The thin middle layer of the eyeball that contains blood vessels for nourishing the retina.

chromatid One of two identical halves of a chromosome formed prior to cell division.

chromatin The genetic material of eukaryotic cells consisting of DNA and associated proteins.

chromist A plant-like organism in the kingdom Chromista, such as an alga.

chromosome A structure consisting of DNA and supporting proteins, usually found in a cell's nucleus.

chyme A semiliquid mixture of partly digested food and digestive juices in the stomach and small intestine.

cilium A short, hair-like extension of a cell used either for movement or as a sensory organelle.

citric acid cycle The second phase of aerobic cellular respiration in which pyruvate reacts with enzymes to produce acetyl CoA, carbon dioxide, hydrogen ions, ATP, and electrons; also called the *Krebs cycle*.

clade A branch on a phylogenetic tree that includes all the descendants of an evolutionary common ancestor.

cladistics The reclassification of organisms that is based on shared characteristics thought to be derived from a common ancestor.

class A taxonomic division within a phylum, composed of one or more orders.

cleavage A series of cell divisions in the development of an embryo during which the zygote forms into a multicellular mass.

climate The average weather in an area over an extended length of time.

climate change The change in global temperatures and weather patterns over time.

climax species Stable, long-lived species that mark the end of succession and characterize a mature ecosystem.

cloaca A common opening for the digestive, urinary, and reproductive tracts in birds, reptiles, amphibians, and some mammals.

clone An organism that is genetically identical to its parent.

closed circulatory system A system of fluid circulation within organisms in which the fluid (typically blood) remains within vessels.

cnidarian A member of the phylum Cnidaria, such as a jellyfish.

coagulation The biochemical process that forms a blood clot.

cochlea The snail-shaped division of the inner ear that functions in sound perception.

codominance A type of inheritance in which different alleles of a gene are expressed simultaneously, producing a phenotype that exhibits contributions from both alleles.

codon A set of three bases in an RNA strand that together code for a specific amino acid.

cohesion The attraction between like particles within polar substances.

cohesion-tension theory The currently accepted theory that explains the flow of water upward in the xylem of plants as a result of the cohesion between water molecules and the exit of water vapor through the stomata of the leaves.

colony (1) Individual organisms of the same species living closely together. (2) A group of cells that live and work together. Unlike in a multicellular organism, cells in a colony may break away and survive on their own.

commensalism A symbiotic relationship between two organisms that benefits one organism without helping or harming the other organism.

compact bone Dense, hard bone tissue made of tightly packed osteons.

comparative anatomy The study of similarities and differences in the anatomy of different species.

competition The conflict that results when organisms attempt to use the same resources.

complete metamorphosis A common form of insect development that normally includes four stages: egg, larva, pupa, and adult.

compound A pure substance made from two or more elements that are chemically combined.

compound eye An eye that is composed of many individual lenses.

cone Any one of the receptors in the eye that is sensitive to color.

conjugation The transfer of plasmid material from one bacterium to another through a conjugation tube.

connective tissue Refers to any of the tissues of the body that connect, support, cushion, and fill spaces around other tissues and organs.

conservation The preservation and wise use of natural resources, usually with consideration for the current and future needs of humans.

consumer A heterotrophic organism, that is, one that cannot produce its own food and must obtain energy by consuming other organisms.

convergence The process of two different species independently evolving the same derived trait.

cork In woody plants, a thick, tough layer of dead epidermal cells that supports the weight of the plant.

cork cambium A layer of meristematic cells that replace the epidermis in woody plant stems.

cornea The transparent front portion of the sclera of the eye.

corpus luteum The structure formed in the follicle of the ovary after ovulation; produces several hormones.

cortisol A hormone released by the adrenal glands that helps regulate glucose metabolism during stressful situations.

cotyledon A structure within a plant seed that nourishes the developing embryo and may, upon germination of the seed, become the seedling's first leaves.

countershading A form of camouflage in certain animals in which the top side of the animal has one color and the bottom side of the animal has another color.

courtship Animal behavior that promotes mate selection and breeding.

Creation Mandate The command given by God to Adam and Eve to fill the earth and have dominion over it (Gen. 1:28).

crocodilian An animal in the order Crocodylia, which includes crocodiles, alligators, caimans, and gharials.

crop A thin-walled portion of the digestive tract in some animals that temporarily stores food prior to digestion.

crossing over The exchange of sections of chromatids between homologous chromosomes during meiosis.

cuticle A waxy protective coating, secreted by the epidermal cells of a plant, on the surface of stems, leaves, and fruits.

cyst A dormant stage for some bacteria, protists, and a few invertebrates that allows an organism to survive within a protective coating during times of unfavorable environmental conditions.

cytokinesis The process during cell division in which the cytoplasm of a cell is divided between two new daughter cells.

cytokinin A plant hormone that promotes cell division and the development of lateral buds.

cytoplasm The thick fluid inside cells that contains the organelles. Also called the *cytosol*.

cytoskeleton The structure within cells that helps define their shape, maintains internal organization, and aids in division and movement.



day-neutral plant A plant that does not exhibit photoperiodism.

decomposer An organism that breaks down dead organic material, recycling nutrients to be used by other organisms.

dendrite The part of a neuron that receives nerve impulses and transmits them toward the cell body.

deoxyribonucleic acid (DNA) The double-stranded molecule used by most cells for storing genetic information.

derived trait A trait that arises within a clade and is shared by all future members of that clade.

dermal tissue Any of the tissues that form the outer layer of a plant or other organism.

dermis The thick inner layer of the skin.

descent with modification Darwin's idea that all organisms come from common ancestors and change a little with each generation.

detritus Small particles of dead organic material.

diaphragm In mammals and humans, the muscle beneath the lungs that controls breathing by expanding and contracting.

dicot Any flowering plant whose embryo has two cotyledons.

diffusion The process by which particles in solution are evenly distributed throughout the solvent by Brownian motion.

dihybrid cross A genetic cross that tests two sets of alleles.

diploid Having two complete sets of chromosomes.

dissolving The process by which one substance, the solute, is broken up into smaller pieces by and distributed within a second substance, the solvent.

divergence The process of two similar species becoming increasingly different over time.

DNA fingerprinting A technique used to identify an individual that is based on sequences in his DNA.

domain The taxonomic division just above the kingdom level that groups organisms on the basis of cellular, chemical, and RNA analyses.

dominant trait A characteristic that is expressed even in the presence of a recessive allele of the gene that codes for that characteristic.

dopamine A naturally-occurring neurotransmitter whose levels can be elevated by some kinds of drug usage.

double fertilization In plants, the fertilization of both the egg cell and the polar bodies, which later form the endosperm.

drug A chemical that causes change in the structure or function of a living tissue.



echinoderm A member of the phylum Echinodermata, such as a sea star.

ecological footprint A measurement of human demand on the earth's ecosystems, based on the amount of resources used, waste generated, and the rate at which resources can be renewed.

ecological pyramid A model for showing the flow of energy through the various trophic levels within an ecosystem from producers to top-level consumers.

ecology The study of the interrelationships between living things and their physical environments.

ecosystem The community of organisms in a particular area along with the physical characteristics of their environment.

ectoderm The outer germ layer of an embryo.

ectothermic Describes an animal whose body temperature remains close to the temperature of its environment. Ectothermic animals regulate their internal temperature by their behavior rather than by internal control mechanisms.

electron transport chain A series of compounds that transfer electrons from electron donor substances to electron acceptors. These chains are an important part of both photosynthesis and cellular respiration.

element A pure substance made of only one kind of atom.

embryo (1) The part of a seed that develops into a plant. (2) The early stage of development in the unborn young of a multicellular organism.

endoderm The inner germ layer of an embryo.

endoplasmic reticulum The cellular organelle that consists of a network of membranes used to transport substances throughout a cell. Rough endoplasmic reticulum is studded with ribosomes; smooth endoplasmic reticulum is not.

endoskeleton An internal skeleton usually made of bone and cartilage; characteristic of vertebrate animals.

endosperm The stored food inside a plant seed.

endothermic Describes an animal whose body temperature is internally regulated and whose body heat is derived mainly from metabolism.

energy The ability to do work. Especially in biology, the driver of the physical and chemical processes necessary for life.

entropy The tendency of energy to disperse and become less available to do work.

envelope A lipid bilayer that surrounds the capsid in some viruses.

environmentalism A broad philosophical and ethical movement that seeks to improve and protect the quality of the natural environment, sometimes at the expense of considerations for human needs and activities.

enzyme A naturally occurring catalyst, usually a protein.

epidermis (1) In plants, the outer layer of cells that usually lack chlorophyll and serve for protection, including the secretion of the cuticle. (2) In animals and humans, a tissue that covers or lines a structure, particularly the outermost layer of the skin.

epididymis A coiled tube on the outer surface of each testis that stores sperm.

epiglottis The flap that protects the trachea during swallowing.

epinephrine The hormone secreted by the adrenal medulla that stimulates the fight-or-flight response needed in an emergency.

epithelial tissue A tissue that covers or lines a body part and functions in absorption, secretion, and protection.

erythrocyte A red blood cell.

esophagus The portion of the alimentary canal connecting the pharynx and stomach.

estivation A period of dormancy entered into by some animals in response to high temperatures and arid conditions.

estrogen A female sex hormone that stimulates the development of secondary sex characteristics.

ethylene A plant hormone that regulates the ripening of fruit, opening of flowers, and shedding of leaves.

eukaryotic Describes cells having a true nucleus as well as membrane-bound organelles.

exoskeleton A system of stiff external plates for support and protection; characteristic of many invertebrate animals.

exponential growth A rate of population growth in which the population size multiplies at a constant rate at regular intervals.

external auditory canal The passageway from the external ear to the eardrum.

external fertilization The uniting of sperm and egg cells outside of an organism's body.

extracellular digestion The breakdown of substances that occurs in spaces outside of cells, such as within the stomach or intestine.

eyespot A light-sensitive area of pigmentation found in some protozoans and invertebrates.

F

facilitated diffusion A type of passive transport in which substances can move across a cell membrane through special protein channels embedded in the membrane.

fallopian tube A tube in female mammals and humans that leads from an ovary into the uterus.

family A taxonomic division within an order, composed of one or more genera.

fascicle A small bundle of muscle fibers.

feather One of the proteinaceous structures that covers a bird and enables flight.

fermentation The anaerobic breakdown of sugars to pyruvate and then to either lactic acid or carbon dioxide and alcohol.

fetus In humans, the term used to describe the unborn child during the second and third trimesters of pregnancy.

fibrous root system A root system lacking a taproot and consisting of many small roots that come straight from a stem.

flagellum A whip-like cellular organelle similar in structure to a cilium but longer and used primarily for movement in many bacteria.

food web The nutritional relationships between populations in an ecosystem involving overlapping food chains.

formula unit The smallest particle of an ionically bonded compound.

founder effect The loss of genetic variation that results when a new population of organisms is established by a small number of individuals from a larger population.

fragmentation A type of asexual reproduction in which new organisms grow from pieces of an original.

frameshift mutation A mutation that deletes or adds a nucleotide base to a DNA sequence, causing a shift in the reading of the sequence during transcription.

frog A short-bodied, tailless amphibian in the order Anura.

frond The leaf of a fern plant.

fruit A ripened plant ovary with or without seeds.

fruiting body A special fungal structure, composed of many hyphae, that is responsible for reproduction.



gallbladder A pear-shaped sac on the underside of the liver that concentrates and stores bile.

gamete A haploid reproductive cell that can unite with another gamete to form a zygote.

gametophyte The haploid stage in the alternation of generations life cycle of plants, during which gametes are produced.

ganglion A bundle of nerve cells.

gastrulation The phase of embryonic development during which the three germ layers are formed.

gene A segment of DNA that codes for a specific protein, resulting in a particular trait.

gene expression The process by which the information in a gene is used to make a functional gene product, usually a protein.

gene flow The movement of alleles into and out of a population of organisms.

gene pool The sum of all the alleles possessed by all the individuals in a population of organisms.

gene therapy The use of genetic engineering to treat genetic disorders or diseases.

genetically modified organism (GMO) An organism whose genetic material has been altered using genetic engineering techniques.

genetic drift A change in allele frequency due to random events, usually within a small population.

genetic engineering The process of manipulating an organism's genes by methods other than natural reproduction.

genetic equilibrium The condition of having a stable allele frequency, usual only in large populations.

genome The full set of genetic information coded in an organism's DNA.

genotype The genetic makeup of an individual organism, especially regarding its particular combination of alleles for a specific trait.

genus A taxonomic division within a family, composed of one or more species.

geologic time scale A system that relates evolutionary history to rock layers in the geologic column.

germination The beginning of growth by a seed, spore, bud, or other structure after a period of dormancy.

germ layer One of two to three primary layers of cells that form early in embryonic development.

gestation The period of time between conception and birth.

gibberellin A plant hormone with a role in regulating many aspects of plant growth, mainly stem elongation and cell division in shoots and leaves.

gill (1) A rib located beneath the cap of some mushrooms used to disperse spores. (2) A respiratory structure found in many aquatic organisms.

gizzard A thick-walled digestive organ that grinds food.

glomerulus The filtering unit within a nephron, consisting of a network of capillaries surrounded by the Bowman's capsule.

glucagon A hormone that raises the blood glucose level and stimulates the breakdown of fats to form glucose.

glycolysis The first phase of cellular respiration, in which glucose is broken down into pyruvate.

Golgi apparatus The cellular organelle that processes and packages proteins in preparation for secreting them from a cell.

gonad A sex gland, referring to the testes in males and the ovaries in females.

granum A stack of disk-shaped thylakoids within a chloroplast.

gravitropism Directional growth of a plant in response to gravity.

greenhouse gas A gas that can trap heat in the earth's atmosphere, such as carbon dioxide or water vapor.

Green Revolution A term used to identify a period during the twentieth century marked by advances in agricultural technology that led to greatly increased global food production.

ground tissue All the tissues in a plant that are not dermal, meristematic, or vascular tissue.

growth The assembling of parts that produces an increase in size and complexity in living organisms, including the replacement of worn-out or damaged cells.

growth hormone A hormone produced by the anterior pituitary gland that primarily affects bone growth.

growth plate A plate of cartilage near each end of a long bone where bone growth takes place in children and adolescents.

guard cell A modified epidermal cell that opens and closes a stoma.

gymnosperm A vascular plant that produces unenclosed seeds, usually in cones.



habitat The physical portion of an ecosystem preferred by an organism.

hair cell The receptor cells in the cochlea that convert vibrations into nerve impulses.

hair follicle The tubular structure from which a hair grows.

halophile An organism in kingdom Archaea that thrives in extremely salty environments, such as Utah's Great Salt Lake.

haploid Having only a single set of chromosomes.

Haversian canal The channel within an osteon that contains the capillaries and nerves that service the osteon's osteocytes.

hemoglobin The red pigment molecule that transports oxygen and carbon dioxide in vertebrate red blood cells.

heredity The passing of traits from one generation to another.

hermaphrodite An organism possessing both male and female reproductive organs.

heterozygous Describes the condition of having different alleles for a gene at the same position on homologous chromosomes.

hibernation A state of inactivity and extremely low metabolism by which some animals survive unfavorable environmental conditions.

homeostasis The internal balance within the systems of living organisms that must be kept stable in order to maintain life. Processes that maintain homeostasis include getting nutrition, expelling wastes, and responding to the environment.

homeotic gene A gene that regulates the development of an anatomical structure in an organism.

homologous Referring to one of a pair of chromosomes that carry the same genes in the same order on each chromosome.

homologous structures Organs that are similar in different organisms and are thought to show evolutionary relationships.

homozygous Describes the condition of having the same two alleles for a gene at the same position on homologous chromosomes.

hormone A chemical regulator produced in an endocrine gland and carried in blood to its target cell.

humoral immunity An immunity to disease involving antibodies and B cells.

hydroskeleton A support structure in many soft-bodied animals consisting of a fluid-filled cavity surrounded by muscles.

hydrotropism Directional growth of plant roots in response to the presence of water.

hypertonic Describes a solution whose solute concentration is greater than the solute concentration of the cytoplasm in a cell.

hypha A slender filament that is the primary structure of a fungal colony.

hypothalamus The region of the brain that controls involuntary activities, emotional expressions, and appetite for food, and links the nervous and endocrine systems.

hypothesis A simple, testable statement that predicts an answer to a question being investigated using the scientific method.

hypotonic Describes a solution whose solute concentration is less than the solute concentration of the cytoplasm in a cell.



image of God The combination of qualities that God has placed in people as a reflection of Himself.

implantation The process whereby an embryo attaches to the uterine wall and forms a placenta.

incomplete dominance A type of inheritance in which different alleles of a gene are neither dominant nor recessive and are expressed simultaneously, resulting in a blended, usually intermediate phenotype.

incomplete metamorphosis A type of insect development in which eggs hatch into nymphs that mature into adults.

incubate To keep an egg at a suitable temperature for development and hatching.

incus The second of the three bones in the middle ear that transmit vibrations from the eardrum to the inner ear; also, the *anvil*.

index fossil A fossil of an accepted age that is used to assign ages to layers of the geologic column.

inferior vena cava The vein that carries blood from the lower body to the right atrium of the heart.

inflammatory response The reaction of tissues to infection or injury; characterized by increased blood flow, redness, pain, and swelling.

inhibitor A substance that binds to an enzyme and reduces its activity, thus slowing a chemical reaction that the enzyme catalyzes.

instinct An unlearned, often highly complex inborn behavior.

insulin A hormone produced by the pancreas that helps control the glucose level in the blood.

internal fertilization The uniting of sperm and egg cells inside the body of a female organism.

interneuron A neuron located in the central nervous system that transmits an impulse from a sensory neuron to another neuron.

internode The region between nodes on a plant stem.

interphase The period of the cell cycle in between cell divisions; the time of regular growth and activity.

interpretation The explanation or meaning given to a set of observations; affected by one's worldview.

intracellular digestion The breakdown of substances within cells.

invasive species A species that moves into a new habitat, either naturally or by human introduction, and then competes with native species for resources.

invertebrate An animal that does not have a backbone or vertebral column.

iris The colored portion of the eye that controls the size of the pupil.

isotonic Describes a solution whose solute concentration is equal to the solute concentration of the cytoplasm in a cell.

J

Jacobson's organ An auxiliary sense of smell organ found in many animals; used to detect moisture-borne scent particles and pheromones.

jawless fishes A group of fishes that includes hagfishes and lampreys.

joint The point where two bones come together.

K

keel The large ridge on a bird's sternum to which the flight muscles attach.

keratin A tough, fibrous protein found in the horns, nails, hair, scales, feathers, and other structures of reptiles, birds, and mammals.

kidney The organ in most vertebrates that filters wastes from the blood and excretes them in the form of urine.

kingdom One of the broad taxonomic groupings just below the domain level, composed of one or more phyla.

L

large intestine The portion of the alimentary canal following the small intestine, where water and some vitamins are absorbed.

larynx An organ located between the pharynx and esophagus in the neck of amphibians, reptiles, and mammals and involved in sound production and the regulation of breathing.

law A description (often mathematical), based on repeated observations, of the relationship between two or more phenomena.

lens The transparent structure within the eye that focuses light rays on the retina.

lenticel An area of porous tissue in the surface of a woody plant stem that allows for gas exchange with the environment.

leucoplast A non-pigmented cellular organelle found in plant cells whose functions include storing starches, lipids, and proteins.

leukocyte A white blood cell.

lichen A composite organism consisting of a fungus and algae in a symbiotic relationship.

ligament A band of connective tissue that holds a joint together.

light-dependent phase That portion of photosynthesis that requires light energy.

light-independent phase That portion of photosynthesis that does not require light energy in order to proceed. The light-independent phase, does, however, require the products of the light-dependent phase, meaning that neither phase occurs during darkness.

limiting factor A factor within an ecosystem that prevents a population from growing beyond a certain size.

lipase A pancreatic enzyme that digests fats.

lipid A class of nonpolar organic compounds that are insoluble in water and are used for energy storage and cell membranes in living things.

lipid bilayer The two layers of phospholipids that make up a cell membrane.

liver An organ of the digestive system that secretes bile, purifies blood, metabolizes food molecules, and stores minerals and vitamins.

long-day plant A plant that requires a short period of darkness in order to flower.

loop of Henle The portion of a nephron that connects the proximal convoluted tubule to the distal convoluted tubule.

lung A structure for the exchange of gases between the atmosphere and the blood; found in most terrestrial vertebrates and some invertebrates.

lung capacity The amount of air that can fill the lungs.

lymph The clear fluid found between body cells, absorbed by the lymphatic system and returned to the bloodstream.

lymph node A small organ of the lymphatic system through which lymph flows and in which lymphocytes are found.

lymphocyte A type of white blood cell that functions in immunity.

lysogenic cycle A type of viral reproduction in which the virus's genetic material is reproduced by the host cell during normal cell division, resulting in daughter cells that contain the viral material.

lysosome A cellular organelle that contains digestive enzymes.

lytic cycle The rapid infection and destruction of a host cell by a virus, resulting in the release of more virus particles.

M

macrophage A large, amoeba-like cell found in the lymphatic system and surrounding tissues.

malleus The first of the three bones in the middle ear that transmit vibrations from the eardrum to the inner ear; also, the *hammer*.

Malpighian tubule One of numerous threadlike tubules in insects that extracts wastes from the blood and empties them into the intestine.

mammary gland An organ of female mammals that produces milk to nourish the young.

mandible A paired chewing mouthpart found in insects and some other arthropods.

mantle The sheath of tissue that covers the body of a mollusk.

matrix Nonliving secretions produced by cells to provide structural and biochemical support.

matter The physical stuff that makes up the universe. Anything that occupies space and has mass.

medusa The free-swimming, umbrella-shaped, sexually reproducing stage in the life cycle of some cnidarians.

meiosis The process by which haploid gametes are produced from diploid cells.

melanin A dark brown or black pigment.

meninges The protective coverings of the brain and spinal cord.

menstrual cycle The regular changes that take place in the ovaries and lining of the uterus to make pregnancy possible.

menstruation The regular shedding of the uterine lining in the event that pregnancy does not occur during a menstrual cycle.

meristematic tissue Undifferentiated cells found in the fast-growing parts of plants, such as root tips and new leaves.

mesoderm The middle germ layer of an embryo.

messenger RNA (mRNA) The RNA molecule that carries the code for a protein from the DNA to the cytoplasm of a cell.

metabolic waste The substances produced during metabolic activities that cannot be used by the body and must therefore be excreted.

metabolism The sum of all the life-sustaining chemical processes within an organism's cells.

metamorphosis A change in shape or form that an animal undergoes in its development from egg to adult.

metaphase The phase of mitosis in which chromosomes are aligned on the cell's equator before being separated and sorted into daughter cells.

methanogen An organism in kingdom Archaea that lives in anaerobic environments and produces methane during metabolism.

microbiome The collective genomes of the microorganisms (microbiota) that live in an environmental niche.

migration The movement of an organism from one location to another, often seasonally and over long distances.

mitochondrion The cellular organelle in which aerobic respiration takes place to release energy from food.

mitosis The phase of the cell cycle in which a cell's duplicated DNA is divided into two identical sets.

mitotic spindle The cellular structure that sorts separated chromatids into daughter cells during mitosis.

model A simple, workable representation of a usually complex object or concept.

molecular clock A technique that uses rates of molecular change to calculate at what point in the past two species diverged.

molecular evolution Slow, gradual change in the genetic material and proteins of organisms.

molecule The smallest particle of a covalently bonded compound.

mollusk A member of the phylum Mollusca.

molting The periodic shedding of an exoskeleton, scales, feathers, or fur.

monocot Any flowering plant whose embryo has one cotyledon.

monohybrid cross A genetic cross that tests only one set of alleles.

motor neuron A neuron that receives impulses from the central nervous system and stimulates a muscle or gland.

multicellular organism An organism consisting of two or more cells and whose cells may not live independently apart from the organism.

multiple alleles A condition in which more than two alleles for a gene are possible.

muscle fiber A muscle cell.

muscle tissue Tissue made of cells that can contract to produce movement.

mutagen A physical or chemical agent that can change the genetic material of an organism.

mutation A random change in the sequence of bases in a DNA molecule.

mutation theory of evolution The idea that mutations could produce favorable variations in a population that could be acted on by natural selection.

mutualism A symbiotic relationship between two organisms that benefits both organisms involved.

mycelium A fungal structure made of interwoven hyphae.

mycorrhiza A symbiotic relationship formed between many fungi and plant roots in which the fungi increase the absorptive area of the roots and receive carbohydrates in return.

myofibril One of the functional fibers within a muscle cell that causes contraction by the movement of actin and myosin filaments.

myosin Along with actin, one of the two types of protein responsible for muscle fiber contraction.

N

nasal cavity A large, air-filled space above and behind the nose.

natural selection The variation in the rates of survival and reproduction among the different phenotypes within a species that tend to make some phenotypes more common than others.

negative feedback A cellular signaling mechanism in which the product of a particular process inhibits the process itself.

nephron One of the microscopic functional units of the kidney.

nerve cord A length of nerve tissue that connects the brain to the rest of a chordate's body.

nerve net A nervous system that lacks a brain or major ganglia.

nervous tissue Tissue made of cells that respond to stimuli and transmit and receive electrical impulses.

neuron The functional unit of the nervous system; the cell that receives and distributes nerve impulses.

neurotransmitter A chemical that a neuron releases into the synaptic cleft for the purpose of stimulating receptor proteins in the membrane of the next neuron.

neutralism A symbiotic relationship in which two organisms share the same habitat without directly affecting each other.

niche The role of an organism within its habitat.

nitrogen fixation The conversion of nitrogen gas (inorganic nitrogen) by one of several mechanisms into nitrogen compounds (organic nitrogen) that living things can use.

node A point along a plant stem where a leaf, branch, or flower is produced.

nondisjunction The failure of homologous chromosomes or chromatids to separate properly during meiosis.

nonsteroid hormone A hormone without a large lipid component that affects its target cell with the aid of a receptor in the target cell's membrane.

nonvascular Of plants, lacking tissues that can transport water.

norepinephrine A hormone secreted by the adrenal medulla that functions with epinephrine during stressful situations.

notochord A tough, flexible rod that provides support for a chordate animal at some time during its life.

nucleic acid Organic molecules that carry genetic information in the form of either DNA or RNA.

nucleoid The non-membrane-bound region in prokaryotic cells that contains most of the genetic material.

nucleolus A spherical structure within a eukaryotic cell's nucleus where ribosomes are manufactured.

nucleotide A class of organic compounds that serve as the building blocks for the information storage molecules DNA and RNA.

nucleus (1) The membrane-bound region of a eukaryotic cell that contains the genetic material. (2) The central portion of an atom where protons and neutrons are located.

nutrient Any of several groups of substances that are necessary for growth and the maintenance of life.

nymph One of the stages in the incomplete metamorphosis of an insect.



observation Information gathered by using one of the five senses, or the process of gathering such information; can include measurements or descriptions.

olfactory sense The sense of smell.

operculum A plate that covers the gills of a fish.

optic nerve The nerve that carries nerve impulses from the photoreceptors to the occipital lobe of the brain.

oral cavity The portion of the mouth behind the teeth and bounded by the tongue and hard and soft palates.

order A taxonomic division within a class, composed of one or more families.

organ A structure made of two or more tissues that work together to perform a particular function.

organ system A group of two or more organs that work together to perform a particular function.

organelle Structures found within the cytoplasm of cells that perform the various functions cells need to stay alive.

organic compound A covalently bonded compound containing the element carbon.

osmosis The diffusion of water molecules through a semipermeable membrane.

ossification The laying down of new bone material by osteoblasts.

osteoblast A cell that builds and mineralizes new bone.

osteoclast A type of cell that breaks down bone tissue.

osteocyte A living bone cell resident in an osteon.

osteon The subunit that makes up compact bone.

ovary The primary reproductive organ in females; produces ova.

oviparous Describes a method of reproduction in which young develop inside eggs that are laid and hatched outside the body of the parent.

ovoviviparous Describes a method of reproduction in which young develop within eggs that hatch inside the parent's body.

ovulation The release of ova from an ovary.

ovule A structure in a plant ovary that contains the egg cell and will mature into a seed.

ovum A female gamete.

oxytocin A hormone that is released at the posterior lobe of the pituitary gland by the hypothalamus and that stimulates smooth muscle to contract.



pancreas An organ that secretes enzymes into the small intestine to perform digestion. Also secretes the hormones insulin and glucagon to control the blood glucose level.

parasitism A symbiotic relationship between two organisms in which one organism benefits at the expense of the other organism, known as the *host*.

parasympathetic nervous system A system of neurons that helps the body return to normal processes after a stressful situation.

parathyroid gland The endocrine gland that helps regulate calcium and phosphorus levels in the body.

passive immunity An immunity in which an individual receives antibodies that have been formed by another individual or an animal.

passive transport The movement of substances across a cell membrane without the need for energy.

pathogen An agent that causes a disease.

pedicel The stalk that connects a flower to the rest of the plant.

pedigree A heredity chart that tracks the expression of a trait through several generations.



pedipalp One of the second pair of arachnid appendages used for sensory perception and sperm transfer.

penis The organ that transfers sperm from male to female in humans and many vertebrates.

pepsin An enzyme produced by the stomach to digest proteins.

peptidoglycan A protein found in the cell walls of bacteria but not in archaea.

periosteum A layer of fibrous connective tissue that covers the outer surface of bones, except the joint ends of long bones.

peripheral nervous system The portion of the nervous system consisting of the nerves and ganglia outside the brain and spinal cord.

peristalsis Wavelike, involuntary muscular contractions that move food through the alimentary canal.

petal A flower structure located just inside the sepals that is often large, conspicuous, and scented.

petiole The small stalk that connects a leaf to the stem of a plant.

pharyngeal pouches Folds of skin along the neck region of chordate embryos. In vertebrates, these develop into gills or structures of the lower face and neck.

pharynx The portion of the throat posterior to the mouth and nasal cavity.

phenomenon A fact or event that can be observed.

phenotype The physical expression of a trait in an organism.

pheromone A chemical released by an animal that influences the behavior of another animal of the same species.

phloem In plants, the type of vascular tissue that transports food in the form of sugars from the leaves to the rest of the plant.

photoperiodism The response of a plant to changes in the duration and intensity of light exposure.

photosynthesis The process whereby plants, algae, and some bacteria form simple sugars from carbon dioxide and water in the presence of light and chlorophyll.

phototropism Directional growth of a plant in response to light.

phylogenetic tree A diagram that shows the supposed evolutionary relationships between groups of organisms.

phylogeny The evolutionary history of a species or population.

phylum A taxonomic division within a kingdom, composed of one or more classes.

physical change A change in a substance that does not change the identity of the substance (e.g., a change of form or state).

physiology The science that deals with the various processes and activities that take place in the body.

phytochrome A plant pigment that regulates a plant's response to photoperiod changes.

pineal gland A small endocrine gland in the brain that secretes melatonin.

pioneer species The plants and animals that first colonize an area during primary succession.

pith The spongy ground tissue located in the center of an herbaceous plant stem.

pituitary gland An endocrine gland attached to the hypothalamus that controls many of the other endocrine glands.

pit viper One of a group of venomous snakes that possess a heat-sensing organ between each eye and nostril.

placenta In most mammals and humans, the structure that consists of a portion of the uterine wall and the chorion of the embryo that allows nutrient and waste exchange between mother and embryo.

plankton Organisms that float in the water columns of oceans, seas, and large lakes and cannot swim against a current.

plasma The liquid portion of the blood that holds blood cells in suspension.

plasmid A small, circular piece of DNA distinct from chromosomal DNA and usually found in bacteria.

platelet A small, nonnucleated component of the blood that functions in blood clotting.

point mutation A mutation that changes a single nucleotide base in a DNA sequence.

polar Quality of molecules having an uneven distribution of electrical charge, resulting in some regions of a molecule having negative charge while others are positive.

polygenic inheritance A type of inheritance in which a trait is determined by more than one gene.

polymerase chain reaction A laboratory process used to quickly generate many copies of a piece of DNA for medical or research purposes.

polyp A sessile, cup-shaped, asexually reproducing cnidarian with a mouth and tentacles at one end and a basal disc at the other.

polyploidy The condition of having three or more complete sets of chromosomes.

population A group of organisms of the same species living and interacting within the same geographic area.

population density The number of organisms in a defined unit of area.

positive feedback A cellular signaling mechanism in which the product of a particular process enhances the process itself.

post-anal tail A structure extending past the anus in all chordate embryos.

prehensile tail A tail that can be flexed and used for gripping or holding things.

pressure-flow hypothesis The best-supported theory for explaining the flow of sap in the phloem of a plant by means of osmosis to move water that carries sugars from the leaves to other parts of the plant.

primary succession The stage of succession characterized by organisms first colonizing a previously barren ecosystem, such as a lava field or ground exposed by a retreating glacier.

prion Short for the term “proteinaceous infectious particle;” prions are infectious agents made entirely of protein.

producer An autotrophic organism, that is, one that can produce its own food from light or chemical energy.

product The substances formed during a chemical reaction, usually indicated on the right-hand side of a chemical equation.

progesterone A female sex hormone involved in the menstrual cycle and in pregnancy.

prokaryotic Describes cells lacking a true nucleus and membrane-bound organelles.

promoter A short sequence of DNA that determines where an RNA polymerase molecule is to begin the transcription of a strand of messenger RNA.

prophase The phase of mitosis during which a cell’s chromatin condenses into X-shaped chromosomes.

prostate gland A structure that produces a portion of the semen.

protein A class of large organic compounds made of amino acids linked by peptide bonds; used for structure and as organic catalysts in living things.

protein synthesis The process by which ribosomes build a sequence of linked amino acids, the basic, or primary, structure of a protein.

protist A microorganism made of eukaryotic cells.

protozoan An animal-like organism in the kingdom Protozoa.

pseudopodium A temporary extension of a cell membrane used by some protozoans to either move about or to engulf food particles.

puberty The period of hormone-induced change during which secondary sex characteristics develop.

pulmonary artery The artery that carries blood from the right ventricle of the heart to the lungs.

pulmonary circulation The flow of blood from the heart to the lungs and back.

pulmonary vein The vein that carries blood from the lungs to the left atrium of the heart.

Punnett square A diagram that is used to visualize genetic crosses.

pupa The resting or inactive stage of development during complete metamorphosis in an insect.

pupil The circular opening in the iris of the eye.

R

radial symmetry A type of symmetry in animals in which any of several imaginary planes through the center of the body divides the organism into mirror-image halves; a body plan without left and right halves.

radiometric dating A method of determining the age of an object by measuring the amount of a radioactive substance in the object.

radula A plate-like structure near the mouth of many mollusks bearing many tiny teeth used for scraping up food into the animal’s mouth.

reactant A substance that is present before a chemical reaction and takes part in it, usually shown on the left-hand side of a chemical equation.

receptacle The thickened top portion of a pedicel that supports the actual parts of a flower.

recessive trait A characteristic that is expressed only in the absence of a dominant allele of the gene that codes for that characteristic.

recombinant DNA DNA molecules produced in a laboratory by combining sequences of DNA from different sources, yielding a new sequence not normally found in any genome.

rectum The final section of the large intestine.

REM sleep The period of the sleep cycle during which dreaming takes place.

replication The process by which a strand of DNA is copied to produce an identical strand.

reproduction The formation by an existing organism of a new organism that is structurally and functionally similar to the original.

reproductive barrier Any biological difference, physical barrier, or behavior that prevents two different species from reproducing with each other.

response An organism’s reaction to changes in its intracellular or extracellular environment.

resting potential The relative charge difference between the inside and outside of a neuron.

restriction enzyme An enzyme used to cut DNA into pieces at specific places in the DNA sequence.

retina The innermost layer of the eyeball composed of light-sensitive photoreceptors and their fibers.

retrovirus A virus that can force a host cell to transcribe the viral RNA into the host’s DNA.

ribonucleic acid (RNA) The single-stranded genetic information molecule, copied from DNA, whose main function is, in conjunction with ribosomes, to build protein molecules. *See also* **messenger RNA**, **ribosomal RNA**, and **transfer RNA**.

ribosomal RNA (rRNA) The RNA molecule that combines with proteins to form a ribosome.

ribosome The cellular organelle that directs the protein-building process.

rod One of the sensory receptors in the eye that is not sensitive to color but can rapidly discern movement and is important in night vision.

rumen The first chamber in a ruminant stomach.

S

salamander A lizard-like amphibian in the order Caudata.

salivary gland A gland that secretes saliva and amylase into the mouth to lubricate food and begin the breakdown of starches.

salt gland A gland located near the eye of a reptile that excretes excess salt from the animal.

sap The fluid transported by xylem or phloem in a plant.

sarcomere One of the functional segments of a muscle.

scale A small body-covering plate on fish and reptiles.

scientific method An orderly way of investigating phenomena by using measurable and repeatable observations to test a hypothesis.

scientific name A two-part name, consisting of a genus name and species epithet, that is unique to a particular species.

sclera The outer layer of the eye; the "white of the eye."

scrotum A skin pouch within which the testes are located.

scute A bony external plate covered with keratin.

sebaceous gland A gland of the skin that releases a mixture of oils, waxes, and metabolic wastes.

secondary succession Succession that takes place in a disturbed area with soil and perhaps a few plants.

semen The fluid that contains sperm.

semicircular canal A structure in the inner ear that maintains dynamic equilibrium.

seminiferous tubule One of the tiny tubes that produces sperm within the testes.

sensory neuron A neuron that carries impulses toward the spinal cord or brain.

sensory receptor A neuron that carries impulses from a sensory organ toward the spinal cord or the brain.

sepal Leaf-like structure that protects a flower bud while forming and supports the flower after blooming.

septum A wall that divides a cavity or structure into smaller chambers.

sequencing The process of determining the order of nucleotides in an organism's DNA.

sessile Describes an organism or phase of an organism's life in which it does not move about freely but remains attached to something else; nonmotile.

sex chromosome A chromosome that determines whether an organism will be male or female.

sex-linked trait A trait coded for by a gene located on a sex chromosome.

sexual reproduction A type of reproduction in which haploid gametes are fused to produce a diploid zygote.

short-day plant A plant that requires a long period of darkness in order to flower.

siphon One of a pair of tubes in many aquatic mollusks that is used to draw in or expel water.

skeletal muscle Striated, voluntary muscle tissue that is attached to and moves the skeleton.

small intestine The portion of the alimentary canal immediately after the stomach, where most of the digestion and absorption of food takes place.

smooth muscle Involuntary muscle tissue that is not composed of sarcomeres and forms the walls of many internal organs.

sorus A structure on the underside of a fern frond that houses and protects the fern's sporangia.

spawning The process of releasing eggs and sperm by aquatic animals.

speciation The formation of new species through natural selection.

species (1) A taxonomic division within a genus, consisting of a single type of organism. (2) A group of organisms that are structurally similar and can interbreed to produce fertile offspring.

spinneret An organ in spiders and some insects that produces a filament made from secretions produced in silk glands.

spiracle One of the small pores in an insect's body that open into the tracheae.

spongy bone The type of bone that contains many small spaces, usually located in the ends of long bones.

spore A type of reproductive cell protected by a hard covering.

sporophyte The diploid stage in the alternation of generations life cycle of plants, during which spores are produced.

squamate An animal in the order Squamata, including snakes and lizards.

stamen The male reproductive structure of a flower; produces pollen.

stapes The third of the three bones in the middle ear that transmit vibrations from the eardrum to the inner ear; also, the *stirrup*.

stem cell A generalized cell that has the potential to differentiate into a cell that performs a specific function.

steroid hormone A hormone composed largely of lipids that is able to diffuse through its target cell's cell membrane.

stipe The stalk of a club fungus's fruiting body supporting the cap.

stoma A small opening in the underside of a leaf that regulates gas exchange.

stomach The muscular pouch of the digestive system that connects to the esophagus.

striated muscle Muscle tissue that is made of sarcomeres.

stroma Material within a chloroplast that surrounds the thylakoids.

subcutaneous layer The layer of fat and connective tissue below the dermis of the skin.

sugar A class of simple organic compounds important in living things as a source of both energy and structure.

superior vena cava The vein that carries blood from the upper body to the right atrium of the heart.

survey A subset of observations gathered from within a larger possible set of data.

survival of the fittest The idea that in any generation of organisms, those that are most fit (i.e., have the most reproductive success) will pass their characteristics on to the next generation.

sustainability The ability of the biosphere to maintain its balance indefinitely.

sweat gland A gland of the skin that releases perspiration to cool the body and also releases wastes.

swim bladder A gas-filled structure in many fish that enables them to maintain neutral buoyancy.

swimmeret One of the small appendages on some crustaceans that is used for swimming and reproduction.

symbiosis The interaction between two different organisms within an ecosystem.

sympathetic nervous system A system of neurons that helps the body adjust to stressful situations.

synapse The space between an axon and a dendrite or between the end of an axon and the body structure that it affects.

syrinx The voice organ in birds.

systematics The study of evolutionary relationships among living things through time.

systemic circulation The flow of blood from the heart to all parts of the body, except the lungs, and back to the heart.

T

taproot system A root system consisting of a large, main root (the taproot) from which smaller roots branch.

target cell The cell that is activated by a hormone.

TATA box A common promoter sequence.

taxon A grouping within a classification scheme.

taxonomy The science of classifying organisms.

T cell A type of lymphocyte involved in cell-mediated immunity.

telomere The repetitive nucleotide sequence that serves as a protective cap at the end of a chromosome.

telophase The final phase of mitosis, during which new nuclei form in the daughter cells and their chromosomes unwind.

temperature A measurement of the average speed of the particles within a substance.

tendon A type of connective tissue that connects muscle to bone.

testis The primary male reproductive organ that produces sperm and male sex hormones.

testosterone The androgen that promotes the development of secondary sex characteristics.

tetrad A group of four chromatids formed during meiosis by the pairing of a chromosome with its homologous partner.

tetrapod An animal in a vertebrate class that typically has four limbs.

thalamus The brain region that receives general sensations and relays impulses to the cerebrum; regulates consciousness and sleep.

theory A model that attempts to explain a set of observations.

thermophile An organism in kingdom Archaea that thrives in hot environments, such as around hydrothermal vents.

thigmotropism Directional growth of a plant in response to touch, primarily found in climbing plants such as vines.

thorax The body region between the head and abdomen.

threshold The strength that a stimulus must reach before it causes an action potential.

thylakoid A flattened, membrane-bound sac inside a chloroplast where the light-dependent phase of photosynthesis takes place.

thymus A mass of lymphatic tissue thought to produce the hormones called *thymosins*; degenerates prior to puberty.

thyroid The endocrine gland that controls the body's overall rate of metabolism and affects bone growth.

thyroxine The thyroid hormone that regulates metabolic rate.

tissue A group of cells that are specialized to perform a particular function.

trachea (1) A chitinous tubule that transfers air directly to the tissues of insects. (2) The passageway that connects the larynx to the lungs.

transcription The process by which a particular segment of DNA is copied into RNA.

transduction The transfer of DNA from one bacterium to another by a bacteriophage.

transfer RNA (tRNA) The RNA molecule that carries a specific amino acid to a ribosome during protein synthesis.

transformation The process of a bacterium taking in free-floating DNA from its environment, after which the bacterium can express traits coded for by the new DNA.

transgenic organism An organism containing genes that have been introduced from a different kind of organism.

translation The process in which a ribosome builds a protein on the basis of the sequence of codons in an mRNA molecule.

transpiration The release of water through the stomata of the leaves of a plant.

tropism A directionally-dependent growth response of plants to external stimuli such as light, gravity, touch, and the presence of water.

tuatara A lizard-like reptile native to New Zealand.

tube feet Small, soft, tubular structures in echinoderms used for locomotion and food capture; part of the water-vascular system.

tumor An abnormal growth of cells.

turgor pressure The pressure exerted by water in a full central vacuole upon the cytoplasm and cell membrane of a plant cell; maintains plant rigidity.

turtle A shell-covered reptile in the order Testudines.

tympanic membrane The circular membranous structure that transmits sound vibrations to the middle ear cavity; also, the *eardrum*.

U

umbilical cord The flexible structure containing blood vessels that conducts the blood of the fetus to the placenta for the exchange of food, wastes, and gases.

ungulate A hoofed mammal.

unicellular organism An organism consisting of only one cell.

ureter One of the tubes that carry urine from the kidney to the bladder.

urethra The passageway by which urine is conducted out of the body from the bladder.

urinary bladder The organ that serves as a storage reservoir for urine.

urine A liquid excreted from the body; contains the metabolic wastes that have been filtered from the blood.

uterus A reproductive organ for storing ova until they are fertilized or laid; in most mammals and in humans, the organ in which an embryo develops.

V

vaccination A method of exposing a person to a controlled amount of a disease-causing factor to develop an immunity to that disease.

vagina The elastic canal that leads from outside the body to the cervix of the uterus.

valve A flap of tissue within a vein that ensures the one-way flow of blood.

variation The range of genotypic differences possible between individuals in the same gene pool.

vascular Of plants, having tissues capable of transporting water.

vascular bundle In plants, a bundle composed of both xylem and phloem; also called a *vein*.

vascular cambium A layer of meristematic cells located between the xylem and phloem in the woody stems of plants that produces new vascular tissues.

vascular tissue In plants, the tissue that transports water and nutrients throughout the plant.

vas deferens The tube that carries sperm from the testis to the urethra.

vegetative propagation Any form of asexual reproduction in a plant.

vein (1) In plant leaves, a bundle composed of both xylem and phloem. (2) In animals, any blood vessel that carries blood toward the heart.

ventricle A chamber of the heart from which blood is pumped into arteries.

vertebrate An animal that has a backbone or vertebral column.

vertical zonation Changes in the plant and animal communities within a biome due to changes in elevation that produce differences in light, precipitation, and temperature.

vestigial structure A structure that seems to have no function in an organism and is thought to be leftover from the evolutionary process.

viroid An infectious agent of plants that consists of a short, circular strand of RNA with no capsid or envelope.

virus A small infectious agent that can replicate only by using the metabolism and machinery of a living cell.

visceral mass The portion of a mollusk's body that contains its internal organs.

viviparous Describes a method of reproduction in which young are born alive after developing inside the female's reproductive system.

W

walking leg An appendage on a crustacean used for locomotion.

water-vascular system A system of canals and tubes within echinoderms that functions in movement, circulating nutrients, and capturing food.

withdrawal The symptoms that occur when the use of a drug is discontinued.

worldview The perspective or collection of presuppositions a person uses to view and interpret the world.

X

xylem In plants, the type of vascular tissue that transports water and dissolved minerals from the roots to the rest of the plant.

Z

zygote A diploid cell formed by the union of two gametes.

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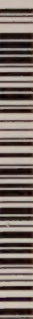
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