

Glencoe Science

Reading Essentials *for* **Biology**

An Interactive Student Textbook



biologygmh.com



Glencoe

New York, New York Columbus, Ohio Chicago, Illinois Peoria, Illinois Woodland Hills, California



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Table of Contents

To the Student	vii
Dinah Zike's Foldables™	viii
Chapter 1 The Study of Life	
1.1 Introduction to Biology	1
1.2 The Nature of Science	4
1.3 Methods of Science	7
Chapter 2 Principles of Ecology	
2.1 Organisms and Their Relationships	11
2.2 Flow of Energy in an Ecosystem	16
2.3 Cycling of Matter	19
Chapter 3 Communities, Biomes, and Ecosystems	
3.1 Community Ecology	23
3.2 Terrestrial Biomes	26
3.3 Aquatic Ecosystems	30
Chapter 4 Population Ecology	
4.1 Population Dynamics	35
4.2 Human Population	40
Chapter 5 Biodiversity and Conservation	
5.1 Biodiversity	43
5.2 Threats to Biodiversity	46
5.3 Conserving Biodiversity	51
Chapter 6 Chemistry in Biology	
6.1 Atoms, Elements, and Compounds	55
6.2 Chemical Reactions	59
6.3 Water and Solutions	62
6.4 The Building Blocks of Life	65
Chapter 7 Cellular Structure and Function	
7.1 Cell Discovery and Theory	69
7.2 The Plasma Membrane	72
7.3 Structures and Organelles	75
7.4 Cellular Transport	80
Chapter 8 Cellular Energy	
8.1 How Organisms Obtain Energy	83
8.2 Photosynthesis	86
8.3 Cellular Respiration	90
Chapter 9 Cellular Reproduction	
9.1 Cellular Growth	93
9.2 Mitosis and Cytokinesis	96
9.3 Cell Cycle Regulation	100

Chapter 10	Sexual Reproduction and Genetics	
10.1	Meiosis	103
10.2	Mendelian Genetics.	109
10.3	Gene Linkage and Polyploidy.	113
Chapter 11	Complex Inheritance and Human Heredity	
11.1	Basic Patterns of Human Inheritance	115
11.2	Complex Patterns of Inheritance.	119
11.3	Chromosomes and Human Heredity	124
Chapter 12	Molecular Genetics	
12.1	DNA: The Genetic Material	127
12.2	Replication of DNA.	132
12.3	DNA, RNA, and Protein	134
12.4	Gene Regulation and Mutations	139
Chapter 13	Genetics and Biotechnology	
13.1	Applied Genetics	143
13.2	DNA Technology.	146
13.3	The Human Genome	152
Chapter 14	The History of Life	
14.1	Fossil Evidence of Change	157
14.2	The Origin of Life	164
Chapter 15	Evolution	
15.1	Darwin’s Theory of Natural Selection.	169
15.2	Evidence of Evolution	172
15.3	Shaping Evolutionary Theory	176
Chapter 16	Primate Evolution	
16.1	Primates	183
16.2	Hominoids to Hominins	189
16.3	Human Ancestry	193
Chapter 17	Organizing Life’s Diversity	
17.1	The History of Classification	197
17.2	Modern Classification.	202
17.3	Domains and Kingdoms.	208
Chapter 18	Bacteria and Viruses	
18.1	Bacteria.	213
18.2	Viruses and Prions.	219
Chapter 19	Protists	
19.1	Introduction to Protists	223
19.2	Protozoans—Animal-like Protists	225
19.3	Algae—Plantlike Protists	229
19.4	Funguslike Protists	234
Chapter 20	Fungi	
20.1	Introduction to Fungi.	237
20.2	Diversity of Fungi	240
20.3	Ecology of Fungi	244

Chapter 21	Introduction to Plants	
21.1	Plant Evolution and Adaptations	247
21.2	Nonvascular Plants	251
21.3	Seedless Vascular Plants	253
21.4	Vascular Seed Plants	255
Chapter 22	Plant Structure and Function	
22.1	Plant Cells and Tissues	259
22.2	Roots, Stems, and Leaves	263
22.3	Plant Hormones and Responses	267
Chapter 23	Reproduction in Plants	
23.1	Introduction to Plant Reproduction	269
23.2	Flowers	274
23.3	Flowering Plants	278
Chapter 24	Introduction to Animals	
24.1	Animal Characteristics	283
24.2	Animal Body Plans	286
24.3	Sponges and Cnidarians	290
Chapter 25	Worms and Mollusks	
25.1	Flatworms	295
25.2	Roundworms and Rotifers	298
25.3	Mollusks	301
25.4	Segmented Worms	305
Chapter 26	Arthropods	
26.1	Arthropod Characteristics	309
26.2	Arthropod Diversity	313
26.3	Insects and Their Relatives	316
Chapter 27	Echinoderms and Invertebrate Chordates	
27.1	Echinoderm Characteristics	321
27.2	Invertebrate Chordates	326
Chapter 28	Fishes and Amphibians	
28.1	Fishes	329
28.2	Diversity of Today's Fishes	336
28.3	Amphibians	340
Chapter 29	Reptiles and Birds	
29.1	Reptiles	345
29.2	Birds	350
Chapter 30	Mammals	
30.1	Mammalian Characteristics	355
30.2	Diversity of Mammals	362
Chapter 31	Animal Behavior	
31.1	Basic Behaviors	367
31.2	Ecological Behaviors	371

Chapter 32	Integumentary, Skeletal, and Muscular Systems	
32.1	The Integumentary System	375
32.2	The Skeletal System	378
32.3	The Muscular System	382
Chapter 33	Nervous System	
33.1	Structure of the Nervous System	385
33.2	Organization of the Nervous System	389
33.3	The Senses	392
33.4	Effects of Drugs	395
Chapter 34	Circulatory, Respiratory, and Excretory Systems	
34.1	Circulatory System	399
34.2	Respiratory System	405
34.3	Excretory System	408
Chapter 35	Digestive and Endocrine Systems	
35.1	The Digestive System	411
35.2	Nutrition	414
35.3	The Endocrine System	417
Chapter 36	Human Reproduction and Development	
36.1	Reproductive Systems	421
36.2	Human Development Before Birth	426
36.3	Birth, Growth, and Aging	431
Chapter 37	Immune System	
37.1	Infectious Diseases	433
37.2	The Immune System	438
37.3	Noninfectious Disorders	443

To the Student

Reading Essentials for Biology takes the stress out of reading, learning, and understanding biology. This book covers important concepts in biology, offers ideas for how to learn the information, and helps you review what you have learned. Understanding biology concepts will help you improve your critical-thinking skills, solve problems effectively, and make useful decisions.

The chapters of *Reading Essentials for Biology* include the following elements.

- **Before You Read** sparks your interest in what you will learn and relates it to your world. The **Main Idea** and **What You'll Learn** statements help focus on the most important concepts in the section.
- **Read to Learn** describes important biology concepts with words and graphics. Next to the text you can find a variety of study tips and ideas for organizing and learning information:
 - **Study Coach** and **Mark the Text** offer tips for getting the main ideas out of the text.
 - **Foldables™ Study Organizers** help you divide the information into smaller, easier-to-remember concepts.
 - **Reading Checks** ask questions about key concepts. The questions are placed so you know whether you understand the material.
 - **Think It Over** elements help you consider the material in-depth, giving you an opportunity to use your critical-thinking skills.
 - **Picture This** questions relate to the illustrations used with the text. The questions will help get you actively involved in illustrating the important concepts.
 - **Applying Math** reinforces the connection between math and science.

Dinah Zike's Foldables™

A Foldable is a 3-D, interactive graphic organizer. By using Foldables, you can quickly organize and retain information. Every chapter in *Reading Essentials for Biology* includes a Foldable that can be used to organize important ideas in the chapter. Later, the Foldable can be used as a study guide for main ideas and key points in the chapter. Foldables can also be used for a more in-depth investigation of the key terms, concepts, or ideas presented in the chapter.

The Foldables for this book can be created using notebook paper or plain sheets of paper. Some will require scissors to cut the tabs. The Foldables created for this book can be stored in a plastic bag, a box, or sheet protectors in a three-ring binder. By keeping your Foldables organized, you will have a ready study tool. You will also be creating a portfolio of your work.

Your teacher might ask you to make the Foldables found on the Start-Up Activities pages in the Student Edition, in addition to the Foldables you will make for *Reading Essentials for Biology*. As you become familiar with Foldables, you might see other opportunities to use Foldables to create additional study tools. Keep together all the Foldables you make for a chapter. Use them as you review the chapter and study for assessments.

● Before You Read

What does it mean to be alive? On the lines below, list characteristics that you think living things have. Then read the section to learn what you have in common with other living things.

MAIN Idea

All living things share the characteristics of life.

What You'll Learn

- the definition of biology
- possible benefits from studying biology
- characteristics of living things

● Read to Learn

The Science of Life

Biology is the science of life. In biology, you will learn the origins and history of life and once-living things. You will also learn structures, functions, and interactions of living things.

What do biologists do?

Biologists make discoveries and look for explanations by performing laboratory and field studies. Some biologists study animals in their natural environment. For example, Jane Goodall's observations helped scientists know how best to protect chimpanzees.

Other biologists research diseases to develop new medicines. Many biologists work to develop new technology. Technology is the application of scientific knowledge to solve human needs and to extend human capabilities. For example, Dr. Charles Drew developed methods to separate blood plasma for transfusions. His research led to blood banks.

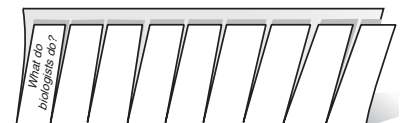
Some biologists study genetic engineering of plants. They try to develop plants that can grow in poor soils and resist insects and disease. Environmental biologists try to protect animals and plants from extinction by developing ways to protect them.

Study Coach

Make Flash Cards Make a flash card for each key term in this section. Write the term on one side of the card. Write the definition on the other side. Use the flash cards to review what you have learned.

FOLDABLES™

Summarize Information Make an eight-tab Foldable from a sheet of paper. Label the tabs with the question heads in this section. As you read, summarize the answers under the tabs.



Picture This

1. Highlight each characteristic of life in the table as you read about it in the section. Use the descriptions in the table to review what you have learned.

The Characteristics of Life

From many observations, biologists concluded that all living things have certain characteristics. The characteristics of life are listed in the table below. An **organism** is anything that has or once had all these characteristics.

Characteristic of Life	Description
Made of one or more cells	The cell is the basic unit of life. Some organisms have one cell only. Others have many cells.
Displays organization	The organization of a biological system begins with atoms and molecules. Each organized structure in an organism has a specific function. For example, an anteater's snout is long because it functions as a container for the long tongue.
Grows and develops	Growth results in an increase in mass. Development results in different abilities. For example, a tadpole grows larger and develops into an adult frog.
Reproduces	Organisms reproduce and pass on traits to the next generation. Reproduction must occur for a species to continue to exist.
Responds to stimuli	Reactions to stimuli from inside and outside the body are called responses. For example, a cheetah responds to the need for food by chasing a gazelle. The gazelle responds by running away.
Requires energy	Energy is needed for life processes. Many organisms get energy by taking in food. Other organisms make their own food.
Maintains homeostasis	Homeostasis is the process that keeps conditions inside the bodies of all organisms stable. For example, humans perspire when hot to lower body temperature.
Adaptations evolve over time	Adaptations are inherited changes that occur over time and help the species survive.

What determines a cell's structure?

Cells are the basic units of structure and function in all living things. Some organisms, such as bacteria, are unicellular—they have just one cell. Humans and plants are multicellular—they have many cells. The structure of a cell is related to its function. For example, each cell in a tree's roots has a structure that enables it to take in water from soil.

How are living things organized?

Living things display **organization**. This means they are arranged in an orderly way. Each cell is made up of atoms and molecules. Tissues are groups of specialized cells that work together. Tissues are organized into organs, which perform functions such as digestion. Organ systems work together to support an organism.

Reading Check

2. Sequence the levels of organization, from least complex to most complex.

How does development differ from growth?

Growth adds mass to an organism. Many organisms form new cells and new structures as they grow. **Development** is the process of natural changes that take place during the life of an organism. For example, after baby birds hatch they cannot fly for a few weeks. As they grow, they develop structures that give them the ability to fly.

Why is reproduction important to a species?

Reproduction is the production of offspring. If a species is to continue to exist, some members of the species must reproduce. A **species** is a group of organisms that can breed with one another and produce fertile offspring. Without reproduction, a species will become extinct.

Why is the ability to respond to stimuli critical?

An organism's external environment includes all things that surround it, such as air, water, soil, rocks, and other organisms. An organism's internal environment includes all things inside it. A **stimulus** (plural, stimuli) is anything that is part of either environment that causes some reaction by the organism. The reaction to a stimulus is a **response**. For example, a houseplant responds to the sunlight coming through a window by growing toward it. The ability to respond to stimuli is important for survival.

How do organisms obtain energy?

Living things need energy to fuel their life functions. Living things get their energy from food. Most plants and some unicellular organisms use light energy from the Sun to make their own food. Organisms that cannot make their own food get energy by consuming other organisms.

Why must an organism maintain homeostasis?

Homeostasis (hoh mee oh STAY sus) is the regulation of an organism's internal conditions to maintain life. If anything upsets an organism's normal state, processes to restore the normal state begin. If homeostasis is not restored, the organism might die. ✓

How do adaptations benefit a species?

An **adaptation** is any inherited characteristic that results from changes to a species over time. Adaptations make the members of a species better able to survive and, therefore, better able to pass their genes to their offspring.



Think it Over

- 3. Apply** Give an example of an internal stimulus for a rabbit. Describe an appropriate response to the stimulus.

Reading Check

- 4. Summarize** the importance of homeostasis.

The Study of Life

section 1 The Nature of Science

MAIN Idea

Science is the process based on inquiry that seeks to develop explanations.

What You'll Learn

- characteristics of science
- how to distinguish science from pseudoscience
- the importance of the metric system and SI

Mark the Text

Restate the Main Point

Highlight the main point in each paragraph. Then restate each main point in your own words.

Reading Check

1. **Identify** the key requirement for an explanation of a natural phenomenon to become a theory.

Before You Read

When you see a headline such as *Alien Baby Found in Campsite*, how do you know whether to believe it? Write your thoughts on the lines below. Then read the section to learn how to tell the difference between science and pseudoscience.

Read to Learn

What is science?

Science is a body of knowledge based on the study of nature and its physical setting. The purpose of science is scientific inquiry—the development of explanations. Scientific inquiry is a creative process as well as a process involving observation and experimentation.

How are scientific theories developed?

A **theory** is an explanation of a natural phenomenon supported by many observations and experiments over time. A scientific explanation combines what is already known about something with many observations and experiments. An explanation becomes a theory only when investigations produce enough evidence to support the idea. For example, the theory of evolution is based on many observations and investigations and has a lot of supporting evidence.

A pseudoscience (soo doh SI uhnts) is an area of study that tries to imitate science. Astrology, horoscopes, and psychic reading are pseudosciences. They are not supported by science-based evidence.

How does science expand knowledge?

Science is guided by research that results in a constant reevaluation of what is known. This reevaluation process leads to new knowledge. It also leads to new questions that require more research. ✓

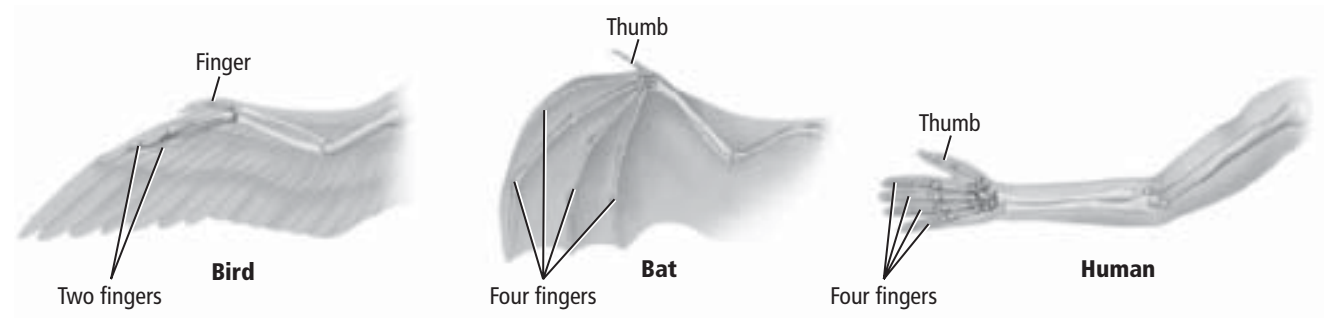
What happens when scientists disagree?

Scientists welcome debate. Disagreements among scientists often lead to further investigation. Science advances when new discoveries are added to the existing body of knowledge. For example, scientific research has dramatically increased our understanding of HIV.

How do scientists deal with inconsistent data?

When observations or data are not consistent with current understanding, scientists investigate the inconsistencies. For example, some early biologists suggested that bats had traits that were more similar to those of mammals than those of birds, as shown in the figure below. This idea led to further investigation. The new evidence confirmed that bats are more closely related to mammals than to birds.

In pseudoscience, observations that are not consistent with beliefs are ignored.



How do scientists test claims?

In science, all research follows standard procedures. Conclusions are based on evidence from carefully controlled investigations. Pseudoscientists make claims that cannot be tested. These claims are a mix of facts and opinions.

How are scientific investigations evaluated?

Scientific investigations undergo peer review. **Peer review** in science is a process in which the procedures used during an experiment and the results are evaluated by scientists who are in the same field or are doing similar research.

✓ Reading Check

2. Contrast the role of research in science and pseudoscience.

Picture This

3. Compare Are the structures of a bat's wing more like a human arm or a bird's wing? Explain.



Think it Over

4. Apply What unit do scientists use to measure the weight of an organism?



Think it Over

5. Summarize Complete the following sentence:
I need to be science literate in order to ...

What system of measurement do scientists use?

Scientists use the metric system of measurement. The **metric system** uses units with divisions that are powers of ten. In 1960, a system of unit standards of the metric system was established. This system is called the International System of Units, or **SI**. In biology, the SI units you will use most often are meter (length), gram (mass), liter (volume), and second (time).

Science in Everyday Life

Science is not limited to the laboratory. It is all around you. Many popular television shows about crime are based on **forensics**—the field that uses science to investigate crime. The media is filled with information on medical advances, new scientific discoveries, and new technologies.

Why is science literacy important?

To evaluate the vast amount of information available in print, online, and on television, you must be science literate. To be science literate, you need to combine a basic understanding of science and its process with reasoning and thinking skills.

Many important issues today relate to biology. Drugs, alcohol, tobacco, AIDS, mental illness, cancer, heart disease, and eating disorders are all subjects for biological research. You and future generations will face environmental issues, such as global warming, pollution, use of fossil fuels, nuclear power, genetically modified foods, and preserving biodiversity.

How do ethics apply to science?

Many scientific inquiries involve ethics. **Ethics** are a set of moral principles or values. Ethical issues are involved in the study of cloning, genetic engineering, eugenics (yoo JEH niks), euthanasia (yoo thuh NAY zhuh), and cryonics (kri AH niks). Eugenics is improving a race or breed by controlling mating. Euthanasia is permitting death for reasons of mercy. Cryonics is freezing a dead organism with the hope of reviving it in the future.

Scientists provide information about new discoveries and technology. As a scientifically literate adult, you will be able to participate in discussions about important issues. You will have the opportunity to support policies that reflect your values.

● Before You Read

Suppose you want to identify a bird that visits the feeder in your yard. On the lines below, describe some methods you might use to identify the bird. Then read the section to learn the methods scientists use to gather information and answer questions.

● Read to Learn

Ask a Question

Scientific inquiry begins with observation. **Observation** is a direct method of gathering information in an orderly way. It often involves recording information. For example, if you want to identify a bird, you observe it. You note how it behaves and what it eats. You might draw or photograph it.

Scientific inquiry involves asking questions and using information from reliable sources. By combining information from other sources with your observations of the bird, you could start making logical conclusions. This process is called making **inferences**, or inferring. For example, if you saw a photo of a bird that was similar to your bird, you might infer that your bird was related to the bird in the photo.

Biologists work in many settings. They work in the field. They work in laboratories, universities, and museums. No matter where they work, all biologists use similar methods to gather information and to answer questions. These methods are an organized series of events called **scientific methods**. Throughout the process, biologists continue to observe and make inferences.

MAIN Idea

Biologists use specific methods when conducting research.

What You'll Learn

- the difference between an observation and an inference
- how a control, an independent variable, and a dependent variable differ

Study Coach

Make an Outline Make an outline of the information you learn in this section. Start with the headings. Include the boldface terms.



Think it Over

1. **Explain** how inferences relate to observation.

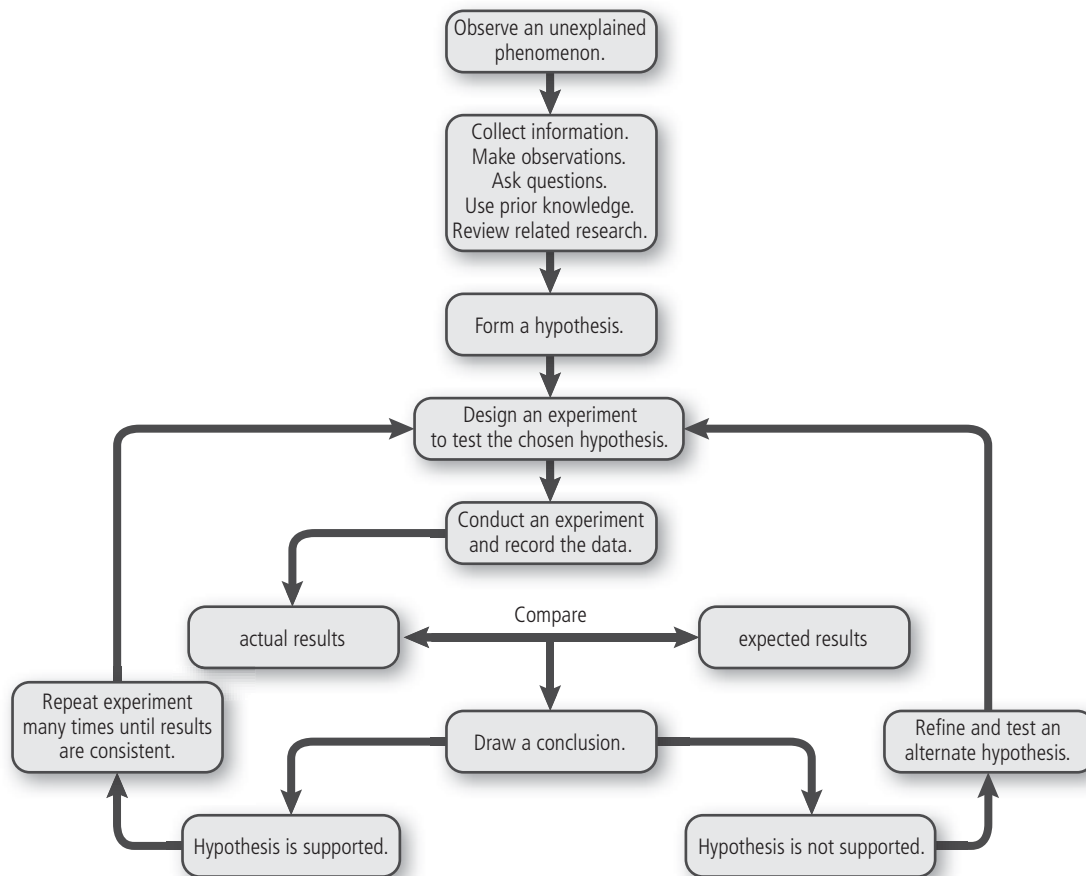
Picture This

- 2. Sequence** After a researcher draws a conclusion, what does he or she do next, whether or not the hypothesis is supported? (Circle your answer.)
- a. draw another conclusion
 - b. conduct another experiment
 - c. compare results again

Form a Hypothesis

The figure below shows the sequence of events in scientific methods. Scientists use the information they gather from observation and other sources to form a hypothesis. A **hypothesis** (hi PAH thuh sus) is a testable explanation of a situation. When enough data from many investigations support a hypothesis, the scientific community accepts the explanation as valid. If the data do not support a hypothesis, the hypothesis is revised and investigated further.

Sometimes scientists make unexpected discoveries. **Serendipity** is the occurrence of accidental or unexpected, but fortunate, results. For example, penicillin was discovered while a scientist was investigating something else.



Reading Check

- 3. Explain** the purpose of an experiment.

Collect the Data

Scientists test a hypothesis through experiments. An **experiment** is an investigation done in a controlled setting that tests the hypothesis. ✓


What is the purpose of a control group?

Experiments have an experimental group and a control group. The **experimental group** is the group exposed to the factor being tested. For example, suppose scientists wanted to test the effects of a vitamin supplement on energy level. The experimental group would receive the vitamin. The **control group** is the group used for comparison. This group would not receive the vitamin.

How do scientists design an experiment?

In a controlled experiment, scientists change only one factor at a time. The factor that is changed in an experiment is called the **independent variable**. It is the tested factor, and it might affect the outcome of the experiment. A **dependent variable** is something that results from or depends on changes to the independent variable. In our example, the vitamin is the independent variable and energy level is the dependent variable. A **constant** is something that remains fixed during an experiment, while the independent and dependent variables change.

What two kinds of data do scientists collect?

Information gained from observations is called **data**. Data in the form of numbers is called quantitative data. Quantitative data might measure time, temperature, length, mass, area, volume, density, or other factors. Qualitative data are descriptions of what the observer senses. Everyone senses things differently. As a result, qualitative data can vary from one observer to another. 

What are some other ways to investigate?

Some biologists focus on observing and collecting data rather than doing controlled experiments. For example, some biologists specialize in finding new species. Others use computers to model the natural behavior of organisms.

Analyze the Data

After biologists collect data from experiments, they interpret the data and look for patterns. They compare their results to expected results to see if the data support their hypothesis. If not, they revise the hypothesis and retest. Even when the data support the hypothesis, the experiment must be repeated many more times. Consistent results from repeated trials give strength to the hypothesis as a valid explanation for the tested phenomenon.



Think it Over

- 4. Apply** Suppose a biologist designed an experiment to study the effect of water pollution on the reproductive rate of salmon. What is the dependent variable in this experiment?

Reading Check

- 5. Classify** “The average high temperature here in March is 22°C.” Is this information qualitative data or quantitative data?

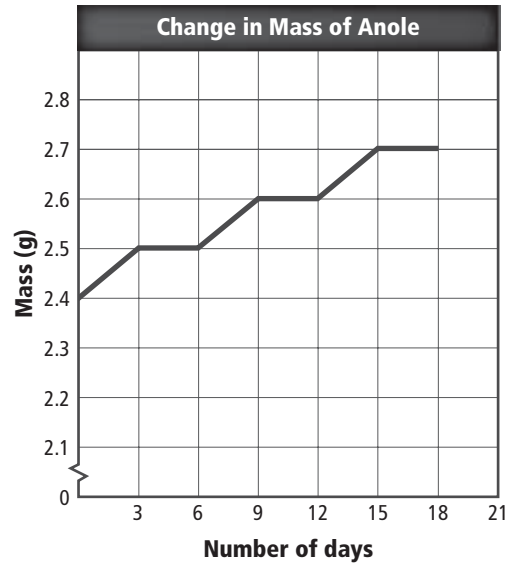
Picture This

6. **Predict** what the mass of the anole will be at 21 days.

Why do biologists use tables and graphs?

Biologists often display data in tables and graphs to make patterns easier to detect. The data about the mass of an anole, a type of lizard, are listed in the table below. The data are plotted on the graph. Note the regular pattern in the graph. The mass increases over a three-day period and then levels off for three days. Then it increases again.

Change in Mass of Anole	
Date	Mass (g)
April 11	2.4
April 14	2.5
April 17	2.5
April 20	2.6
April 23	2.6
April 26	2.7
April 29	2.7



Report Conclusions

Scientists write a report of their experiments for peer review. Other scientists in the same field examine the methods, analysis, and conclusions in the report. If the reviewers agree that the report has value, then the report is published in a scientific journal.

Student Scientific Inquiry

As you study biology, you might have opportunities to do your own investigations. If so, develop a research plan based on the scientific methods described in this chapter. Ask meaningful questions. Form hypotheses. Collect data by conducting careful experiments. Analyze the data. Draw conclusions and report them.

During biology labs, warning statements and safety symbols will alert you to possible hazards. A **safety symbol** is a logo designed to alert you about a specific danger. Refer to the safety symbols chart at the front of the textbook before beginning any field or lab activity. Learn where safety equipment is located in the classroom. You are responsible for performing your investigations safely at all times.

Reading Check

7. **Explain** the purpose of a safety symbol.

Principles of Ecology

section 1 Organisms and Their Relationships

● Before You Read

On the lines below, list the organisms that you have encountered today. You share the same environment with these organisms. In this section you will learn how many organisms exist in the same environment.

MAIN Idea

Biotic and abiotic factors work together in an ecosystem.

What You'll Learn

- the differences between biotic and abiotic factors
- the levels of biological organization
- the difference between an organism's habitat and its niche

● Read to Learn

Ecology

Each living organism depends on nonliving factors for survival in its environment. Each living organism also depends on other living organisms in its environment. Green plants are a food source and can be a place where other organisms live. The animals that eat plants provide food for other organisms. Organisms depend on each other in all types of environments—deserts, tropical rain forests, and grassy meadows. **Ecology** is the study of the interactions between organisms and their environments.

What do ecologists do?

Scientists who study ecology are called ecologists. The German biologist Ernst Haeckel introduced the word *ecology* in 1866. Eventually, it became a separate field of study.

Ecologists use various tools and methods to observe, experiment, and create models. Ecologists conduct tests to learn why and how organisms survive. For example, tests might help explain how some organisms survive in cold water.

Ecologists also learn about the interactions between organisms by observing them in their environments. Sometimes observations are made over long periods of time. This process is called longitudinal analysis.

Study Coach

Make an Outline Create an outline of this section. Use the headings to organize your outline. List details from what you have read to complete your outline.

Reading Check

1. **List** three ways ecologists study interactions between organisms.

 **Reading Check**

2. Define the biosphere.


 **Think it Over**

3. Evaluate Describe the abiotic factors in the environment where you currently live.

Why do ecologists use models?

Studying organisms in their environments is not always possible. Ecologists use models to represent a process or system in the environment. By using models, ecologists can control the number of variables. Scientists can measure the effect of each variable one at a time, on the model.

The Biosphere

The **biosphere** (BI uh sfhr) is the portion of Earth that supports life. Ecologists study what takes place in the biosphere. The biosphere includes the air, water, and land where organisms can live, both above and below the ground. 

The biosphere supports a wide variety of organisms in a wide range of conditions. Climates, soils, plants, and animals differ in different parts of the world. Frozen polar regions, deserts, and rain forests contain organisms. The organisms are adapted to survive in the conditions of their environments. The factors in all environments can be divided into two groups—living factors and nonliving factors.

What are biotic factors?

Biotic (bi AH tihk) **factors** are the living factors in an organism's environment. For example, the algae, frogs, and microscopic organisms in the stream are biotic factors for salmon in a stream. Other biotic factors live on the land bordering the stream. These include plants, insects, and small animals. Birds that feed on organisms in the stream are also part of the salmon's biotic factors. These factors interact directly or indirectly. The salmon depend on biotic factors for food, shelter, reproduction, and protection, and in turn can provide food for other organisms.

What are abiotic factors?

The nonliving factors in an organism's environment are called **abiotic** (ay bi AH tihk) **factors**. The abiotic factors for the salmon might be the temperature range of the water, the pH of the water, and the salt concentration of the water. For a plant, abiotic factors might include the amount of rainfall, the amount of sunlight, the type of soil, the range of air and soil temperatures, and the nutrients available in the soil.

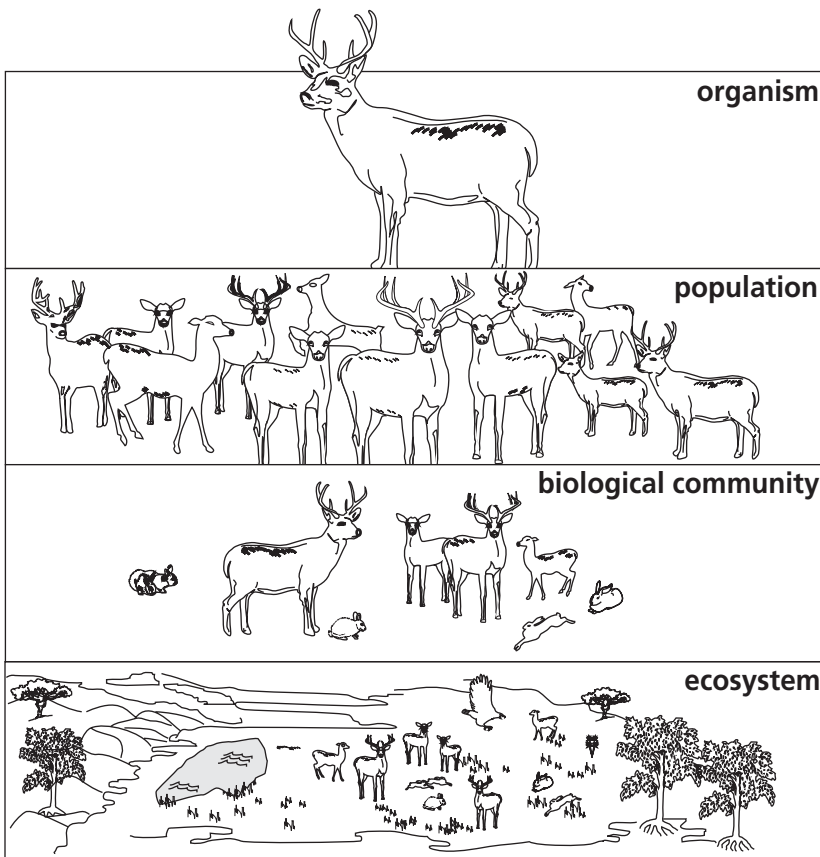
Organisms are adapted to the abiotic factors in their natural environment. If an organism moves to a different location with a different set of abiotic factors, the organism must adjust, or it will die.

Levels of Organization

The biosphere is too large to study all the relationships at one time. Scientists use smaller pieces, or levels of organization, for their studies. The numbers and interactions among organisms increase at higher levels of organization. The following are levels of organization from simplest to most complex:

1. organism
2. population
3. biological community
4. ecosystem
5. biome
6. biosphere

The first four of these levels of organization are shown in the figure below.



How do available resources affect a population?

The lowest level of complexity that ecologists study is an individual organism. Individual organisms of the same species living in the same geographic location at the same time make up a **population**. A school of fish is a population. Individual organisms in the population must compete to survive. They compete for food, water, mates, and other resources.

Picture This

4. Generalize How do the levels become more complex?

Reading Check

- 5. Identify** Which of the following is a population? (Circle your answer.)
- a. all rabbits living on Earth
 - b. all white-tailed rabbits living in a meadow today
 - c. all white-tailed rabbits that have ever lived in a meadow

 **Reading Check**


6. Draw Conclusions

If a population is growing, what can you conclude about the amount of resources available to the organisms?

 **Think it Over**

7. Explain the difference between a habitat and a niche.

What limits the size of a population?

A population can keep growing as long as resources are available to its members. If a population grows too large, there will not be enough resources for all members of the population. The population will get smaller until it reaches a number that can be supported by the available resources. 

What is a biological community?

A **biological community** is a group of populations that interact in the same geographic area at the same time. Organisms might or might not compete for available resources in a biological community. The plants and animals that live in a park are a biological community.

Who defines the boundaries of an ecosystem?

An **ecosystem** is a biological community and all the abiotic factors that affect it. Water temperature and available light are examples of abiotic factors. An ecosystem can be large or small. The ecologist defines the boundaries of the ecosystem. Boundaries can change or overlap each other.

A **biome** is a large group of ecosystems that share the same climate and have similar types of biological communities. You will learn more about biomes in Chapter 3. All the biomes on Earth combine to form the biosphere.

Ecosystem Interactions

Organisms increase their chances of survival by using available resources in different ways. Birds might use a tree for shelter, while insects use the tree's leaves for food.

The tree is the habitat for the community of organisms that live there. A **habitat** is an area where an organism lives. An organism such as an insect might spend its entire life on one tree. Its habitat is that tree. A bird flies from tree to tree. Its habitat is the grove of trees.

Organisms also have a niche. A **niche** (NIHCH) is the role an organism has in its environment. It is how the species meets its specific needs for food and shelter. It is how and where the species survives and reproduces.

Community Interactions

Organisms living in biological communities interact constantly. Ecosystems are shaped by these interactions and the abiotic factors. In a biological community, each organism depends on other organisms and competes with other organisms.

When do organisms compete?

Competition occurs when organisms need to use the same resource at the same time. Organisms compete for such resources as food, water, space, and light. When strong organisms compete with weak organisms, the strong organisms usually survive. During a drought, water might be scarce for many organisms. Strong organisms will use the available water. Weak organisms might die or move to another location.

What is predation?

The act of one organism consuming another organism for food is **predation** (prih DAY shun). Most organisms obtain their food by eating other organisms. If you have seen a cat stalk and capture a mouse, you have seen a predator catch its prey. The organism that pursues—the cat—is the predator. The organism that is pursued—the mouse—is the prey. Predators can be plants, animals, or insects.

What is symbiosis?

Some species survive because of relationships with other species. A relationship in which two organisms live together in close association is called **symbiosis** (sihm bee OH sus). The three kinds of symbiosis are mutualism, commensalism, and parasitism.

Mutualism A relationship between two species that live together and benefit from each other is called **mutualism** (MYEW chuh wuh lih zum). A lichen (LI kun) is a mutualistic relationship between algae and fungi. The algae provide food for the fungi. The fungi provide a habitat for the algae. Food and shelter are the benefits of this relationship.

Commensalism A relationship in which one organism is helped and the other organism is not harmed or helped is called **commensalism** (kuh MEN suh lih zum). For example, mosses sometimes grow on tree branches. This does not harm or help the tree, but the mosses benefit from a good habitat.

Parasitism A relationship in which one organism benefits and another organism is harmed is called **parasitism** (PER us suh tih zum). When a tick lives on a dog, it is good for the tick but bad for the dog. The tick gets food and shelter, but the dog might get sick. The tick is the parasite and is helped by the relationship. The dog is the host. Usually the parasite does not kill the host, but it might harm or weaken it. If the host dies, the parasite will also die, unless it can find another host.



Think it Over

- 8. Classify** List two more examples of predation that you have seen or of which you have learned.



Think it Over

- 9. Apply** Clown fish live among sea anemones. The anemones provide protection for the clown fish. The clown fish eats food missed by the sea anemones. What term best describes this relationship?

Principles of Ecology

section 2 Flow of Energy in an Ecosystem

MAIN Idea

Autotrophs capture energy, making it available for all members of a food web.

What You'll Learn

- the flow of energy through an ecosystem
- food chains, food webs, and pyramid models

Study Coach

Make Flash Cards Make a flash card for each question heading in this section. On the back of the flash card, write the answer to the question. Use the flash cards to review what you have learned.

Reading Check

- 1. Define** What type of heterotroph consumes plants for energy?

● Before You Read

If a pet had to survive without your care, how would its diet change? Write your ideas on the lines below. Read about how organisms get food and energy in their environment.

● Read to Learn

Energy in an Ecosystem

One way to study the interactions within an ecosystem is to trace how energy flows through the system. All organisms are classified by the way they obtain energy.

How do autotrophs obtain energy?

All green plants and other organisms that produce their own food are the primary producers of food in an ecosystem. They are called autotrophs. An **autotroph** (AW tuh trohf) is an organism that captures energy from sunlight or inorganic substances to produce food. Autotrophs make energy available for all other organisms in the ecosystem.

How do heterotrophs differ from autotrophs?

A **heterotroph** (HE tuh roh trohf), also called a consumer, is an organism that obtains energy by consuming other organisms. A heterotroph that consumes only plants is an **herbivore** (HUR buh vor). Cows, rabbits, and grasshoppers are herbivores.

Heterotrophs that prey on other heterotrophs are known as **carnivores** (KAR nuh vorz). Wolves and lions are carnivores. **Omnivores** (AHM nih vorz) eat both plants and animals. Bears, humans, and mockingbirds are examples of omnivores.

How do detritivores help an ecosystem?

Detritivores (duh TRYD uh vorz) decompose organic materials in an ecosystem and return the nutrients to the soil, air, and water. The nutrients then become available for use by other organisms. Hyenas and vultures are detritivores. They feed on animals that have died. Fungi and bacteria are also detritivores.

Detritivores play an important role in the biosphere. Without them, the biosphere would be littered with dead organisms. The nutrients in these dead organisms would not be available to other organisms. Detritivores make these nutrients available for use by other organisms. ✓

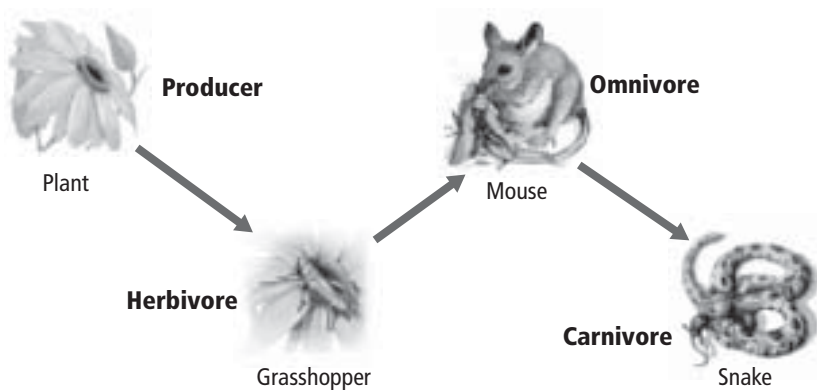
Models of Energy Flow

Ecologists study feeding relationships to learn how energy flows in an ecosystem. Ecologists use food chains and food webs to describe the flow of energy. Each step in a food chain or food web is called a **trophic** (TROH fihk) **level**. Autotrophs are the first trophic level in all ecosystems. Heterotrophs make up the remaining levels.

Organisms at the first trophic level produce their own food. Organisms at all other levels get energy from the trophic level before it.

What is a food chain?

A **food chain** is a simple model that shows how energy flows through an ecosystem. A typical grassland food chain is shown in the figure below. Each organism gets energy from the organism it eats. The flow of energy is always one way—into the consumer. An organism uses part of the energy to build new cells and tissues. The remaining energy is released into the environment and is no longer available to these organisms.



✓ Reading Check

2. Explain How do organisms in an ecosystem depend on detritivores?

Picture This

3. Label Draw a circle around the autotroph. Draw a box around the heterotrophs.

Think it Over

4. Synthesize Why might an ecologist use a food chain for one study and a food web for another study?

Picture This

5. Explain How is mass measured on the pyramid of biomass?

What does a food web show?

Feeding relationships are usually more complex than a single food chain model can show. Most organisms feed on more than one species. A **food web** is a model that shows all the possible feeding relationships in an ecosystem. Food webs give a more accurate picture of how energy flows in an ecosystem than food chains.

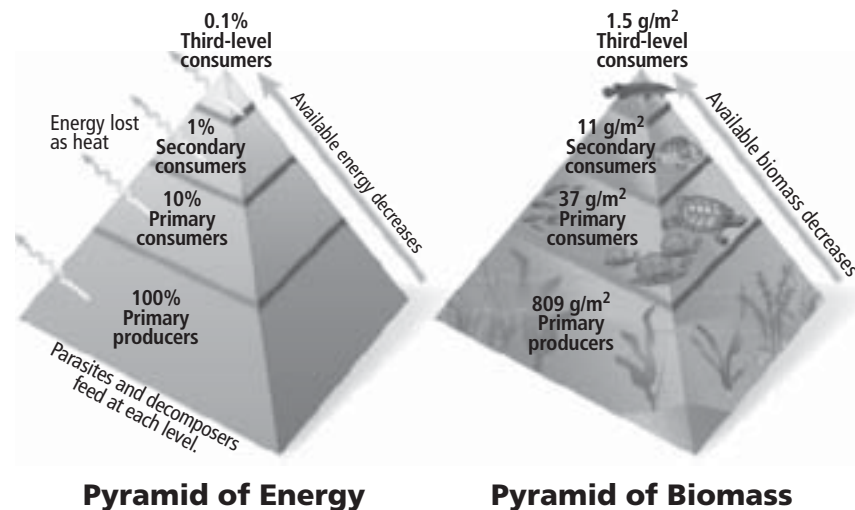
What do ecologists model with an ecological pyramid?

Ecologists also use ecological pyramids to model how energy flows through ecosystems. A pyramid model can be used to show energy flow in three different ways. Each level of the pyramid represents a trophic level.

A pyramid of energy indicates the amount of energy available to each trophic level. Notice in the energy pyramid below that about 90 percent of the available energy is used by the organisms at each level. Some of the energy is used to build cells and tissues. Some is released into the environment as heat. Only about 10 percent is available to the next level of the pyramid.

The **biomass**, or total mass of living matter at each trophic level, can also be modeled by an ecological pyramid. In a pyramid of biomass, each level shows the amount of biomass consumed by the level above it.

A pyramid of numbers shows the number of organisms consumed at each trophic level in an ecosystem. The number decreases at each level because less energy is available to support organisms.



● Before You Read

By looking at calendars, you can observe cycles, such as the cycle of the school year and summer vacation. On the lines below, write about cycles in your life. Read about the cycles in nature.

● Read to Learn

Cycles in the Biosphere

The law of the conservation of mass states that matter is not created or destroyed. Instead, matter is cycled through the biosphere. **Matter** is anything that takes up space and has mass.

Matter provides the nutrients needed for organisms to function. A **nutrient** is a chemical substance that an organism needs to perform life processes. An organism obtains nutrients from its environment. The bodies of all organisms are built from water and nutrients. Common nutrients include carbon, nitrogen, and phosphorus.

How do nutrients cycle through the biosphere?

Nutrients cycle through the biosphere through organisms. Producers begin the cycle. In most ecosystems, plants obtain nutrients from air, water, and soil. Plants convert the nutrients into organic compounds that they use. Most capture energy from the Sun and convert it into carbohydrates. When a consumer eats a producer, the nutrients in the producer pass to the consumer. For example, the nutrients in green grass pass to the cow that eats the grass. The cycle continues until the last consumer dies. Detritivores return the nutrients to the cycle, and the process begins again.

MAIN Idea

Nutrients move through the biotic and abiotic parts of an ecosystem.

What You'll Learn

- the importance of nutrients to living organisms
- the biogeochemical cycles of nutrients

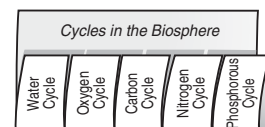
Mark the Text

Identify Main Ideas

Circle the names of the cycles described in this section. Underline the text that summarizes the steps in each cycle.

FOLDABLES™

Take Notes Make a five-tab Foldable, as shown below. As you read, take notes and organize what you learn about five cycles in the biosphere.



Reading Check

1. Synthesize What three processes form the biogeochemical cycle?

Picture This

2. Identify Complete the figure by labeling the missing steps in the water cycle.

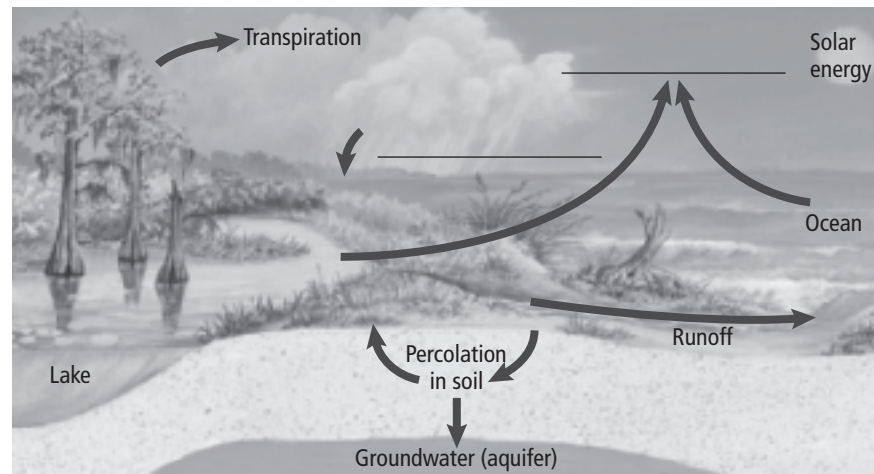
What is the biogeochemical cycle?

Both biological processes and chemical processes are needed to cycle matter in living organisms. The cycle also requires geological processes such as weathering. Weathering breaks down large rocks into small pieces. Plants and other organisms obtain nutrients from these pieces. Scientists use the name **biogeochemical cycle** to describe the combination of processes that exchange matter through the biosphere.

How does water cycle?

Evaporation occurs when liquid water changes into water vapor—a gas—and enters the atmosphere. Water evaporates from bodies of water, from water in the soil, and from the surfaces of plants.

As water vapor rises, it begins to cool in the atmosphere. Clouds form when water vapor condenses into droplets around dust particles in the atmosphere. When the droplets become large and heavy, they fall from the clouds as precipitation. Precipitation can be in the form of rain, hail, sleet, or snow. Most falls directly back into the ocean. The figure below shows the water cycle. It is a model that describes how water moves from the surface of Earth to the atmosphere and back to the surface again.



Why are carbon and oxygen important to organisms?

Living organisms are composed of molecules that contain carbon. Living things also need oxygen for many life processes. Carbon and oxygen make up molecules needed for life, including carbon dioxide and sugar.

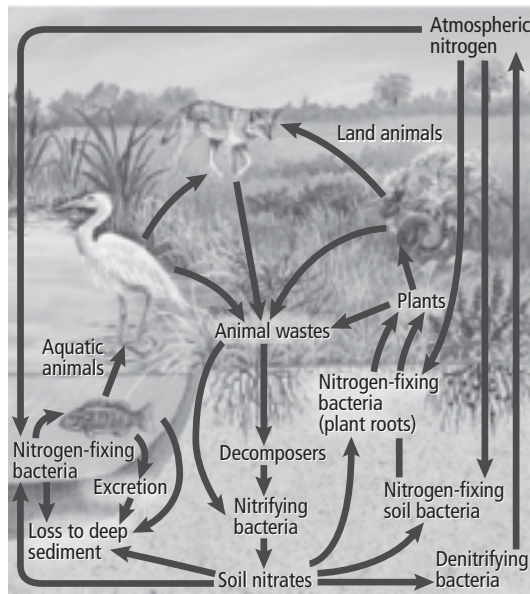
What are the carbon and oxygen cycles?

During photosynthesis (foh toh SIHN thuh sus), producers change carbon dioxide into carbohydrates and release oxygen into the air. The carbohydrates are a source of energy for all organisms in a food web. Autotrophs and heterotrophs release carbon dioxide into the air during cellular respiration. Carbon and oxygen cycle quickly through living organisms.

Carbon is also part of a cycle that takes much longer. During a process that could take millions of years, carbon is converted into fossil fuels such as gas, peat, or coal. Carbon is released into the atmosphere in the form of carbon dioxide when fossil fuels are burned.

What is the nitrogen cycle?

Organisms need nitrogen to produce proteins. The atmosphere is 78 percent nitrogen. However, most organisms cannot use nitrogen directly from the air. Nitrogen gas is captured from the air by a species of bacteria, as shown in the figure below. These bacteria live in water, the soil, or grow on the roots of some plants. **Nitrogen fixation** is the process of capturing and changing nitrogen into a form that plants can use. Humans add nitrogen to the soil when they apply chemical fertilizers to a lawn or to crops.



How does nitrogen enter food webs?

Nitrogen enters the food web through plants. Consumers get nitrogen by eating producers or other animals that contain nitrogen. At each step in the food web, organisms reuse nitrogen to make proteins. The amount of nitrogen is limited, and will often determine the growth of producers.



Think it Over

3. Summarize How do photosynthesis and cellular respiration differ?

Picture This

4. Determine What captures the atmospheric nitrogen?

Reading Check

5. Name the nitrogen compound that is changed by organisms in the soil.

Picture This

6. Explain how phosphates are added to water.

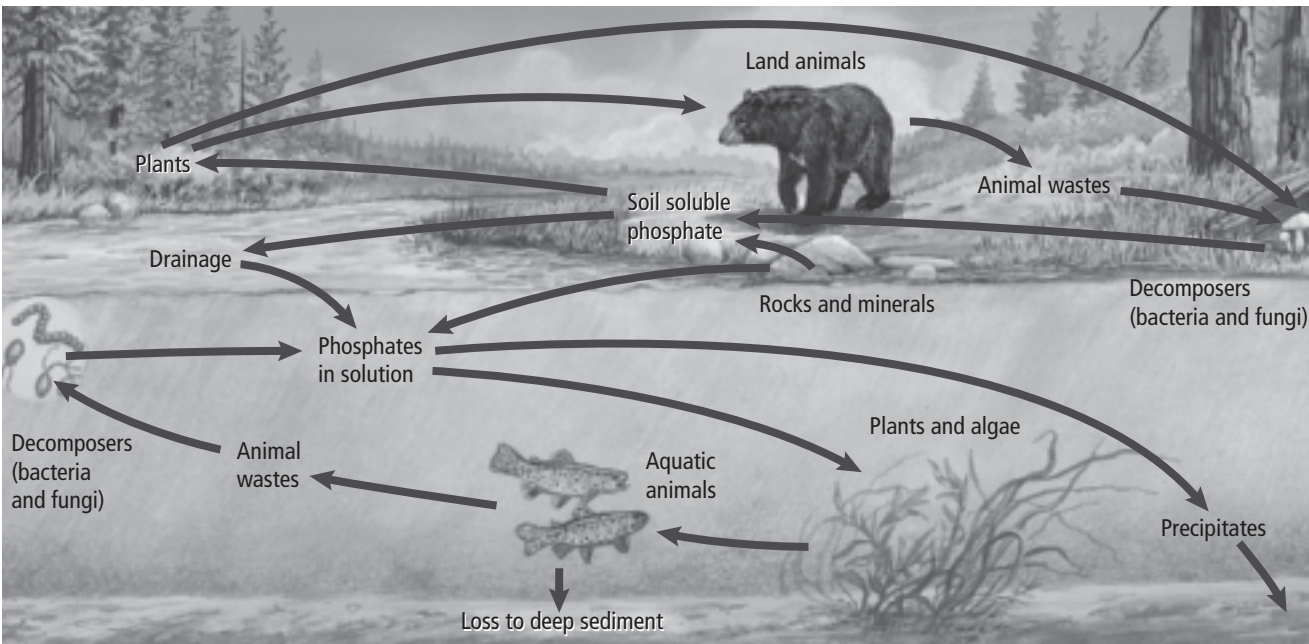
What is denitrification?

Nitrogen returns to the soil when animals urinate and when organisms die and decay. When organisms die, decomposers break down matter in the organisms into a nitrogen compound called ammonia. Ammonia is changed by organisms in the soil into nitrogen compounds that can be used by plants. Some bacteria in the soil change nitrogen compounds into nitrogen gas in a process called **denitrification**. This process releases nitrogen into the atmosphere.

What is the phosphorus cycle?

Organisms must have phosphorus to grow and develop. Large amounts are used to build bones and teeth. There are two phosphorus cycles—a short-term cycle and a long-term cycle. In the short-term cycle, phosphorus is cycled from the soil to producers to consumers. Phosphorus returns to the soil when organisms die or produce waste products, as shown in the figure below.

In the long-term cycle, phosphorus is added to soil from weathering or erosion of rocks that contain phosphorus. Weathering and erosion are long processes. They slowly add phosphorus to the soil. Phosphorus does not dissolve in water, and only small amounts are present in soil. The growth of producers is limited by the amount of phosphorus available to them.



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Communities, Biomes, and Ecosystems

section 1 Community Ecology

● Before You Read

On the lines below, list several plants and animals that live in your community. Then name one organism that would have trouble surviving where you live. Read the section to learn why some species can live in an area while others cannot.

MAIN Idea

All living organisms are limited by factors in the environment.

What You'll Learn

- how ranges of tolerance affect the distribution of organisms
- the stages of primary and secondary succession

● Read to Learn

Communities

Your biological community includes more than just the people around you. It also includes the plants, other animals, bacteria, and fungi in your area. A biological **community** is a group of interacting populations that occupy the same area at the same time. Organisms that live in a desert community are different from organisms that live in an arctic community. Organisms that live in a city differ from organisms that live in the country.

In Chapter 2, you learned that abiotic factors affect individual organisms. Abiotic factors also affect communities. For example, soil is an abiotic factor. If soil becomes too acidic, some species might die. This might affect the food sources of other organisms. As a result, the community would change.

Organisms are adapted to the conditions where they live. A wolf's fur coat enables it to survive in cold winter climates. Depending on which factors are present and in what quantities, organisms can survive in some ecosystems but not in others.

Study Coach

Make an Outline Make an outline of the information you learn in this section. Start with the headings. Include the underlined terms.



Think it Over

1. **Predict** Suppose a fungus killed a species of tree in a forest community. What might happen to the woodpecker species that nests in that kind of tree?

Reading Check

- 2. Identify** The average winter temperature in the Arctic is about -30°C . What type of limiting factor is this? (Circle your answer.)
- a. abiotic
 - b. biotic

Picture This

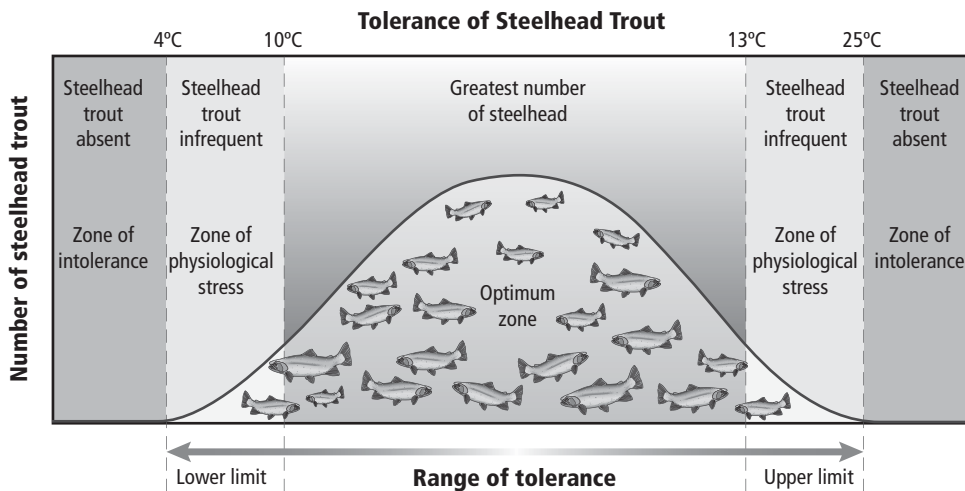
- 3. Explain** what the curved graph line represents.

What factors limit populations in communities?

Any abiotic factor or biotic factor that restricts the numbers, reproduction, or distribution of organisms is called a **limiting factor**. Abiotic limiting factors include sunlight, climate, water, fire, and space. Biotic limiting factors include other plant and animal species. Factors that limit one species might enable another to thrive. For example, water is a limiting factor. Organisms that need less water will be part of a desert community.

How does range of tolerance affect species?

For any environmental factor, there is an upper limit and a lower limit that defines the conditions in which an organism can live. **Tolerance** is the ability of any organism to survive when exposed to abiotic or biotic factors. The figure below shows a range of tolerance for steelhead trout. The limiting factor in this case is water temperature. Trout can tolerate water temperatures between 9°C and 25°C . Most trout live in the optimum zone, which is the temperature range that is best for trout survival. The zone of physiological stress lies between the optimum zone and the tolerance limits. Fewer trout live in this zone. Trout that do live in this zone experience physiological stress, such as the inability to grow.



Ecological Succession

Ecosystems constantly change. A tree falling in a forest affects the forest ecosystem. A fire might alter the forest habitat so much that some species cannot survive and others can thrive. The process of one community replacing another as a result of changing abiotic and biotic factors is called **ecological succession**.

How does soil form in primary succession?

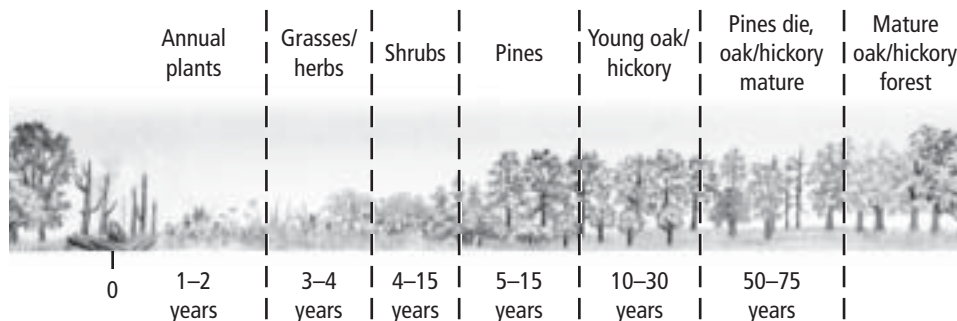
There are two types of ecological succession—primary succession and secondary succession. **Primary succession** is the establishment of a community in an area of bare rock that does not have topsoil. For example, suppose a lava flow alters an ecosystem. The lava hardens to form bare rock. Usually, lichens begin to grow on the rock first. Because lichens and some mosses are among the first organisms to appear, they are called pioneer species.

Pioneer species secrete acids that help break down rocks. As pioneer species die, their decaying organic materials mix with small pieces of rock. This is the first stage of soil development. Small weedy plants begin to grow in the soil. These organisms die, adding to the soil. Seeds brought by animals, water, and wind begin to grow. Eventually, enough soil forms to support trees and shrubs. ✓

It might take hundreds of years for the ecosystem to become balanced and achieve equilibrium. When an ecosystem is in equilibrium, there is no net change in the number of species. New species come into the community at about the same rate that others leave the community. This is a **climax community**—a stable, mature community in which there is little change in the number of species.

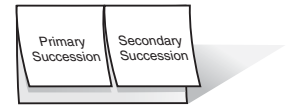
How does secondary succession occur?

Disturbances such as fire or flood can disrupt a community. After a disturbance, new species of plants and animals might occupy the habitat. Over time, the species belonging to the climax community are likely to return. **Secondary succession** is the orderly and predictable change that takes place after a community of organisms has been removed but the soil remains. Pioneer species begin the process of restoring a habitat after a disruption. The figure below shows how the community changes after a forest fire, leading again to a mature climax community.



FOLDABLES™

Record Information Make a two-tab Foldable to record what you learn about the two types of ecological succession.



Reading Check

- 4. Summarize** the importance of pioneer species in primary succession.

Picture This

- 5. Draw Conclusions**

How many years after a forest fire would trees begin to grow?

Communities, Biomes, and Ecosystems

section 3 Terrestrial Biomes

MAIN Idea

Ecosystems are grouped into biomes based on the plant communities within them.

What You'll Learn

- the three major climate zones
- the major abiotic factors
- how climate and biotic factors differ among land biomes

Mark the Text

Identify Biomes Highlight each term that introduces a biome. Then use a different color to highlight important facts about each biome.

Picture This

1. **Identify** the latitude below that has the highest average temperature. (Circle your answer.)
 - a. 30°S
 - b. 60°N
 - c. 90°S

Before You Read

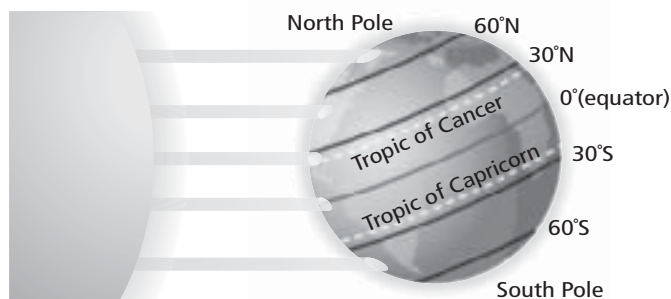
On the lines below, describe the climate in your area. Include seasonal differences in temperatures and precipitation. Then read the section to learn how climate influences the location of biomes.

Read to Learn

Effects of Latitude and Climate

Weather is the condition of the atmosphere at a specific place and time. **Climate** is the average weather conditions in an area, including temperature and precipitation. An area's latitude has a large effect on its climate. **Latitude** is the distance of any point on the surface of Earth north or south of the equator. The equator is 0° latitude. The poles, which are the farthest points from the equator, are 90° latitude.

As shown in the figure below, sunlight strikes Earth more directly at the equator than at the poles. As a result, different areas of Earth's surface are heated differently. Ecologists call these areas polar, temperate, and tropical zones.



What other factors affect biome location?

Recall from Chapter 2 that a biome is a large group of ecosystems that share the same climate and have similar types of communities. The plant and animal communities are adapted to the area's climate. Factors that determine climate include elevation, landmass features, winds, and ocean currents.

Major Land Biomes

Biomes are classified mainly by the characteristics of their plants. This section describes each major land biome.

What are the characteristics of tundra?

Below the polar ice caps, a band of tundra runs across northern North America, Europe, and Asia, as shown in the figure below. **Tundra** is a treeless biome with a layer of permanently frozen soil called permafrost beneath the surface. Mosses, lichens, and short grasses can grow in the tundra. ✓

Where is the boreal forest?

As shown in the figure below, the taiga extends across North America, Europe, and Asia, south of the tundra. The **boreal forest**, or taiga, is a broad band of dense evergreen forest. It is also known as the northern coniferous forest. The boreal forest does not have permafrost because temperatures are a bit warmer and summers are longer than in the tundra. Spruce, fir, and pine trees and low-growing shrubs and bushes grow in the boreal forest.



✓ Reading Check

2. Define permafrost.

Picture This

3. Identify Does any tundra lie within the United States? If so, where?

What trees thrive in the temperate forest?

Temperate forests are located south of the boreal forests.

Temperate forests are composed mostly of broad-leaved deciduous (dih SIH juh wus) trees. These are trees that shed their leaves over a short period. Areas of temperate forest have four seasons, with hot summers and cold winters. As shown in the figure below, temperate forests cover much of southeastern Canada, eastern North America, most of Europe, and parts of Asia and Australia.

Where do woodlands and shrublands occur?

Woodlands occur in areas surrounding the Mediterranean Sea, along the western coasts of North and South America, in South Africa, and in Australia. Open **woodlands** and shrub communities receive less rainfall than temperate forests. Areas with mostly shrubs are called chaparral. Summers are hot and dry. Winters are cool and wet. ✓

What keeps grasslands from becoming forests?

Temperate grasslands are found on many continents. Grasslands are called steppes in Asia; prairies in North America; pampas, llanos, and cerrados in South America; savannahs and velds in Africa; and rangelands in Australia. The fertile soils of **grasslands** support a thick cover of grasses. Grazing animals and fires keep grasslands from becoming forests. Grasslands have hot summers and cold winters.

Do any plants and animals live in a desert?

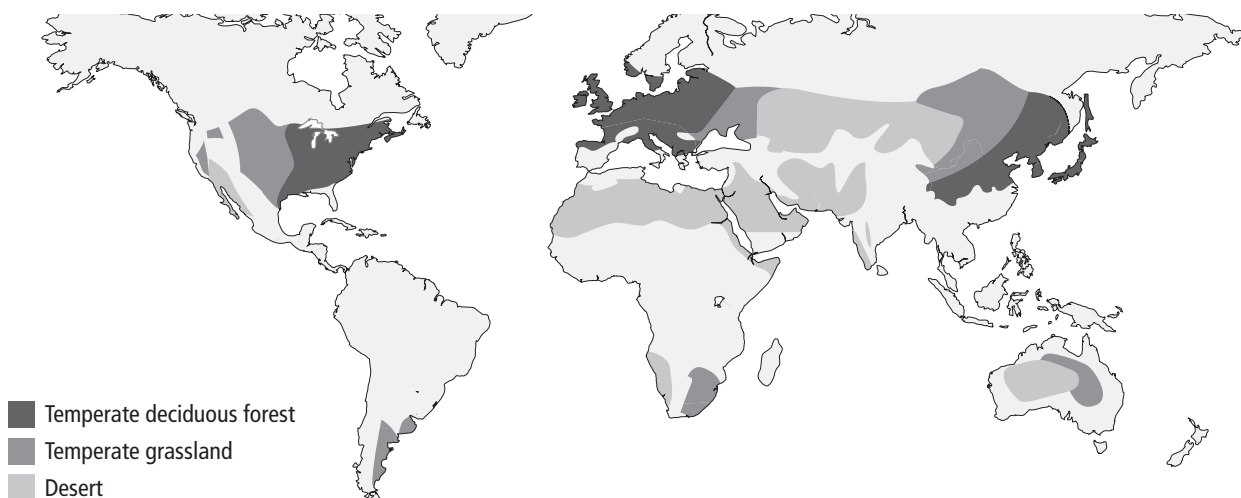
As shown in the figure below, deserts exist on every continent except Europe. A **desert** is any area where evaporation occurs at a faster rate than precipitation falls. In spite of dry conditions, deserts support cacti, sage brush, some grasses and bushes, as well as a variety of animals.

✓ Reading Check

4. **Contrast** How do woodlands differ from temperate forests?

Picture This

5. **Classify** Based on the map below and the map on the previous page, what is the main land biome in your state?



What are features of a tropical savanna?

Tropical savannas occur in Africa, South America, and Australia. A **tropical savanna** is characterized by grasses and scattered trees in climates with less precipitation than other tropical areas. Summers are hot and rainy. Winters are cool and dry.

Where are tropical seasonal forests?

Tropical seasonal forests occur in Africa, Asia, Australia, and South and Central America. **Tropical seasonal forests**, also called tropical dry forests, have a wet season and a dry season. During the dry season, almost all of the trees drop their leaves to conserve water.

What biome supports the most diversity?

Tropical rain forests are found in much of Central and South America, southern Asia, western Africa, and northeastern Australia. A **tropical rain forest** has warm temperatures and lots of rainfall throughout the year. The tropical rain forest is the most diverse of all biomes. Tall trees covered with mosses, ferns, and orchids form the canopy, or upper layer. Shorter trees, shrubs, and creeping plants make up the understory, or lower layer.

Other Terrestrial Areas

Mountains do not fit the definition of a biome because their climate and plant and animal life depend on elevation. Polar regions are also not true biomes because they are ice masses that lack land areas with soil.

How do conditions change with elevation?

If you climb a mountain, you might notice that temperatures fall as you climb higher. Also, precipitation varies as you climb. As a result, many communities are able to exist on a mountain. Grasslands are at the bottom, pine trees grow farther up, and the cold elevations at the top support communities similar to the tundra.

Do polar regions support life?

A thick layer of ice covers the polar regions. In spite of year-round cold, polar regions support life. Polar bears and arctic foxes live in the arctic polar region in the north. Antarctica, in the south, supports colonies of penguins. Whales and seals prey on penguins, fish, and shrimplike krill in the coastal waters of Antarctica.



Think it Over

- 6. Contrast** How does rainfall differ between tropical rain forests and tropical seasonal forests?



Think it Over

- 7. Draw Conclusions** Name one adaptation of polar bears that helps them survive in their polar home.

Communities, Biomes, and Ecosystems

section 3 Aquatic Ecosystems

MAIN Idea

Aquatic ecosystems are grouped by abiotic factors.

What You'll Learn

- how depth and water flow affect freshwater ecosystems
- how to identify transitional aquatic ecosystems
- the zones of marine ecosystems

Study Coach

Make Flash Cards Think of a quiz question for each paragraph. Write the question on one side of the flash card. Write the answer on the other side. Use the flash cards to quiz yourself until you know all the answers.

Picture This

1. **Calculate** the percentage of freshwater that is not ice. Show your work.

Before You Read

On the lines below, list some characteristics of a body of water near you. How deep is it? Is the water salty? Is it calm or fast flowing? Then read the section to learn the characteristics of different water ecosystems.

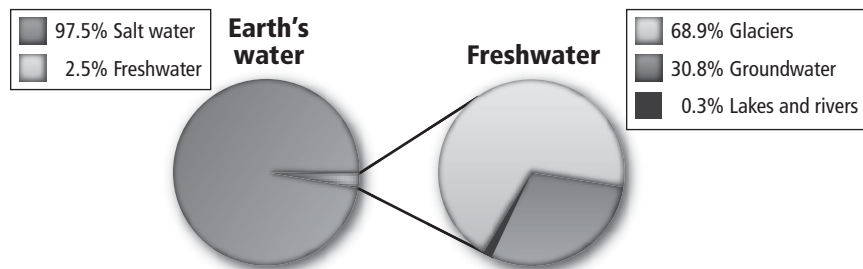
Read to Learn

The Water on Earth

Most of Earth is covered with water. Aquatic ecosystems include freshwater, transitional, and marine ecosystems.

Freshwater Ecosystems

Ponds, lakes, streams, rivers, and wetlands are freshwater ecosystems. The graph on the left below shows that only about 2.5 percent of Earth's water is freshwater. The graph on the right shows that 68.9 percent of the freshwater is contained in glaciers, 30.8 percent is groundwater, and 0.3 percent is found in lakes, ponds, rivers, streams, and wetlands. Almost all freshwater species live in the 0.3 percent.



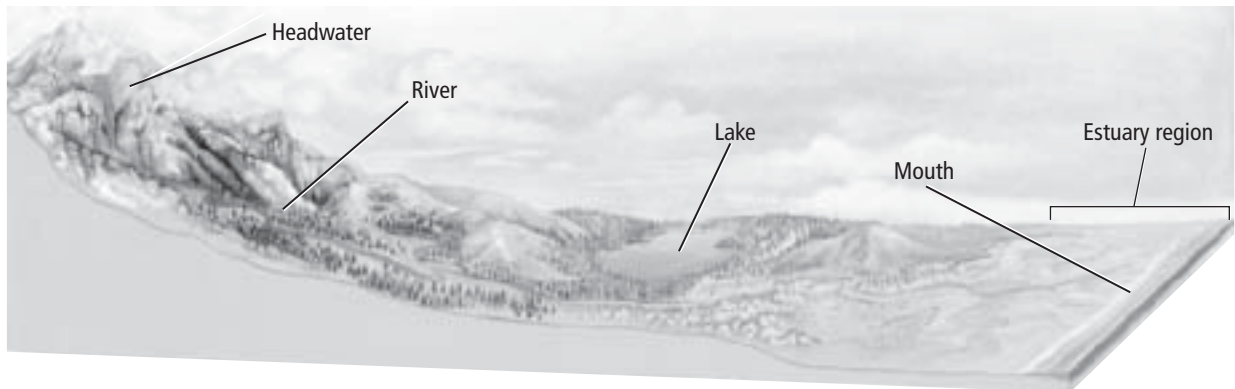
What affects water flow in rivers and streams?

The water in rivers and streams flows in one direction. As illustrated in the figure below, the water flow begins at a source called a headwater. The water flows to the mouth, where it empties into a larger body of water. Rivers and streams also might start from underground springs or from melting snow.

The slope of the land determines direction and speed of the water flow. Water flows quickly down a steep slope. Fast-flowing water picks up a lot of sediment. **Sediment** is material left by water, wind, or glaciers. As the slope levels, the fast-flowing water slows. This causes the sediment to be deposited in the form of silt, mud, and sand.

Rivers and streams change during their journey from source to mouth. Wind stirs up the water's surface and adds oxygen to the water. Water erodes the land, changing the path of the river or stream.

Currents of fast-moving rivers and streams prevent organic materials and sediments from building up. As a result, fewer species live in rapid waters. Organisms living in rivers and streams must be able to withstand the water current. Plants take root in streambeds where rocks and sand bars slow the water flow. In slow-moving water, insect eggs are the main food source for many fish. Calm water also provides a home for crabs, tadpoles, and frogs.



How does altitude affect life in lakes and ponds?

Some lakes and ponds last only a couple of weeks every year. Other lakes might exist for thousands of years. Nutrient-poor lakes, called oligotrophic (uh lih goh TROH fihk) lakes, are found high in the mountains. Few plant and animal species live in these lakes. Many plant and animal species live in nutrient-rich lakes, called eutrophic (yoo TROH fihk) lakes, at lower elevations.

Picture This

2. Label the area of the river where most sediment will be deposited. On the lines below, explain why.

Reading Check

3. Identify the limiting factor in oligotrophic lakes.

What distinguishes zones in lakes and ponds?

Lakes and ponds are divided into three zones that are determined by depth and distance from the shoreline. The area closest to shore is the **littoral** (LIH tuh rul) **zone**. Species in this zone includes algae, rooted and floating plants, snails, clams, insects, fishes, and amphibians. Some insect species lay eggs in the littoral zone and the larvae develop there.

The **limnetic** (lihm NEH tihk) **zone** is the open water area. It is well lit and full of plankton. **Plankton** are free-floating photosynthetic autotrophs that live in freshwater or marine ecosystems. Many species of freshwater fish live in the limnetic zone because food is plentiful there.

The deepest area of a lake is the **profundal** (pruh FUN dul) **zone**. It is much colder and has less oxygen than the other two zones. Less light reaches the profundal zone, which limits the species that are able to live there.



Think it Over

4. **Explain** why you would expect to find few plankton in the profundal zone.



Think it Over

5. **Contrast** How do estuaries differ from wetlands?

Transitional Aquatic Ecosystems

Transitional aquatic ecosystems are a combination of two or more different environments. Transitional aquatic ecosystems can be areas where land and water mingle. They can also be areas where salt water and freshwater mix. Examples of transitional aquatic ecosystems are wetlands and estuaries.

What kinds of life thrive in wetlands?


Wetlands are areas of land that are saturated with water and support aquatic plants. Examples include marshes, swamps, and bogs. Bogs are wet and spongy areas of decomposing vegetation. Wetlands support a diversity of species. Pond lilies, cattails, amphibians, reptiles, birds, and mammals live in wetlands.

How do estuaries differ from wetlands?

An **estuary** (ES chuh wer ee) is an ecosystem that forms where a freshwater river or stream merges with the ocean. The mixing of waters with different salt concentrations creates a unique ecosystem. Algae, seaweed, and marsh grasses thrive in estuaries. Animals such as worms, oysters, and crabs feed on tiny organic matter called detritus (dih TRY tus). Many species of fishes, shrimp, ducks, and geese use estuaries as nurseries for their young.

Salt marshes are transitional ecosystems similar to estuaries. Salt-tolerant grasses live along the shoreline. Animals such as shrimp and shellfish live in salt marshes.

Marine Ecosystems

Marine ecosystems have a major impact on the planet. For example, marine algae consume large amounts of carbon dioxide from the atmosphere. In the process, they supply much of the oxygen in the atmosphere. Also, water that evaporates from the oceans eventually provides most of Earth's precipitation—rain and snow. Oceans are separated into zones, as shown in the figure below. 

How do the tides affect the intertidal zone?

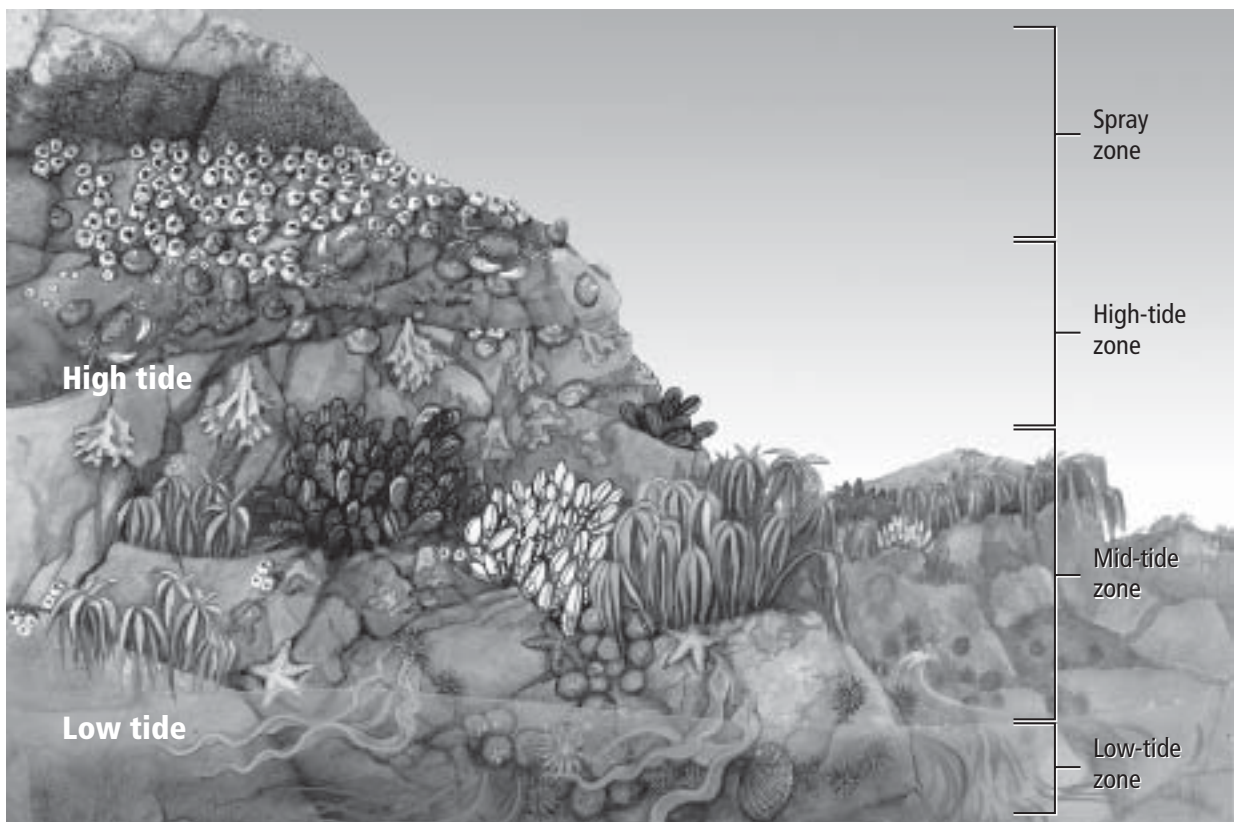
The **intertidal** (ihn tur TY dul) **zone** is a narrow band where the ocean meets land. As tides and waves move in, the intertidal zone is submerged. As tides and waves move out, the intertidal zone is exposed. Only a few species of algae and mollusks live where the highest tides reach. A diversity of species, including algae and small animals such as snails, crabs, sea stars, and fishes, live in areas that are submerged during high tide. The bottom of the intertidal zone is exposed only during the lowest tides. Many species of invertebrates, fishes, and seaweed live here. On sandy coasts, waves constantly shift the sand. The constant shifting makes it hard for algae and plants to grow on sandy beaches. Animals that live on beaches include worms, clams, predatory crustaceans, crabs, and shorebirds.

Reading Check

- 6. Describe** two important ways that marine ecosystems impact the planet.

Picture This

- 7. Identify** the zone in the figure that the tide does not submerge.



How do layers of the pelagic zone differ?

The open ocean is divided into the pelagic (puh LAY jihk) zone, abyssal (uh BIH sul) zone, and benthic zone. The **photic zone** is the area in the pelagic zone from the surface of the water down to about 200 m. The photic zone is shallow enough for sunlight to penetrate. As depth increases, light decreases. The photic zone supports seaweed, plankton, fishes, whales, and dolphins.

Below the photic zone lies the **aphotic zone** where sunlight cannot penetrate. This region of the pelagic zone remains in constant darkness. Organisms that depend on sunlight for energy cannot live in the aphotic zone. The water in the aphotic zone is generally cold.

Where are the benthic and abyssal zones?

The **benthic zone** is the area along the ocean floor. It consists of sand, silt, and dead organisms. In shallow areas, sunlight can penetrate to the ocean floor. As depth increases, less sunlight can penetrate and temperatures decrease. As a result, species diversity also decreases as depth increases. Many species of bacteria, fungi, sponges, sea anemones, and fishes live in shallower parts of the benthic zone.

The **abyssal zone** is the deepest region of the ocean. The water is very cold. Most organisms depend on pieces of food that drift down from the zones above. Hydrothermal vents on the seafloor release hot water, hydrogen sulfide, and other minerals. Communities of bacteria live around these vents. These bacteria can use the sulfide molecules for energy.

What organisms do coral reefs support?

A coral reef is an ecosystem that exists in warm, shallow marine waters. The hard, stony structure of the reef is formed by secretions of tiny animals—coral polyps. Most coral polyps have a symbiotic relationship with algae. The algae provide corals with food. In turn, the corals provide algae with protection and access to light. Corals also feed by extending tentacles to catch plankton. Sea slugs, octopuses, sea urchins, sea stars, and fishes are part of the great diversity of the coral reef.

Like all ecosystems, a coral reef is sensitive to changes in the environment. A natural event such as a tsunami as well as human activity such as land development can damage or kill a coral reef. Ecologists monitor coral reef environments to help protect them from harm.

Reading Check

8. **Name** two limiting factors as depth increases in the benthic zone.

Reading Check

9. **Define** What is a coral?
(Circle your answer.)
- a plant
 - an animal
 - a colorful shell

● Before You Read

On the lines below, explain why animals that live in your area might be found in greater or smaller numbers than in other places on Earth. Then read the section to learn about factors that limit the growth of any population.

MAIN Idea

Populations of species are described by density, spatial distribution, and growth rate.

What You'll Learn

- concepts of carrying capacity and limiting factors
- ways in which populations are distributed

● Read to Learn

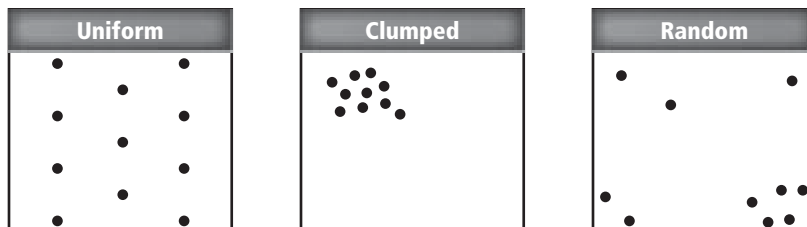
Population Characteristics

Every organism belongs to a population. A population is a group of organisms of the same species that live in a specific area. Populations of organisms include plants, animals, and bacteria. All populations have certain characteristics, such as population density, spatial distribution, and growth rate.

What are common patterns of dispersion?

Population density is the number of organisms per unit area. For example, there was an average of four American bison per square kilometer in Northern Yellowstone in 2000.

Dispersion is the pattern of spacing of a population within an area. The figure below shows three main types of dispersion—uniform, clumped, and random. Black bears are dispersed in a uniform, or even, arrangement. American bison are dispersed in clumped groups or herds. White-tailed deer are dispersed in random groups.



Mark the Text

Identify Concepts

Highlight each question heading in this section. Then use a different color to highlight the answers to the questions.

Picture This

1. **Apply** Wolverines spread across their range, with each individual patrolling a territory of about 320 km². What type of dispersion do wolverines represent?
-

FOLDABLES™

Record Information

Make a layered Foldable from two sheets of paper to record what you learn about how populations of species are described.

Populations of species are described by
Density
Spatial Distribution
Growth Rate

✓ Reading Check

2. **Explain** why water pollution is a density-independent factor.



Think it Over

3. **Apply** Which is an example of a density-dependent factor? (Circle your answer.)
- frost that destroys tomato plants
 - fungus that spreads from plant to plant

What limits spatial distribution?

No population lives in all habitats of the biosphere. A species might not be able to expand its spatial distribution because it cannot survive the conditions in the new area. Abiotic factors, such as temperature, humidity, and rainfall, could make the new area unlivable for a species. Biotic factors, such as predators and competitors, also might prevent a species from surviving in the new area.

Population-Limiting Factors

All species have limiting factors. Limiting factors keep a population from growing indefinitely. For example, the food supply is a limiting factor. The number of individuals in a population cannot increase beyond the amount of food available to support that number.

There are two categories of limiting factors. They are density-independent factors and density-dependent factors.

What limiting factors are density independent?

Recall that population density is the number of members of a population per unit area. A **density-independent factor** is any factor in the environment that does not depend on population density. Usually these factors are abiotic. For example, populations are limited by weather events such as drought, floods, and hurricanes.

Human activities can also be density-independent limiting factors. For example, dam building alters the water flow of rivers, limiting some species. Pollution resulting from human activities reduces the available resources by making air, water, and land toxic in some areas.

What limiting factors are density dependent?

A **density-dependent factor** is any factor in the environment that depends on population density. Often these are biotic factors, such as disease, competition, parasites, and predators.

Disease Outbreaks of disease tend to occur when a population has increased and population density is high. When population density is high, individuals come into contact more frequently. Frequent contact enables disease to spread easily and quickly between individuals. The spread of disease limits populations of humans as well as protists, plants, and other animals.

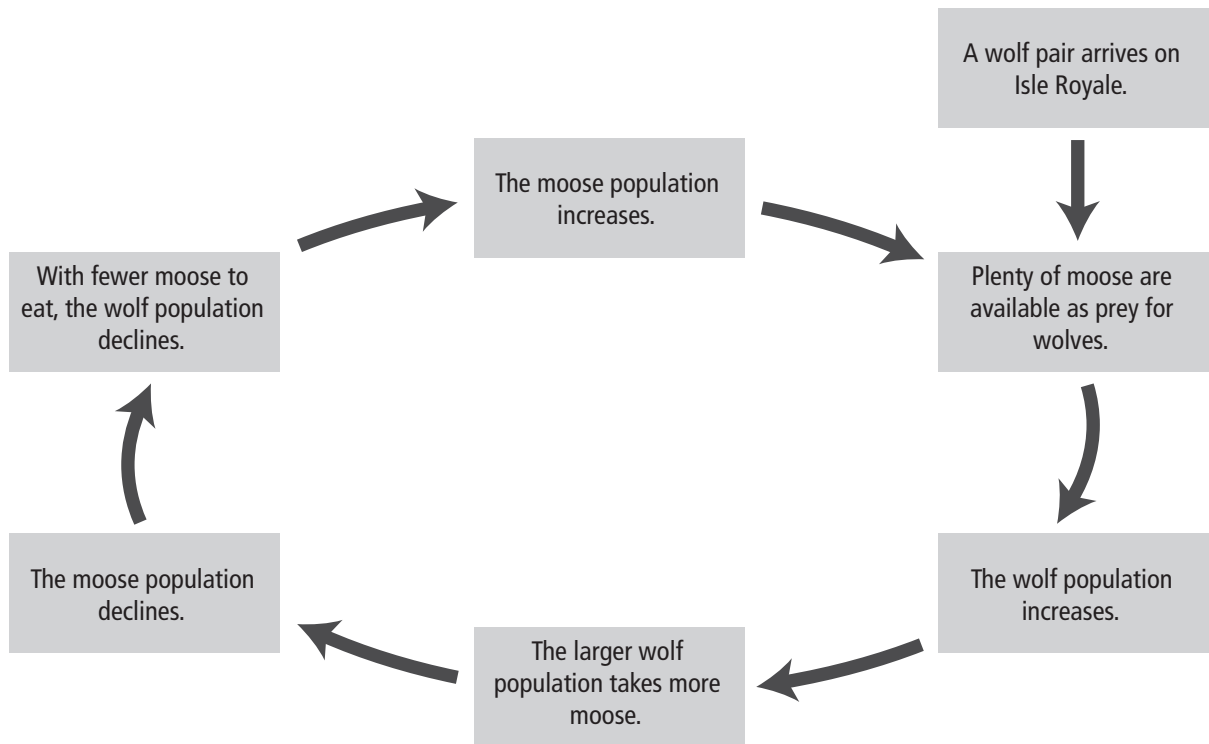
Competition High population density increases competition among individuals for resources. When a population grows to a size that food and space become limited, individuals must compete for the available resources. Competition occurs within a species or between different species that use the same resources. As a result of competition, some individuals might die of starvation. Others move to different areas in search of resources. As population density decreases, competition decreases.

Parasites When population density is high, parasites spread in a way similar to the way disease spreads. The spread of parasites limits population growth.

Predators The figure below illustrates how the interaction of predators and prey limits the populations of both groups. Before the winter of 1947, there were no wolves on Isle Royale, located in Lake Superior. That winter, a pair of wolves crossed the ice on Lake Superior and reached the island. With plenty of moose available as prey, the wolf population increased. Follow the events in the figure below to see how the populations of wolves and moose depend on one another. As the population density of one decreases, the population density of the other increases.

Picture This

4. Predict how the cycle might change for the moose population if the wolves were removed from Isle Royale.



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What factors affect a population's growth rate?

The **population growth rate** is a measure of how fast a given population grows. Two factors that influence a population's growth rate are birthrate and death rate. Birthrate, or natality, is the number of individuals that are born in a given time period. Death rate, or mortality, is the number of individuals that die in a given time period.

Emigration and immigration also affect the rate of population growth. **Emigration** (em uh GRAY shun) is the number of individuals moving away from a population. **Immigration** (ih muh GRAY shun) is the number of individuals moving into a population. ✓

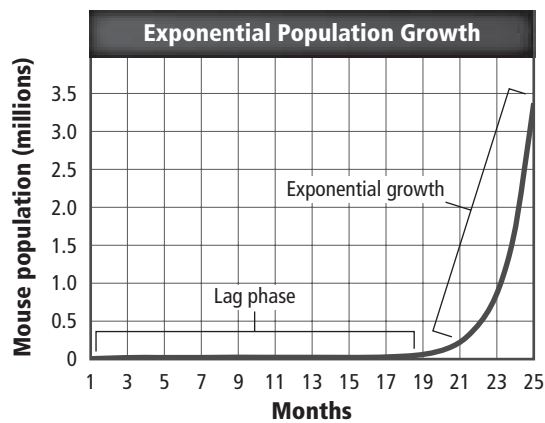
✓ Reading Check

5. **Name** four factors that influence a population's growth rate.

Picture This

6. **Calculate** the increase in the mouse population between months 23 and 25. Show your work.

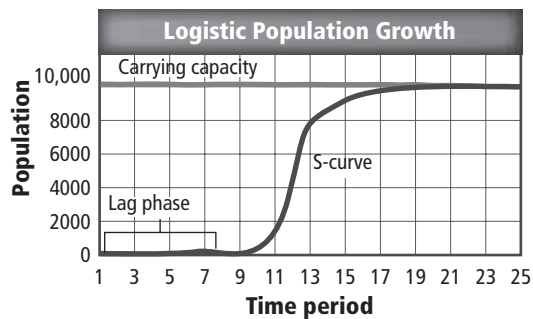
Exponential Growth The graph below shows how a population of mice would grow if there were no environmental limiting factors. The graph starts with a population of two adult mice. They breed and have a litter of young. At first, the population increases slowly. This slow period is the lag phase in the graph. Without limiting factors, all of the young survive and breed. The population increases rapidly, or grows exponentially. All populations grow exponentially until some limiting factor slows the growth. Notice that exponential growth gives the graph a J shape.



Logistic Growth Populations cannot grow exponentially forever. At some point, the rapidly increasing population will strain available resources. Then population growth will slow or stop. A population stops increasing when the number of deaths outnumbers the number of births or when emigration exceeds immigration. Logistic growth occurs when the population's growth slows or stops at the population's carrying capacity.

Carrying Capacity The graph below shows logistic growth. Notice that the graph begins in a J-shaped pattern of exponential growth, as in the previous graph. Then limiting factors slow population growth, causing the graph to bend into an S-shape. This S-pattern is typical of logistic growth. The population stops growing at the carrying capacity, as shown on the graph. The **carrying capacity** is the maximum number of individuals in a species that an environment can support for the long term. Carrying capacity is limited by resources such as water, oxygen, and nutrients.

When populations develop in an area with plenty of resources, there are more births than deaths. The population reaches the carrying capacity, and resources become limited. If a population becomes larger than the carrying capacity, there will be more deaths than births because there are not enough resources to support the population. The population falls below the carrying capacity as individuals die. Populations tend to stabilize near their carrying capacity.



How do reproductive strategies differ?

Species vary in their reproductive factors, such as the number of offspring born during each reproductive cycle, the age that reproduction begins, and the life span of the organism. Both plants and animals are placed into reproductive strategies based on their reproductive factors.

Rate strategists, or *r*-strategists, are small organisms. They usually have short lives. They produce as many offspring as possible and do not nurture them. Typically, the population of *r*-strategists is controlled by density-independent factors and does not stay near the carrying capacity.

Carrying-capacity strategists, or *k*-strategists, are large organisms. They usually have long lives. They produce few offspring and nurture them. Typically, the population of *k*-strategists is controlled by density-dependent factors and stays near the carrying capacity.

Picture This

7. Identify For the population represented on the graph, what is the maximum number of individuals that the environment can support over a long time period?

Reading Check

8. Summarize the reproductive strategies of *r*-strategists and *k*-strategists for ensuring continuation of their species.

Population Ecology

section 2 Human Population

MAIN Idea

Human population growth changes over time.

What You'll Learn

- the age structure of nongrowing, slowly growing, and rapidly growing countries
- consequences of continued population growth

Study Coach

Create a Quiz As you read this section, write quiz questions based on what you have learned. After you write the questions, answer them.

Think it Over

- Describe** a technology, not yet invented, that could increase the human carrying capacity.

Before You Read

Think about the characteristics of populations that you read about in Section 1. On the lines below, explain how these characteristics might apply to human populations. Then read the section to learn about human populations.

Read to Learn

Human Population Growth


Demography (de MAH gra fee) is the study of human population size, density, distribution, movement, and birth and death rates. The human population remained fairly stable for thousands of years, but it has recently increased.

How has technology affected growth?

Humans have learned to change their environment in ways that increase the carrying capacity. Agriculture and domestication of animals have increased the human food supply. Technological advances, such as in medicine and shelter construction, have reduced the death rate. As a result, about 70 million people are added to the world population each year. The world's population is expected to double in about 53 years.

Although the human population is growing, the rate of growth has slowed. Human population growth peaked at over 2.2 percent in 1962. By 2003, the rate of growth had dropped to almost 1.2 percent. The decline in growth is due primarily to diseases such as AIDS and voluntary population control.

Trends in Human Population Growth

Events such as disease and war can change population trends. Human population growth is not the same in all countries. However, countries with similar economies tend to have similar population growth trends. 

For example, one trend is a change in the population growth rate in industrially developed countries, such as the United States. An industrially developed country has advanced industry and technology and a high standard of living. Early in its history, the United States had a high birthrate and a high death rate. Many children died before reaching adulthood. Typically, individuals died by their early forties. In recent years, the birthrate in the United States has decreased a lot. The average lifespan is now more than 70 years. A change from high birth and death rates to low birth and death rates in a population is called a **demographic transition**.

How is population growth rate calculated?

In the United States, the birthrate in 2004 was 14 births per 1000 people. The death rate was 8 deaths per 1000 people. Using these figures, the population growth rate can be calculated as shown in the box below.

Calculating Population Growth Rate

$$14 \text{ births} - 8 \text{ deaths} = 6 \text{ additional people per 1000}$$
$$6/1000 = 0.006, \text{ or } 0.6\% \text{ growth rate for 2004}$$

A developing country, such as Honduras, had a birthrate of 33 births per 1000 people and a death rate of 5 deaths per 1000 people. These rates result in a population growth rate of 2.8 percent for 2004.

Between now and 2050, developing countries will add about 73 million people to the world population. Industrially developed countries will add only about three million people.

What is zero population growth?

Zero population growth (ZPG) occurs when the birthrate equals the death rate. According to one estimate, the world will reach zero population growth between 2020 and 2029. Although the population will have stopped growing, births and deaths will continue at the same rate. At zero population growth, the number of people in different age groups should be nearly equal.

Reading Check

2. **List** two events that can change human population trends.

Applying Math

3. **Apply** Use the statistics for Honduras in the paragraph to calculate the growth rate for Honduras in 2004.

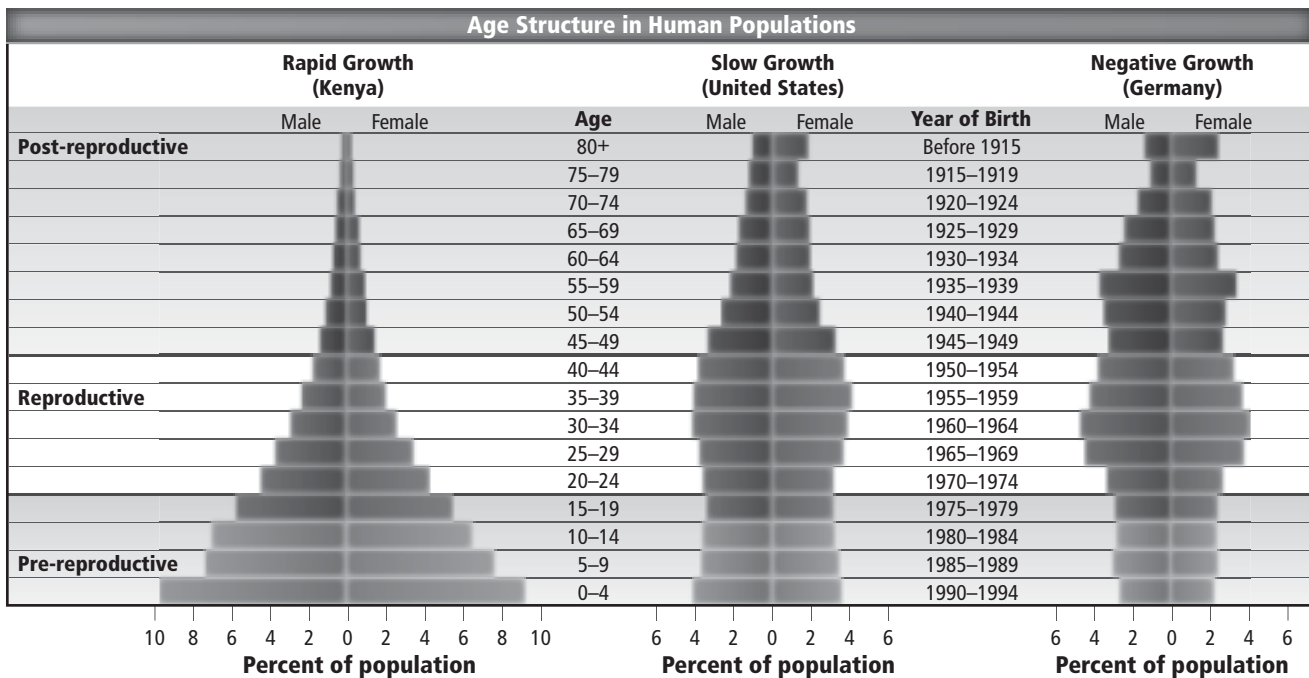
Picture This

4. Label the pre-reproductive stage that represents the largest and the one that represents the smallest portion of its country's population.

How does age structure predict growth?

A population's **age structure** is the number of males and females in each of three age groups. The groups are pre-reproductive (up to age 20), reproductive (ages 20 through 44), and post-reproductive (after age 44).

The figure below shows the age structure for three countries. Compare the shapes of the three diagrams. When the largest portion of the population is in the pre-reproductive stage, as in Kenya, the population is growing rapidly. When the smallest portion is pre-reproductive, as in Germany, the population is decreasing. When the reproductive and pre-reproductive groups are roughly equal, as in the United States, the population is growing slowly.



Reading Check

5. Summarize the possible consequences of rapid human population growth.

Why is human population growth a concern?

All populations have carrying capacities, including human populations. Scientists are concerned that the human population might exceed Earth's ability to support it. Like populations of other organisms, human overcrowding will lead to disease and starvation. Family planning in many countries is being used to slow the growth rate.

Currently, individuals in industrially developed countries use far more resources than individuals in developing countries. Populations in developing countries are increasing rapidly. As these countries industrialize, resource use will also increase rapidly.

section 1 Biodiversity

● Before You Read

Think about the different organisms that live in your area. On the lines below, list as many of them as you can. Then read about the importance of biological diversity.

MAIN Idea

Biodiversity maintains a healthy biosphere.

What You'll Learn

- the three types of diversity
- why biodiversity is important
- the direct and indirect value of biodiversity

● Read to Learn

What is biodiversity?

Biodiversity is the variety of life in one area that is determined by the number of different species in that area. The variety of species in the biosphere decreases as species become extinct. **Extinction** occurs when the last member of a species dies.

Biodiversity increases the health and stability of an ecosystem. Three important types of biodiversity are genetic diversity, species diversity, and ecosystem diversity.

Why is genetic diversity important?

Two individuals of the same species will show differences. For instance, two ladybird beetles might differ in color, their ability to resist disease, or their ability to obtain nutrients from a new food source should the old food source disappear. These differences come from differences in the beetles' genes.

Genetic diversity is the variety of genes present in a population. Some populations of a species have a lot of genetic diversity. Other populations have little. A population with more genetic diversity is more likely to survive during environmental changes, an outbreak of disease, or the disappearance of a food source.

Mark the Text

Restate Main Ideas

Underline or highlight the main ideas in each paragraph. Stop after every paragraph and state what you just read in your own words.

FOLDABLES™

Compare Make a folded table Foldable to compare the three types of biodiversity. Include a description and explain the importance of each type.

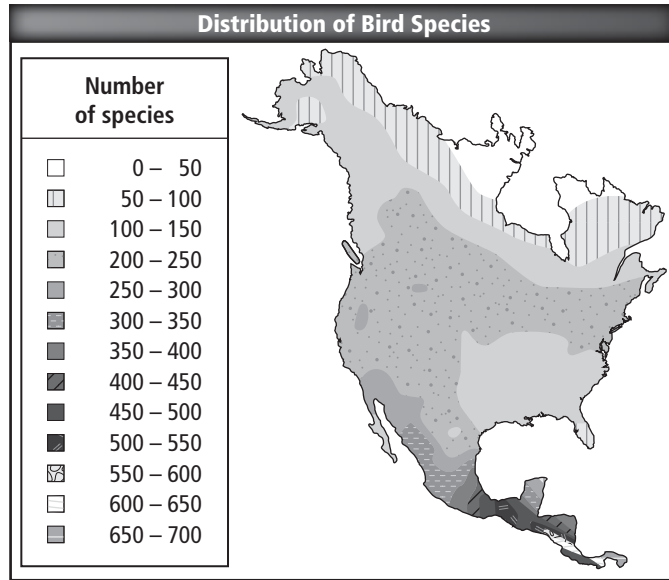
Biodiversity	Genetic Diversity	Species Diversity	Ecosystem Diversity
Description			
Importance			

How does species diversity contribute to biodiversity?

Species diversity is the number of different species and the abundance of each species in a biological community. Areas with many species have a high level of species diversity. Species diversity is higher in tropical regions along the equator and lower in polar regions. This can be seen in the figure below.

Picture This

- 1. Identify** Circle the areas with the lowest and highest amounts of species diversity.



What is ecosystem diversity?

Ecosystem diversity is the variety of ecosystems that are present in the biosphere. Recall that an ecosystem includes all populations that interact and the abiotic, or non-living, factors that support them. The interactions among organisms are important to developing stable ecosystems. Different locations have different abiotic factors that support different types of life.

The Importance of Biodiversity

Many people work to preserve biodiversity for economic and scientific reasons. Other people work to preserve species that are beautiful.


Why is biodiversity valuable to humans?

People depend on other living things for food, clothing, energy, medicine, and shelter. Preserving the genetic diversity of species that people use directly is important. It is also important to preserve the genetic diversity of species that are not used directly. These species are possible sources of desirable genes that might be needed in the future.

Reading Check

- 2. Name** three things people need that come from ecosystems.

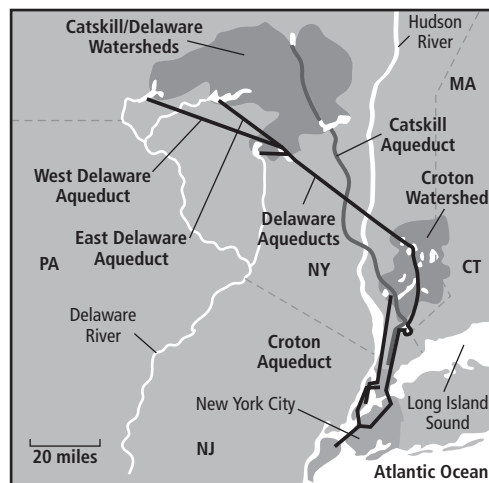
Why might a species be valuable someday?

One reason to preserve biodiversity is that wild species might someday be needed to create better crops for growing food. Biologists are beginning to learn how to transfer genes that control inherited characteristics from one species to another. Another reason is that scientists continue to find new medicines in nature. Many medicines were first identified in living things. Aspirin was discovered in willow, and penicillin was discovered in bread mold. In remote regions, many plants and other organisms have not been identified. These unknown species offer the promise of new medicines. 

What are the indirect values of biodiversity?

People, like all living things, benefit from a healthy biosphere. Scientists have begun to team up with economists to understand the dollar value of healthy ecosystems.

In the 1990s, New York City needed to clean up its drinking water. Much of the water for the city came from watersheds. Watersheds are land areas where the water on or underneath them drains to the same place. Two of the city's watersheds were not clean enough to supply drinking water. The city faced a choice: build a water-filtration system, which would cost 6 billion dollars, or clean up the watersheds, which would cost 1.5 billion dollars. The city found that cleaning up the ecosystem was a less expensive solution than using technology.



Are there other values to biodiversity?

Many people work to preserve ecosystems for scientific reasons and also because ecosystems are beautiful. These factors are important and worthwhile, although it is difficult to attach a dollar value to them.

Reading Check

3. Name one medicine that was discovered in nature.

Picture This

4. Explain Highlight the watersheds that supply New York's drinking water.

Biodiversity and Conservation

section 2 Threats to Biodiversity

MAIN Idea

Some human activities destroy biodiversity in ecosystems.

What You'll Learn

- factors that threaten biodiversity
- how the decline of one species can impact an ecosystem

● Before You Read

You have probably read or heard about environmental issues in the news. On the lines below, list some environmental problems. Then read to learn about the possible consequences of human activities on the environment.

Mark the Text

Identify Threats to Biodiversity Highlight or underline the threats to biodiversity that you read about in this section.

● Read to Learn

Extinction Rates

Many species have become extinct during Earth's long history. Scientists have learned a lot about life on Earth by studying the fossils of extinct species. The gradual process of species becoming extinct is known as **background extinction**. This low level of extinction is always present. It is caused by natural processes, such as the activity of other organisms, climate changes, or natural disasters.

Many scientists worry about a recent increase in the rate of extinction. Some scientists estimate that today's rate of extinction is about 1000 times the normal background extinction rate.

Some scientists predict that as many as two-thirds of all plant and animal species will become extinct during the second half of this century. Most of these extinctions will occur near the equator.

Some scientists believe we are in a period of a mass extinction. During a **mass extinction** a large percentage of all living species become extinct in a relatively short period of time. The last mass extinction, in which the dinosaurs became extinct, occurred about 65 million years ago.

✓ Reading Check

1. **Define** *mass extinction*.

How many species have become extinct?

The table below shows the high rate of extinctions since the year 1600. Many extinctions have occurred on islands. For example, 73 percent of mammals that have become extinct in the last 500 years were island species.

Species on islands are vulnerable to extinction for several reasons. Many island species evolved without natural predators. As a result, they do not have the ability to protect themselves. When a cat, dog, or other predator is introduced to the population, it can harm populations of native species. Nonnative species also harm native species by bringing diseases. The native population often does not have resistance to the disease and dies.

Picture This

2. Identify What two groups of living things have the highest rate of extinction?

Estimated Number of Extinctions Since 1600						
Group	Mainland	Island	Ocean	Total	Estimated Number of Species	Percent of Group Extinct
Mammals	30	51	4	85	4000	2.1
Birds	21	92	0	113	9000	1.3
Reptiles	1	20	0	21	6300	0.3
Amphibians	2	0	0	2	4200	0.05
Fish	22	1	0	23	19,100	0.1
Invertebrates	49	48	1	98	1,000,000+	0.01
Flowering plants	245	139	0	384	250,000	0.2

Factors that Threaten Biodiversity

The high extinction rate today is due to the activities of a single species—*Homo sapiens*. Humans are changing conditions on Earth faster than new traits can evolve to cope with the new conditions. Evolving species might not have the natural resources they need. **Natural resources** are all materials and organisms found in the biosphere. Natural resources include minerals, fossil fuels, plants, animals, soil, clean water, clean air, and solar energy.

How does overexploitation harm a species?

One factor that is increasing the current rate of extinction is overexploitation. **Overexploitation** is the excessive use of a species that has economic value. For example, at one time, about 50 million bison roamed the central plains of North America. The bison nearly became extinct because of overhunting. By 1889, there were fewer than 1000 bison left.

Reading Check

3. Define What is overexploitation?

✓ Reading Check

- 4. Identify** What caused passenger pigeons to become extinct? (Circle your answer.)
- a. pollution
 - b. overhunting
 - c. climate change

How has overexploitation caused extinction?

At one time, passenger pigeons were numerous in North America. Large flocks of the birds would darken the skies. Passenger pigeons were overhunted and forced from their habitats. By the early 1900s, the birds had become extinct. Animals today that suffer from overexploitation include the ocelot and the white rhinoceros. People kill ocelots for their fur and white rhinoceroses for their horns.

Why is habitat loss a problem?

Overexploitation was once the main cause of extinction. Today, the main cause is the loss or destruction of habitat. When a habitat is destroyed, the native species might have to move or they will die.

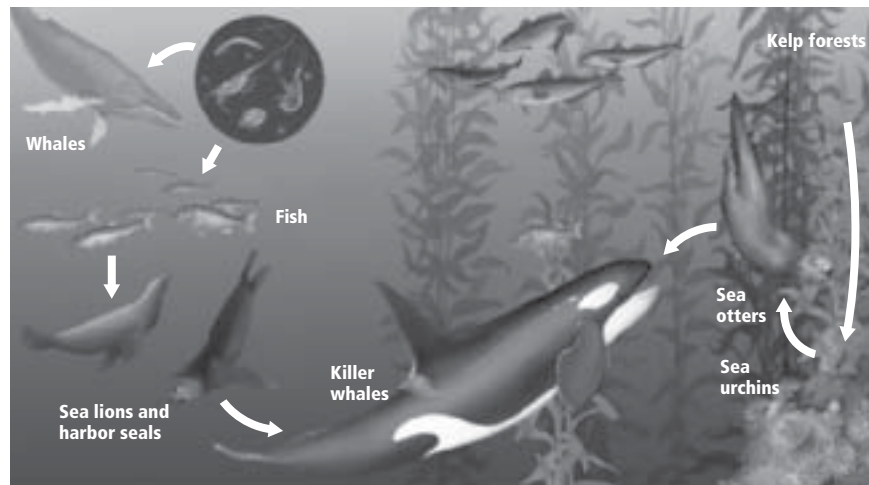
An example of habitat destruction occurs in tropical rain forests. Clearing of tropical rain forests is a serious threat to biodiversity. Remember that tropical areas have high levels of biodiversity. More than half of the world's plants and animals live in tropical rain forests. Removal of these forests would cause high numbers of extinction.

How can habitat disruption affect biodiversity?

Changing one thing in a habitat can also lead to loss of biodiversity. The figure below shows an example of how the decline of one species can affect an entire ecosystem. This chain of events occurred off the coast of Alaska in the 1970s when plankton-eating whales began to disappear. This caused the number of plankton to increase and began a chain reaction that affected many species, disrupting their habitat.

Picture This

- 5. Explain** What caused the decline in the number of sea otters?



Can biodiversity be preserved in small areas?

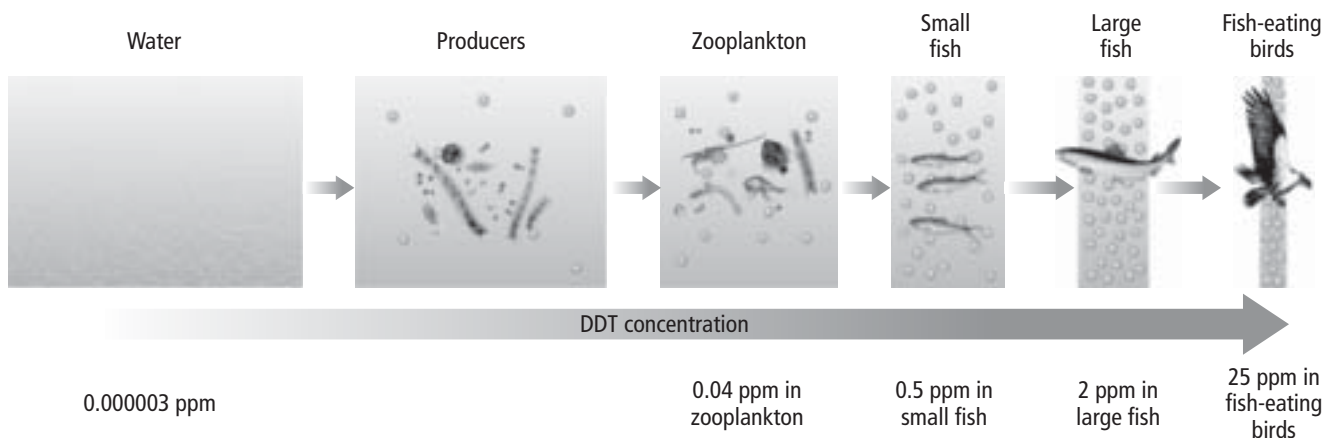
Another source of habitat disruption is **habitat fragmentation**, the separation of an ecosystem into small areas. Species stay within the small areas because they are unable or unwilling to cross the human-made barrier. This causes several problems for the survival of species.

First, small areas of land cannot support large numbers of species. Second, individuals in one area cannot reproduce with individuals in another area, causing genetic diversity to decrease. Less genetically diverse populations are less able to resist disease and adjust to environmental changes.

Third, several small areas have more edges than one large area. Environmental conditions along the boundaries of an ecosystem are different, a factor known as the **edge effect**. Temperature, humidity, and wind are often different along the edge of a habitat than they are at its center. Some species are better adapted to living in the edge environment, but other species might find it difficult to survive there.

Picture This

6. Identify Circle the habitat that would be harmed most by the edge effect.



How does pollution impact biodiversity?

Pollution damages ecosystems and decreases biodiversity by releasing harmful substances into the environment. Pesticides and industrial chemicals are examples of pollutants that are in food webs. Organisms ingest these substances in their food or water.

Some pollutants accumulate in the tissues of these organisms. Animals that eat other animals are most affected by the buildup of pollutants. **Biological magnification** happens when pollutants build up to high levels in bodily tissues of carnivores. The amount of pollutants might be relatively low when it enters the food web, but it increases as it spreads to a higher trophic level.



Think it Over

7. Synthesize Which animal would likely be more affected by biological magnification? (Circle your answer.)

- cow
- wolf

 **Reading Check**

8. Name two effects of acid precipitation.

 **Reading Check**


9. Identify three factors that keep biodiversity in balance.

What effects did DDT have on some species of birds?

Some pollutants might disrupt normal bodily functions. The pesticide DDT causes eggshells of birds to be fragile and thin, leading to the death of developing birds. From the 1940s to the 1970s, DDT use caused populations of the American bald eagle and the peregrine falcon to become nearly extinct. DDT is now banned in some parts of the world.

How does acid precipitation affect ecosystems?


Acid precipitation is another pollutant. When fossil fuels are burned, compounds that form sulfuric acid and nitric acid are released into the environment. These acids fall back to Earth in rain, sleet, snow, or fog.

Acid precipitation removes nutrients from the soil. It damages plants and slows their growth. It pollutes lakes, rivers, and streams, killing fish and other organisms. 

What is eutrophication?

Water pollution can destroy underwater habitats for fish and other species. **Eutrophication** (yoo troh fih KAY shun) occurs when fertilizers, animal waste, and sewage flow into waterways. These substances are rich in nitrogen and phosphorus, and they cause algae to grow. The algae use up the oxygen, causing other organisms in the water to suffocate. Sometimes the algae release toxins that poison the water.

How do nonnative species change ecosystems?

Organisms that have been moved to a new habitat are known as **introduced species**. In their native habitat, these organisms are kept in balance by predators, parasites, and competition with other species. When they are introduced into a new area, these controlling factors are not in place. Introduced species often reproduce in large numbers and become invasive species in their new habitat. 

An example is the imported fire ant, which is native to South America. These ants were introduced to the United States in the 1920s. They have spread throughout many parts of the southern and southwestern United States and have caused damage by feeding on native wildlife.

About 40 percent of the extinctions in the last few hundred years might have been caused by introduced species. Billions of dollars are spent each year to control the damage caused by introduced species.

Biodiversity and Conservation

section ③ Conserving Biodiversity

● Before You Read

On the lines below, list some activities that you could do in your home or school to use fewer natural resources. Then read to learn about ways people are preserving biodiversity.

MAIN Idea

People are working to preserve biodiversity.

What You'll Learn

- two classes of natural resources
- how biodiversity can be conserved
- two methods used to restore biodiversity

● Read to Learn

Natural Resources

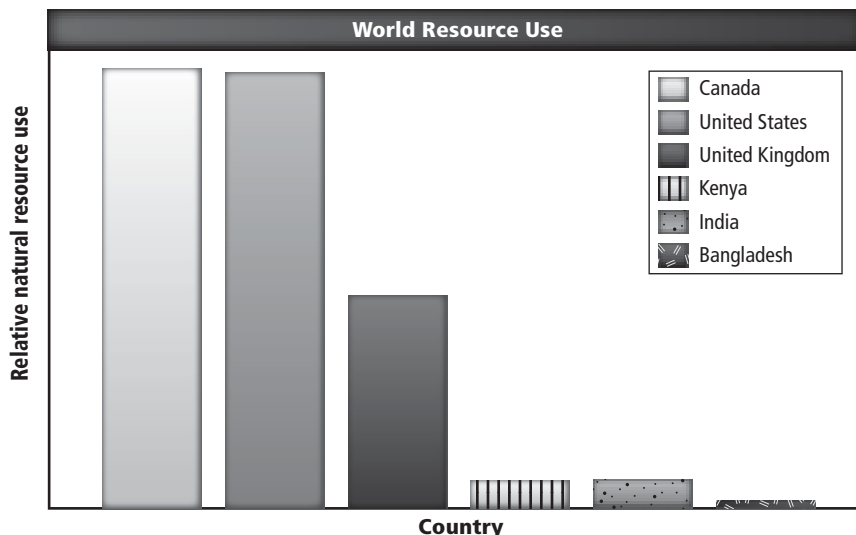
There are more than six billion people living in the world today, and the number keeps growing. As the human population grows, the need for natural resources also grows.

The figure below shows the natural resources used by people in different parts of the world. Notice that people in some countries, like the United States and Canada, use more resources, while people in other countries use fewer resources. As countries become industrialized, people living there consume more resources.

Mark the Text

Locate Information

Underline every heading in the reading that asks a question. Then highlight or underline the answers to those questions as you find them.



Picture This

1. **Name** two countries with high consumption and two countries with low consumption.



Think it Over

- 2. Identify** Which of these energy resources is a nonrenewable resource? (Circle your answer.)
- a. wind
 - b. gasoline
 - c. solar

Reading Check

- 3. Identify** two ways people can sustainably use resources.

What are examples of renewable resources?

The two types of natural resources are renewable resources and nonrenewable resources. **Renewable resources** are resources that are replaced by natural processes faster than they are consumed. Solar energy is a renewable resource. Other renewable resources include plants used for food, animals, clean water, and clean air. It is important to remember that the supply of these resources is not endless. These resources might run out if we do not manage them carefully.

Why are some resources nonrenewable?

Nonrenewable resources are resources that are replaced by natural processes slower than they are consumed. Fossil fuels and minerals are nonrenewable resources. Species are considered to be nonrenewable resources because an extinct species cannot be replaced.

A small group of trees in a large forest ecosystem is renewable because replacement trees can be grown from seeds in the soil. Enough of the forest is still intact to be the habitat for the organisms that live there. When an entire forest is cleared of many of its trees, it is not a renewable resource. The organisms that lived in the forest have lost their habitat and might die.

How can natural resources be managed?

Sustainable use means using resources at a rate in which they can be replaced or recycled while preserving the long-term environmental health of the biosphere. Sustainable use includes reducing the amount of resources that are used, recycling, and using resources responsibly.

Protecting Biodiversity

In Section 2, you learned how human activity has affected ecosystems. Now you will learn about efforts to preserve biodiversity. Many people around the world are involved in efforts to protect biodiversity and use resources in a sustainable way.


How do national parks protect biodiversity?

One way to protect biodiversity is to establish protected areas where biodiversity can succeed. The United States established its first national park—Yellowstone National Park—in 1872. Many more national parks and nature reserves have been established in the United States since then.

How much of the world's land is protected?


Many countries have established their own natural parks and nature reserves. Today about 7 percent of the world's land is protected for biodiversity.

Biodiversity in these areas can be threatened by the activity of people. Many of the protected areas are small and surrounded by areas of human activity. The human activity could damage the ecosystem in the protected areas.

Costa Rica has established megareserves in which one or more zones are surrounded by buffer zones. In a buffer zone, sustainable use of natural resources is permitted. 

What is a biodiversity hot spot?

Scientists have identified locations around the world that are characterized by many **endemic** species—species that are only found in that one location. These areas are called hot spots. To be called a hot spot, there must be at least 1500 species of vascular plants that are endemic and the area must have lost at least 70 percent of its original habitat.

About one-third of all plant and animal species are found in hot spots. These hot spots originally covered 15.7 percent of Earth's surface. Currently, about a tenth of that habitat remains. 

Biologists do not always agree about how to preserve biodiversity. Some biologists believe we should focus most of our efforts on hot spots in order to preserve the greatest number of species. Other biologists believe that while focusing on hot spots, other problems might be neglected.

How can corridors between habitats work?

One way biologists hope to improve biodiversity is by providing pathways, or corridors, between habitat fragments. Protected corridors connect small areas of land and give animals a way to move safely from one fragment of habitat to the next. One problem with this approach is that small fragments connected in this way are subject to edge effects.

Restoring Ecosystems

Sometimes, biodiversity in an ecosystem is destroyed. The ecosystem no longer has all the needed biotic and abiotic factors to maintain its health. When this happens, the ecosystem no longer functions properly. People have devised ways of restoring ecosystems.

Reading Check

4. Explain What happens in a buffer zone?

Reading Check

5. State What portion of the world's plant and animal species live in biodiversity hot spots?



Think it Over

6. Draw Conclusions

Why do larger disturbed areas take longer to recover?

Reading Check

7. Explain the purpose of the Endangered Species Act.

What kinds of ecosystems need to be restored?

Natural causes, such as volcanic eruptions or floods, can destroy biodiversity. People can destroy biodiversity when they do not use resources sustainably. Damaged ecosystems might take a long time to recover.

Think of what happens when a tropical rain forest is cleared for farmland. After a few years, people abandon the farmland because the soil is in poor condition. The ecosystem might take many years to recover. Another example of a damaged ecosystem that needs restoration occurs when an accidental oil spill or toxic chemical spill pollutes the area and kills native species.

Given time, ecosystems can recover. Typically, larger areas take longer to recover. Some types of disturbances recover more quickly than others. Ecologists use two methods to speed recovery—bioremediation and biological augmentation.

How does bioremediation clean up pollution?


Bioremediation is the use of living organisms to remove toxins from a polluted area. Bioremediation relies on bacteria, fungi, or plants to clean up pollutants in the soil.

Some species of plants can be used to remove toxic metals such as zinc, lead, and nickel. The plants are planted in contaminated soils. The plants grow and store the toxic metals in their tissues. People then harvest the plants, removing the metals from the ecosystem.

What is biological augmentation?

Biological augmentation involves adding natural predators to a degraded ecosystem. For example, ladybugs are predators that eat other insects. Ladybugs can be introduced to help control insect populations.

Legally Protecting Biodiversity

During the 1970s, people's awareness of environmental problems grew. In 1973 the Endangered Species Act was passed in the United States. It gives legal protection to species that are in danger of becoming extinct. In 1975 an international treaty was signed that outlawed the trade of endangered animals and animal parts, such as elephant tusks and rhinoceros horns. Since then, many more laws and treaties have been enacted with the purpose of preserving biodiversity and the health of the biosphere. 

● Before You Read

On the lines below, describe how you think chemistry relates to living things. Then read the section to learn about the chemical building blocks of life.

MAIN Idea

Matter is composed of tiny particles called atoms.

What You'll Learn

- the particles that make up atoms
- the difference between covalent bonds and ionic bonds
- about van der Waals forces

● Read to Learn

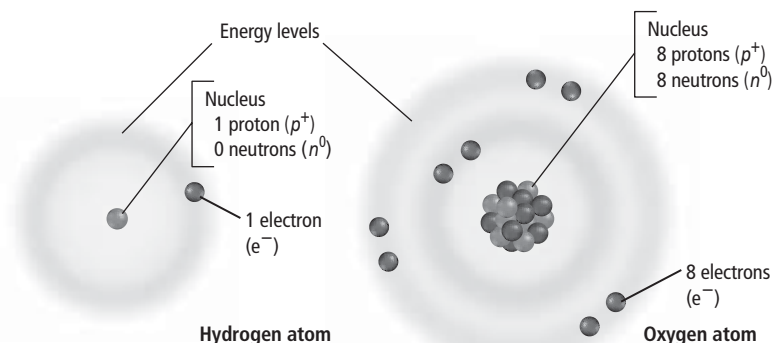
Atoms

Chemistry is the study of matter. Matter is anything that has mass and takes up space. All organisms are made of matter.

Atoms are the building blocks of matter.

Atoms are made up of neutrons, protons, and electrons, as shown in the figure below. The **nucleus** is the center of the atom where the neutrons and protons are located. **Protons** are positively charged particles (p^+). **Neutrons** are particles that have no charge (n^0). **Electrons** are negatively charged particles (e^-) that are located outside the nucleus.

Electrons move around the nucleus in energy levels. The atom's structure is the result of the attraction between protons and electrons. Atoms contain an equal number of protons and electrons. As a result, the overall charge of an atom is zero.



Mark the Text

Read for Understanding

As you read this section, highlight any sentences that you do not understand. After you finish the section, reread the highlighted sentences.

Picture This

1. **Identify** the number of electrons in the outermost energy level of the oxygen atom.
-



Think it Over

2. Apply Another carbon isotope has six protons and seven neutrons in its nucleus. What do you think this carbon isotope is called?

Picture This

3. Draw Conclusions Table salt is a compound made of sodium and chlorine. Could you separate the sodium from the chlorine by crushing the salt crystals? Explain.

Elements

An **element** is a pure substance that cannot be broken down into other substances. The periodic table of elements organizes information about elements in rows, called periods, and columns, called groups. A periodic table is located inside the back cover of this workbook. Each block includes the element's name, number, symbol, and mass. Living things are composed mainly of three elements—carbon, hydrogen, and oxygen.

How are isotopes identified?

Atoms of the same element have the same number of protons and electrons but sometimes different numbers of neutrons. Atoms of the same element with different numbers of neutrons are called **isotopes**. Isotopes are identified by adding the number of protons and neutrons. Carbon-12 has six protons and six neutrons. Carbon-14 has six protons and eight neutrons.

What makes an isotope radioactive?

Changing the number of neutrons in an atom can cause the nucleus to decay, or break apart. When a nucleus breaks apart, it gives off radiation. Isotopes that give off radiation are called radioactive isotopes. All living things contain the radioactive isotope carbon-14. Scientists know the half-life of carbon-14, or the amount of time it takes for half of carbon-14 to decay. By finding how much carbon-14 remains in an object, scientists can calculate the object's age.

Compounds

When two or more elements combine, they form a **compound**. Each compound has a chemical formula made up of the chemical symbols from the periodic table. For example, water is made of hydrogen (H) and oxygen (O). Its formula is H₂O. The table below lists characteristics of compounds.

Characteristics of Compounds	Example
Always formed from a specific combination of elements in a fixed ratio	Water is always a ratio of two hydrogen atoms and one oxygen atom: H ₂ O.
Chemically and physically different than the elements that comprise them	Water has different properties than hydrogen and oxygen.
Cannot be broken down into simpler compounds or elements by physical means	Passing water through a filter will not separate the hydrogen from the oxygen.
Can be broken down by chemical means	An electric current can break water down into hydrogen and oxygen.

Chemical Bonds

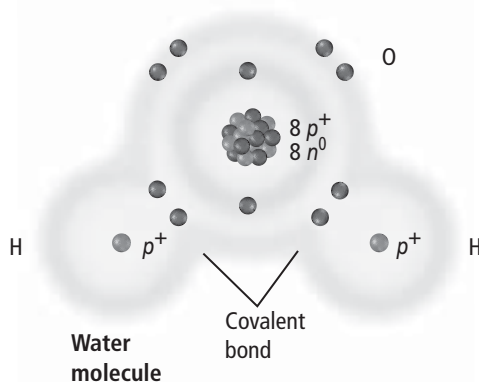
The force that holds substances together is called a chemical bond. Chemical bonding involves electrons. Electrons travel around the nucleus of an atom in energy levels. Each energy level can hold only a certain number of electrons. The first energy level, which is closest to the nucleus, can hold up to two electrons. The second level can hold up to eight electrons.

A partially-filled energy level is not as stable as a full or an empty energy level. Atoms become more stable by losing electrons or attracting electrons from other atoms. This electron activity forms chemical bonds between atoms. The forming of chemical bonds stores energy. The breaking of chemical bonds releases energy for an organism's life processes—growth, development, and reproduction. The two main types of chemical bonds are covalent and ionic.

How do covalent bonds form?

A **covalent bond** forms when atoms share electrons. The figure below shows the covalent bonds between oxygen and hydrogen to form water. Each hydrogen (H) atom has one electron in its outer energy level, and the oxygen (O) atom has six. The outer energy level of oxygen is the second level, so it can hold up to eight electrons. Oxygen has a strong tendency to fill the energy level by sharing electrons from the two nearby hydrogen atoms. Hydrogen also has a strong tendency to share electrons with oxygen to fill its outer energy level. Two covalent bonds form a water molecule.

Most compounds in living things are molecules. A **molecule** is a compound in which the atoms are held together by covalent bonds. Covalent bonds can be single, double, or triple. A single bond shares one pair of electrons. A double bond shares two pairs of electrons. A triple bond shares three pairs of electrons.



Think it Over

- 4. Apply** Look back at the oxygen atom illustrated on the first page of this section. Is the second energy level of the oxygen atom full? Explain.

Picture This

- 5. Label** the first energy level and second energy level in the oxygen atom. Include in each label the number of electrons required to fill the level.

✓ Reading Check

6. Describe what happens to an atom's electric charge if the atom gives up an electron.

✓ Reading Check

7. Identify the substances that are held together by van der Waals forces. (Circle your answer.)

- atoms
- molecules

How do ionic bonds form?

Recall that atoms do not have an electric charge. Also recall that an atom is most stable when its outer energy level is either empty or full. To become more stable, an atom might give up electrons to empty its outer energy level. Or, the atom might accept electrons to fill the outer energy level. An atom that has given up or gained one or more electrons becomes an **ion** and carries an electric charge.

For example, the outer energy level of sodium (Na) has one electron. Sodium can become more stable if it gives up this electron to empty the energy level. When it gives up this one negative charge, the neutral sodium atom becomes a positively charged sodium ion (Na^+). Chlorine (Cl) needs just one electron to fill its outer energy level. When it accepts an electron from another atom, chlorine becomes a negatively charged ion (Cl^-). ✓

An **ionic bond** is an electrical attraction between two oppositely charged ions. When sodium gives its electron to chlorine, the positively charged sodium ion (Na^+) is attracted to the negatively charged chlorine ion (Cl^-). The ionic bond between them forms the ionic compound sodium chloride (NaCl), or table salt.

Ions in living things help maintain homeostasis as they travel in and out of cells. Ions also help transmit signals that enable you to see, taste, hear, feel, and smell.

Some atoms give up or accept electrons more easily than other atoms. The elements identified as metals in the periodic table tend to give up electrons. The elements identified as nonmetals tend to accept electrons.

van der Waals Forces

Electrons travel around the nucleus randomly. The random movement can cause an unequal distribution of electrons around the molecule. This creates temporary areas of slightly positive and negative charges. Attractions between these positive and negative regions hold molecules together. These attractions between molecules are called **van der Waals forces**. These forces are not as strong as covalent and ionic bonds, but they play a key role in biological processes. For example, attractions between positive and negative regions hold water molecules together. As a result, water can form droplets. Note that van der Waals forces are the attractive forces between water molecules. They are not the forces between the atoms that make up water. ✓

● Before You Read

On the lines below, explain why you think rust forms on metal. Then read the section to learn the role of chemical reactions in living things.

● Read to Learn

Reactants and Products

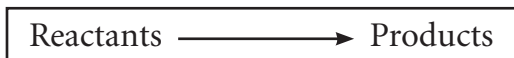
Chemical reactions occur inside your body all the time. You digest food. Your muscles grow. Your cuts heal. These functions and many others result from chemical reactions.

A **chemical reaction** is the process by which atoms or groups of atoms in substances are reorganized into different substances. Chemical bonds are broken and formed during chemical reactions. For example, rust is a compound called iron oxide. It forms when oxygen in the air reacts with iron.

What was once silver and shiny becomes dull and orange-brown. Other clues that a chemical reaction has taken place include the production of heat or light, and formation of gas, liquid, or solid.

How are chemical equations written?

Scientists express chemical reactions as equations. On the left side of the equation are the starting substances, or **reactants**. On the right side of the equation are the substances formed during the reaction, or the **products**. An arrow is between these two parts of the equation. You can read the arrow as “yield” or “react to form.” The general form of a chemical equation is shown below.



MAIN Idea

Chemical reactions allow living things to grow, develop, reproduce, and adapt.

What You'll Learn

- the parts of a chemical reaction
- how energy changes relate to chemical reactions
- the importance of enzymes in organisms

Study Coach

Create a Quiz After you read this section, create a five-question quiz from what you have learned. Then, exchange quizzes with another student. After taking the quizzes, review your answers together.

Picture This

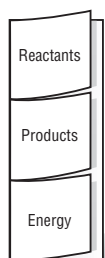
1. **Describe** how this general chemical equation would be expressed in words.

Picture This

2. **Label** the subscripts and the coefficients in this equation after you read the discussion on this page.

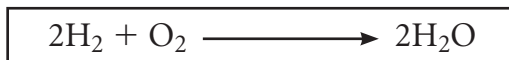


Take Notes Make a three-tab foldable from a sheet of notebook paper. As you read, record what you learn about reactants, products, and the energy required to start a chemical reaction.



Why must chemical equations balance?

The following chemical equation describes the reaction between hydrogen (H) and oxygen (O) to form water (H₂O).



Matter cannot be created or destroyed in chemical reactions. This is the principle of conservation of mass. Therefore, mass must balance in all chemical equations. This means that the number of atoms of each element on the reactant side must equal the number of atoms of the same element on the product side. In our example, the number of H atoms on the left side must equal the number of H atoms on the right side. The same must be true of O atoms.

The larger 2 to the left of the element H is called a coefficient. Coefficients are used to balance chemical equations. If no coefficient or subscript appears with an element, both are assumed to be 1.

To see that the above equation is balanced, multiply the coefficient by the subscript for each element. Then add up the total number of atoms of each element. Follow along in the equation above as you read the analysis below.

Reactant side:

$$2 \text{ (coefficient of H)} \times 2 \text{ (subscript of H)} = 4 \text{ H atoms}$$

$$1 \text{ (coefficient of O)} \times 2 \text{ (subscript of O)} = 2 \text{ O atoms}$$

Product side:

$$2 \text{ (coefficient of H)} \times 2 \text{ (subscript of H)} = 4 \text{ H atoms}$$

$$2 \text{ (coefficient of O)} \times 1 \text{ (subscript of O)} = 2 \text{ O atoms}$$

The equation has the same number of H atoms on both sides. It also has the same number of O atoms on both sides. No mass has been gained or lost. The equation balances.

Energy of Reactions

Energy is required to start a chemical reaction. The minimum amount of energy needed for reactants to form products in a chemical reaction is called the **activation energy**. For example, a candle will not burn until you light the wick. The flame from a match provides the activation energy for the candle wick to react with oxygen in the air. Some reactions need higher activation energy than others.

How does energy change in chemical reactions?

Chemical reactions can be exothermic or endothermic. In exothermic reactions, energy is released in the form of heat or light. As a result, the energy of the product is lower than the energy of the reactants. In endothermic reactions, energy is absorbed. As a result, the energy of the product is higher than the energy of the reactants. ✓

Enzymes

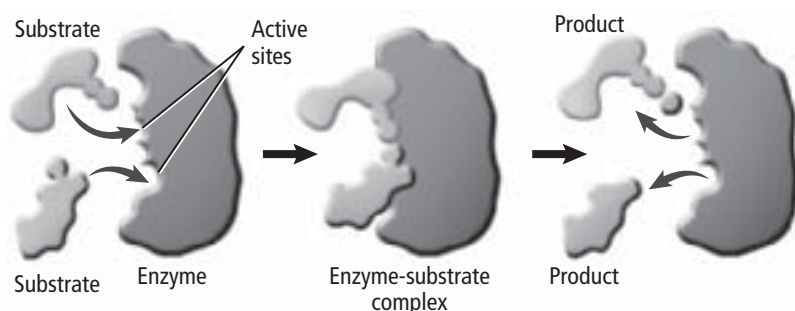
Some chemical reactions occur slowly in a laboratory because the activation energy is high. To speed up the chemical reaction, scientists use catalysts. A **catalyst** is a substance that lowers the activation energy needed to start a chemical reaction. A catalyst does not increase how much product is made, and it does not get used up in the reaction.

In living things, special proteins called **enzymes** are biological catalysts. Enzymes speed up the rate of chemical reactions in the body. Like all catalysts, enzymes are not used up by the chemical reaction. They can be used again. Also, most enzymes act in just one type of reaction. For example, the enzyme amylase is found in saliva. Amylase helps begin the process of food digestion in the mouth.

The figure below shows how an enzyme works. The reactants that bind to the enzyme are called **substrates**. The specific location where a substrate binds on an enzyme is called the **active site**. The substrate and active site are shaped to fit together exactly. Only substrates shaped to fit the active site will bind to the enzyme.

The bond between the enzyme and substrates creates the enzyme-substrate complex. This complex helps to break bonds in the reactants and form new bonds, changing the substrates into products. The enzyme then releases the products.

Enzymes are the chemical workers in cells. The actions of enzymes enable cell processes that supply energy. Factors such as pH and temperature affect enzyme activity.



✓ Reading Check

3. Explain why the energy of the product might be lower than the energy of the reactants.

Picture This

4. Label each of the three parts of this process with a brief description of what the part shows.

MAIN Idea

The properties of water make it well-suited to help maintain homeostasis in an organism.

What You'll Learn

- why water is a good solvent
- the differences between suspensions and solutions
- how acids differ from bases

Mark the Text

Restate the Main Point

Highlight the main point in each paragraph. Then restate each main point in your own words.

Picture This

1. **Label** the H and O atoms. Then label each electron with the symbol for a negative charge (–). Most negative charges are close to the nucleus of which atom?

Before You Read

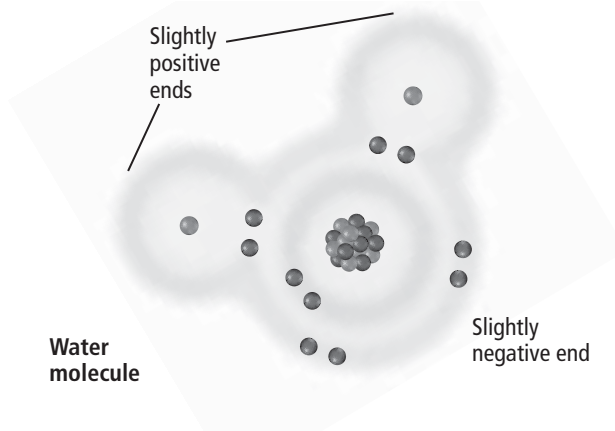
How you ever stirred a spoonful of a powdered drink into water? On the lines below, describe what happened to the powder. Then read the section to learn the properties of different types of mixtures.

Read to Learn

Water's Polarity

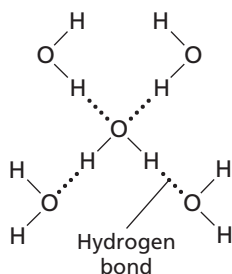
Earlier you learned that water molecules are formed by covalent bonds that link two hydrogen (H) atoms to one oxygen (O) atom. The electrons in a water molecule are attracted more strongly to an oxygen atom's nucleus. As a result, the electrons in the covalent bond are not shared equally. The electrons spend more time near the oxygen nucleus than near the hydrogen nuclei, as shown in the figure below.

Note that the water molecule has a bent shape. This shape and the unequal distribution of electrons result in oppositely charged regions. The oxygen end has a slightly negative charge. The hydrogen end has a slightly positive charge.



Why is polarity important?

Molecules that have an unequal distribution of charges are called **polar molecules**. Polarity means having two opposite poles, or ends. A magnet has polarity. When the opposite poles of a magnet are close to each other, they attract. In the same way, when oppositely charged regions of polar molecules are close together, they attract each other. In water, the attraction is called a hydrogen bond. A **hydrogen bond** is a weak interaction involving a hydrogen atom and a fluorine, oxygen, or nitrogen atom. The hydrogen bonds between water molecules are illustrated in the diagram below.



Mixtures with Water

When you make a fruit-flavored drink, you dissolve drink powder in water. It does not react with water to form a new product. A mixture has been created. A **mixture** is a combination of two or more substances in which each substance keeps its individual characteristics and properties.

What is a homogeneous mixture?

A homogeneous (hoh muh JEE nee us) mixture has the same composition throughout. A **solution** is another name for a homogeneous mixture. A solution has two parts: a solvent and a solute. A **solvent** is a substance in which another substance is dissolved. A **solute** is the substance that is dissolved in the solvent. In the fruit-flavored drink, water is the solvent and drink powder is the solute.

How does a heterogeneous mixture differ?

In a heterogeneous mixture, the parts remain distinct—that is, you can identify the individual parts. For example, in a salad, you can tell the lettuce from the tomatoes.

Sand mixed with water is a suspension. A suspension is a type of heterogeneous mixture. Over time, the particles in a suspension will settle to the bottom. In a heterogeneous mixture called a colloid, the particles do not settle out.

Picture This

- 2. Circle** each water molecule in this diagram. Remember, a water molecule is made up of two H atoms and one O atom. Hydrogen bonds link the water molecules together. How many water molecules are shown in this diagram?
-



Think it Over

- 3. Apply** Are coins in your pocket a homogeneous mixture or heterogeneous mixture? Explain.
-
-
-

Reading Check

4. Identify the property of water that makes water a good solvent.

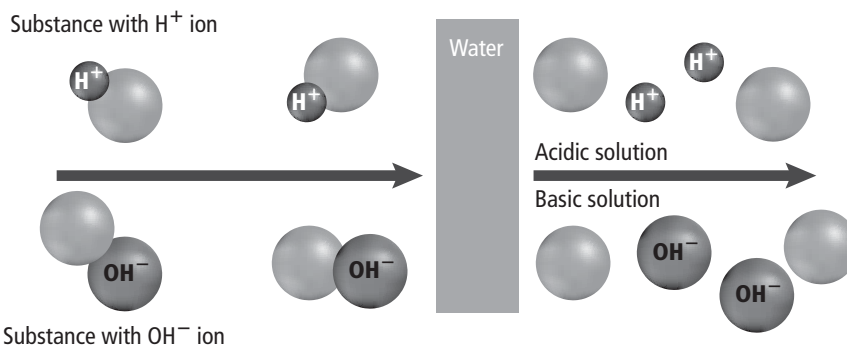
Picture This

5. Apply Suppose you want to make the acid solution in this figure more acidic. Add drawings that would result in a more acidic solution.

How do acids differ from bases?

Water's polarity enables many solutes to dissolve easily in water. The human body is about 70 percent water and contains many solutions. When a substance containing hydrogen is dissolved in water, the substance might release a hydrogen ion (H^+), as illustrated in the figure below. Substances that release hydrogen ions when dissolved in water are called **acids**. The more hydrogen ions released, the more acidic the solution.

Substances that release hydroxide ions (OH^-) when dissolved in water are called **bases**. The more hydroxide ions released, the more basic the solution.



How do buffers affect pH?

The measure of concentration of H^+ in a solution is called **pH**. Scientists use a pH scale like the one below to compare the strengths of acids and bases. Water is neutral and has a pH of 7.0. Acidic solutions have more H^+ and have pH values lower than 7. Basic solutions have more OH^- and have pH values higher than 7. To maintain homeostasis, H^+ levels must be controlled. **Buffers** are mixtures that can react with acids or bases to keep the pH within a certain range.

Picture This

6. Determine which solutions are acidic and which are basic. Draw a circle around the buffer.

Examples	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Battery acid															
Stomach acid															
Lemon juice, vinegar															
Orange juice, cola															
Tomatoes															
Bananas															
Normal rainwater															
Urine, healthy lake															
Pure water															
Blood, tears															
Seawater															
Baking soda															
Great Salt Lake															
Household ammonia															
Soapy water															
Oven cleaner															
Sodium hydroxide (NaOH)															

← Increasingly acidic Neutral Increasingly basic →

● Before You Read

You have probably heard about DNA—the “genetic code.” On the lines below, describe what you think DNA does. Then read the section to learn about DNA and the other compounds that make up all living things.

MAIN Idea

Organisms are made up of carbon-based molecules.

What You'll Learn

- the four major families of biological macromolecules
- the functions of each group of biological macromolecules

● Read to Learn

Organic Chemistry

Almost all biological molecules contain the element carbon. For this reason, all life is considered carbon-based. Organic chemistry is the study of organic compounds—the compounds that contain carbon.

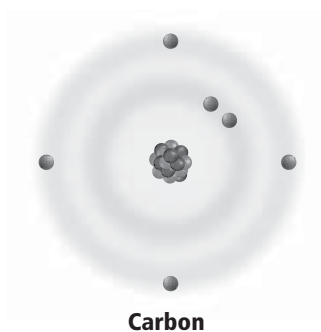
In the figure below, notice that carbon has four electrons in its outer energy level. Recall that the second energy level can hold eight electrons. Therefore, a carbon atom can form four covalent bonds with other atoms. Carbon atoms can bond with each other, forming a variety of organic compounds. These organic compounds can take the form of straight chains, branched chains, and rings, as illustrated in the figure below. Carbon compounds are responsible for the diversity of life on Earth.

Study Coach

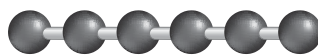
Make an Outline Make an outline of the information you learn in this section. Start with the headings. Include the boldface terms.

Picture This

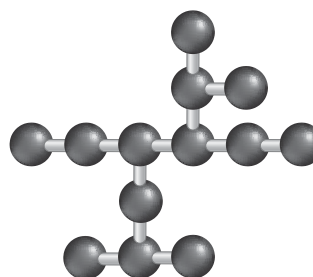
- 1. Calculate** What percentage of the carbon atom's second energy level is filled?
-



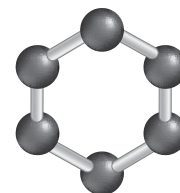
Straight chain molecules



Branched molecules



Ring molecules



Picture This

2. Draw Conclusions

To what group of macromolecules do you think DNA belongs?

Applying Math

3. Calculate If a monosaccharide has four carbon atoms, how many hydrogen atoms does it have?

Macromolecules

Macromolecules are large molecules that are formed by joining smaller organic molecules together. Macromolecules are also called polymers. **Polymers** are made from repeating units of identical or nearly identical compounds called monomers. The monomers are linked together by a series of covalent bonds.

The four major groups of biological macromolecules are carbohydrates, lipids, proteins, and nucleic acids. The table below summarizes the functions of each group.

Biological Macromolecules	
Group	Function
Carbohydrates	<ul style="list-style-type: none">• stores energy• provides structural support
Lipids	<ul style="list-style-type: none">• stores energy• provides steroids• waterproofs coatings
Proteins	<ul style="list-style-type: none">• transports substances• speeds reactions• provides structural support• provides hormones
Nucleic acids	<ul style="list-style-type: none">• stores and communicates genetic information

What roles do carbohydrates play in biology?


Carbohydrates are composed of carbon, hydrogen, and oxygen with a ratio of one oxygen and two hydrogen atoms for each carbon atom: CH_2O . Short chains of carbohydrates are monosaccharides (mah nuh SA kuh ridz), or simple sugars. A disaccharide (di SA kuh rid) is two monosaccharides linked together. Longer carbohydrate chains are called polysaccharides.

Carbohydrates serve as energy sources for organisms. Also, carbohydrates provide structural support in the cell walls of plants and in the hard shells of shrimp, lobsters, and some insects.

What is the main function of lipids?

Lipids are molecules made mostly of carbon and hydrogen. Fats, oils, and waxes are all lipids. The main function of lipids is to store energy. A lipid called a triglyceride (tri GLIH suh rid) is a fat when solid and an oil when liquid. Plant leaves are coated with lipids called waxes to prevent water loss.

Saturated and Unsaturated Fats When the carbon atoms in a fat cannot bond with any more hydrogen atoms, the fat is a saturated fat. The carbon atoms of unsaturated fats can bond with more hydrogen atoms.

Phospholipids A lipid called a phospholipid is responsible for the structure and function of the cell membrane. Lipids do not dissolve in water. This characteristic enables lipids to serve as barriers in biological membranes. 

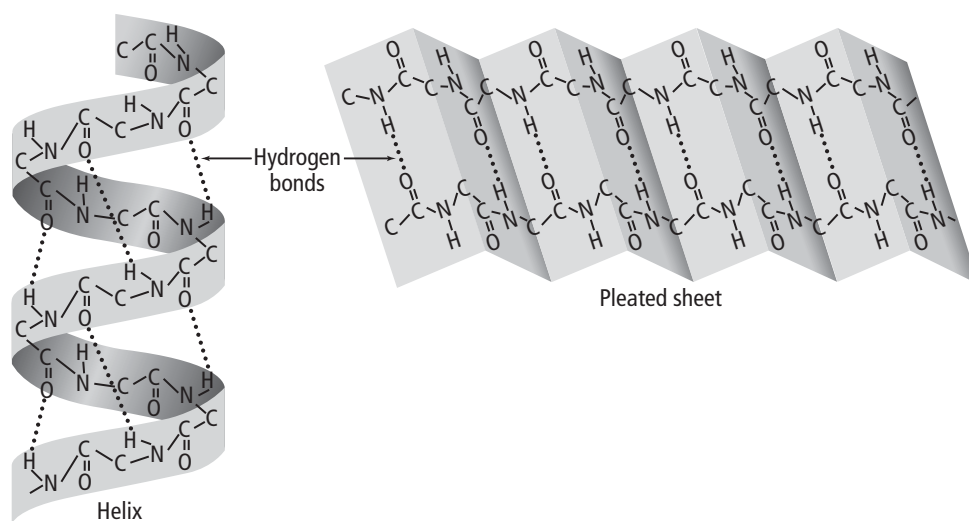
Steroids Cholesterol and hormones are types of steroids, another group of lipids. In spite of its bad reputation, cholesterol provides the starting point for other important lipids, such as the hormones estrogen and testosterone.

What compounds make up proteins?

A **protein** is made of small carbon compounds called amino acids. **Amino acids** are made of carbon, nitrogen, oxygen, hydrogen, and sometimes sulfur.

Amino Acids There are 20 different amino acids. Proteins are made of different combinations of all 20 amino acids. Covalent bonds called peptide bonds join amino acids together to form proteins.

Protein Structure A protein's amino acid chain folds into a three-dimensional shape. The figure below shows two basic protein shapes—the helix and the pleat. A protein might contain many helices, pleats, and folds. Hydrogen bonds help the protein hold its shape.



Reading Check

4. Identify the key characteristic of lipids that enables them to keep unwanted substances from penetrating cell membranes.

Picture This

5. Label Add these descriptive labels to the appropriate protein shape in the figure: *folded paper* and *spiral*.

Think it Over

6. Draw Conclusions

What protein function listed here suggests that most enzymes are proteins?

Protein Function Proteins are involved in nearly every function of your body. Your muscles, skin, and hair are made of proteins. Your cells contain about 10,000 different proteins that serve many functions. They

- provide structural support;
- transport substances inside the cell and between cells;
- communicate signals within the cell and between cells;
- speed up chemical reactions;
- control cell growth.

What roles do nucleic acids play in organisms?

Nucleic acids are the fourth group of biological macromolecules. **Nucleic acids** are complex macromolecules that store and transmit genetic information. Repeating subunits, called **nucleotides**, make up nucleic acids.

Nucleotides are composed of carbon, nitrogen, oxygen, phosphorus, and hydrogen. All nucleotides have the three units shown in the figure below—a phosphate, a nitrogenous base, and a sugar.

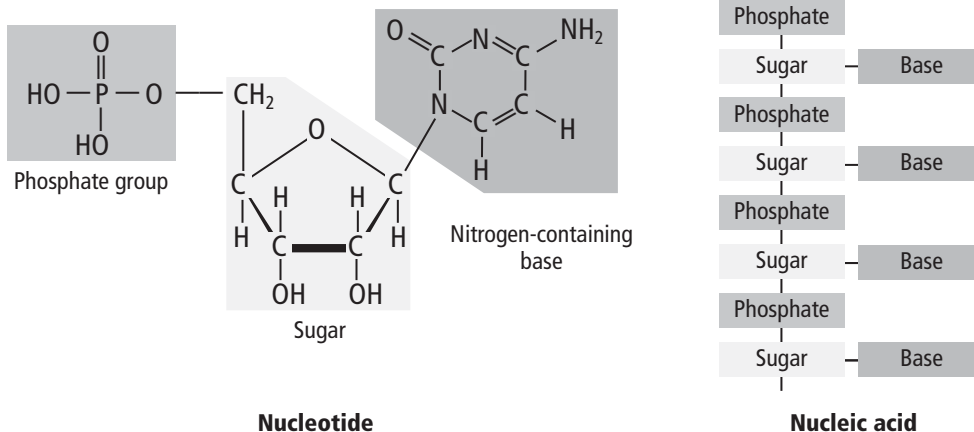
To form a nucleic acid, the sugar of one nucleotide bonds to the phosphate of another nucleotide, as illustrated in the figure on the right. The nitrogenous base sticks out from the chain. It is available to bond with bases in other nucleic acids.

Two types of nucleic acids are found in living things. One is deoxyribonucleic (dee AHK sih rib oh noo klay ihk) acid, or DNA. The other is ribonucleic (rib oh noo KLAY ihk) acid, or RNA.

DNA is the “genetic code.” DNA stores all the instructions for organisms to grow, reproduce, and adapt. The main function of RNA is to use the information stored in DNA to make proteins.

Picture This

7. Circle each nucleotide grouping in the nucleic acid on the right of the figure.



Cellular Structure and Function

section 1 Cell Discovery and Theory

● Before You Read

Have you ever looked at anything through a magnifying glass or a microscope? Describe on the lines below how the magnifying glass or microscope changed the object. In this section you will learn about some important discoveries made using microscopes.

MAIN Idea

The microscope led to the discovery of cells.

What You'll Learn

- the principles of the cell theory
- how compound light microscopes differ from electron microscopes
- how prokaryotic and eukaryotic cells differ

● Read to Learn


History of the Cell Theory

A **cell** is the basic structural and functional unit of all living things. The human body consists of trillions and trillions of cells. But cells are too small to see with the human eye. The invention of the microscope allowed scientists to discover that cells existed.

In 1665, an English scientist named Robert Hooke made a simple microscope. He used the microscope to look at a piece of cork, which is the dead cells of oak bark. Hooke saw small, box-shaped structures in the cork, which he called *cellulae*. Today, we call them cells.

In the late 1600s, Anton van Leeuwenhoek (LAY vun hook), a Dutch scientist, made another microscope. He examined pond water, milk, and other substances. He was surprised to find living organisms in these substances.

What discoveries led to the cell theory?

In 1838, German scientist Matthias Schleiden studied plants under microscopes. He concluded that all plants are composed of cells. Another German scientist, Theodor Schwann, declared that animal tissues were made up of cells. 

Mark the Text

Focus As you read, underline or highlight the main ideas in each paragraph.

Reading Check

1. **Compare** What is one thing that plants and animals have in common?

Picture This

- 2. Highlight** the principle in the cell theory that resulted from the discoveries of Matthias Schleiden and Theodor Schwann.

Picture This

- 3. Calculate** If each lens in this example magnified the image 20 \times , what is the total magnification? (Show your work.)

What is the cell theory?

Scientists continued to learn more about cells. Scientist Rudolf Virchow proposed that cells divide to form new cells. He suggested that every cell came from a cell that already existed. The observations and ideas of the various scientists who studied cells are summarized as the cell theory. The **cell theory** is a fundamental idea of modern biology and includes the principles listed in the table below.

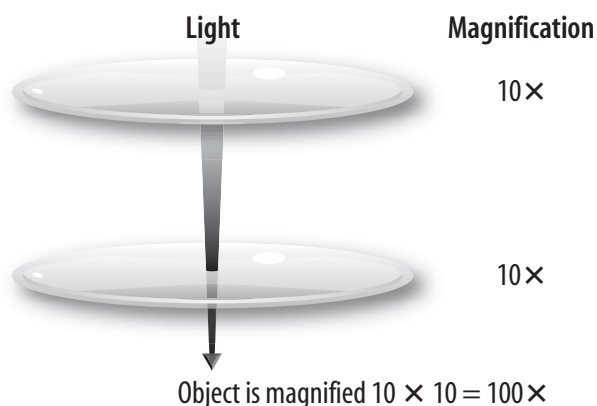
The Cell Theory	
Principle	Explanation
1. All living organisms are made up of one or more cells.	An organism can have one or many cells. Most plants and animals have many cells.
2. The cell is the basic unit of organization in living organisms.	Even in complex organisms such as humans, the cell is the basic unit of life.
3. All cells come from cells. Cells pass copies of their genetic material on to their daughter cells.	Cells contain hereditary information that passes from cell to cell during cell division.

Microscope Technology

The development of the microscope made the discovery of cells possible. Improvements made to early microscopes have helped scientists learn much more about cells.

What is a compound light microscope?

The modern compound light microscope uses a series of glass lenses to magnify, or enlarge, an object. When visible light passes through each lens, it magnifies the image of the previous lens. For example, two lenses that each magnify an image 10 \times result in a microscope that magnifies the object 100 \times , as shown in the figure below.



What is an electron microscope?

The best compound light microscopes only magnify an image about 1000 \times . Scientists needed more powerful microscopes to learn more about cells. The electron microscope was invented in the 1940s. It doesn't use lenses. Instead, the transmission electron microscope (TEM) uses magnets to aim a beam of electrons at the image to be magnified. Some TEMs can magnify an image 500,000 \times .

The scanning electron microscope (SEM) was a further improvement in technology. It produces a three-dimensional image of the cell. One problem with the TEM and SEM is that only nonliving cells can be examined. A more recent invention, the scanning tunneling electron microscope (STM), can magnify living cells.

Basic Cell Types

Cells have different sizes, shapes, and functions, but all cells have a plasma membrane. A **plasma membrane** is a boundary that helps control what enters and leaves the cell.

Some basic functions are common to most cells. For example, most cells have some form of genetic material that provides instructions for making substances that the cell needs. In addition, all cells break down molecules to generate energy for metabolism.

What are the two categories of cells?

Scientists group cells into two broad categories based on their internal structures. These categories are prokaryotic cells and eukaryotic cells.

Simple cells that have no specialized structures are known as **prokaryotic** (pro kar ee AW tik) **cells**. Cell functions in these simple cells occur in the plasma membrane. Most unicellular organisms, such as bacteria, are prokaryotic cells. Thus, they are called prokaryotes. Prokaryotic cells are believed to be similar to the first cells on Earth.

Eukaryotic (yew kar ee AW tik) cells are the other category of cells. They are usually larger and more complex. **Eukaryotic cells** contain a nucleus and other structures called organelles. **Organelles** are specialized structures that carry out specific functions. The **nucleus** contains the genetic material for the cell. Organisms that are made up of eukaryotic cells are called eukaryotes. Eukaryotes can be unicellular or multicellular.



Think it Over

4. Draw Conclusions

What is an advantage of viewing living cells?



Think it Over

5. Compare

Which cells are more complex? (Circle your answer.)

- a. prokaryotic cells
- b. eukaryotic cells

Cellular Structure and Function

section 2 The Plasma Membrane

MAIN Idea

A cell's plasma membrane helps maintain homeostasis.

What You'll Learn

- how the cell's plasma membrane functions
- the role of proteins, carbohydrates, and cholesterol in the plasma membrane

Mark the Text

Make Flash Cards Make a flash card for each question heading in this section. On the back of the flash card, write the answer to the question. Use the flash cards to review what you have learned.

Picture This

- 1. Highlight** the items in the figure that enter the cell through the plasma membrane. Circle the items that exit the cell.

Before You Read

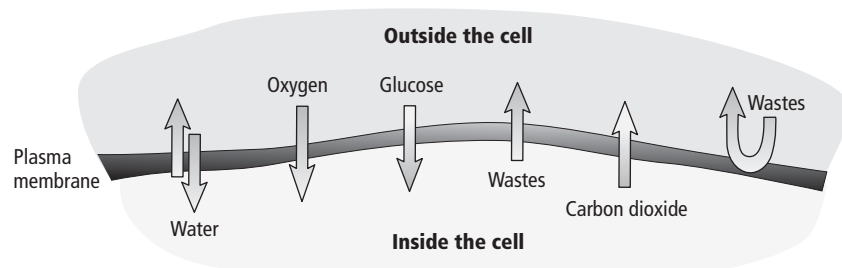
A window screen in your home allows air to pass through while keeping insects out. In this section, you will learn about a cell structure that has the same basic function. On the lines below, list some things you think would be allowed to pass into a cell and some things that would be kept out.

Read to Learn

Function of the Plasma Membrane

A cell's survival depends on maintaining balance, called homeostasis. The plasma membrane is the cell structure primarily responsible for homeostasis. It is the thin, flexible boundary between the cell and its watery environment. Nutrients enter the cell and wastes leave the cell through the plasma membrane.

Selective permeability (pur mee uh BIH luh tee) of the plasma membrane allows some substances to pass through while keeping others out. The figure below shows selective permeability of the cell's plasma membrane. The arrows show common substances that enter and leave the cell. The plasma membrane controls how, when, and how much of these substances enter and leave the cells.



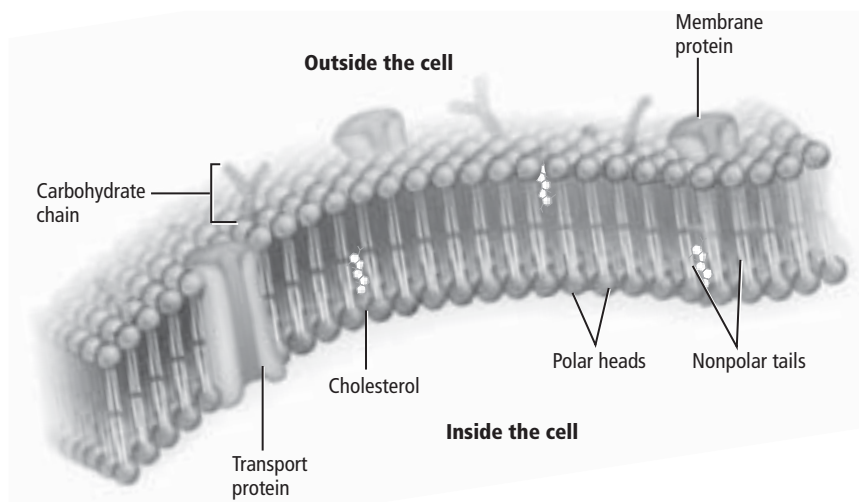
Structure of the Plasma Membrane

You have learned that lipids are large molecules made up of glycerol and three fatty acids. A phospholipid (fahs foh LIH pid) is made up of glycerol, two fatty acids, and a phosphate group. The plasma membrane is made up of two layers of phospholipids arranged tail-to-tail in what is called a **phospholipid bilayer**. The phospholipid bilayer allows the plasma membrane to survive and function in its watery environment. ✓

What is the structure of the phospholipid bilayer?

Each phospholipid has a polar head and two nonpolar tails. The phosphate group in the phospholipid makes it polar. The polar head is attracted to water because water is also polar. The nonpolar tails, made of the fatty acids, are repelled by water.

The phospholipid bilayer is arranged so that the polar heads can be closest to the water that is inside and outside the cell. Likewise, the nonpolar tails are farthest from the water because they are inside the phospholipid bilayer, as shown in the figure below. This bilayer structure is important for the formation and function of the plasma membrane.



How does the phospholipid bilayer function?

The phospholipid bilayer forms a barrier that is polar on the surface and nonpolar in the middle. Substances that can dissolve in water will not pass through the plasma membrane because they are stopped by the nonpolar middle. This allows the plasma membrane to separate the environment inside the cell from the environment outside the cell.

✓ Reading Check

2. Explain the purpose of the phospholipid bilayer.

Picture This

3. Identify Circle one phospholipid. Label its head and tails.

 **Reading Check**

4. Define the role of transport proteins.


 **Reading Check**

5. Name three substances that move among the phospholipids of the plasma membrane.

What else is found in the plasma membrane?

Cholesterol, proteins, and carbohydrates move among the phospholipids in the plasma membrane. Proteins are found on both the inner surface and the outer surface of the plasma membrane. Proteins on the outer surface are called receptors because they send signals to the inside of the cell. Proteins on the inner surface anchor the plasma membrane to the cell's internal support structure. These proteins give the cell its shape.

What are transport proteins?

Proteins also create tunnels through the plasma membrane. These proteins, known as **transport proteins**, move needed substances or waste materials through the plasma membrane. Transport proteins contribute to the selective permeability of the plasma membrane. 


How does cholesterol help cells?

Cholesterol molecules are nonpolar. They move among the tails of the phospholipids. Cholesterol helps prevent the fatty-acid tails from sticking together, keeping the plasma membrane fluid. Cholesterol also helps maintain homeostasis in a cell.

What substances help identify chemical signals?

Carbohydrates and proteins might stick out from the plasma membrane. They help the cell identify chemical signals from the environment. For example, carbohydrates in the plasma membrane might help disease-fighting cells identify and attack a potentially harmful cell.

What is the fluid mosaic model?

All the components of the plasma membrane are in constant motion. Phospholipids can move sideways within the plasma membrane. Proteins, carbohydrates, and cholesterol molecules move among the phospholipids. 

The phospholipid bilayer creates a sea in which all the other molecules float. As the individual molecules move around, a pattern, or mosaic, is formed on the surface of the plasma membrane. This organization of the plasma membrane is called the **fluid mosaic model**. It is fluid because the molecules are moving and being rearranged. It is called a mosaic because scientists can observe clear patterns on the surface of the plasma membrane.

● Before You Read

For cells to function correctly, each part must do its job. Members of families have jobs that help the whole family. On the lines below, list your family members and their jobs.

MAIN Idea

The eukaryotic cell contains organelles.

What You'll Learn

differences in the structures of plant and animal cells


● Read to Learn

Cytoplasm and Cytoskeleton

The environment inside the plasma membrane is a semifluid material called **cytoplasm**. Scientists once thought the organelles of eukaryotic cells floated freely in the cell's cytoplasm. As technology improved, scientists discovered more about cell structures. They discovered a structure within the cytoplasm called the cytoskeleton. The **cytoskeleton** is a network of long, thin protein fibers that provide an anchor for organelles inside the cell. The cell's shape and movement depend on the cytoskeleton.

Two types of protein fibers make up the cytoskeleton. Microtubules are long, hollow protein cylinders that form a firm skeleton for the cell. They assist in moving substances within the cell. Microfilaments are thin protein threads that help give the cell shape and enable the entire cell or parts of the cell to move.

Cell Structures

All chemical processes of a typical eukaryotic cell take place in the organelles, which move around in the cell's cytoplasm. Proteins are produced, food is transformed into energy, and wastes are processed in the organelles. Each organelle has a unique structure and function. 

Mark the Text

Identify the Parts Highlight each cell structure as you read about it. Underline the function of each part.

Reading Check

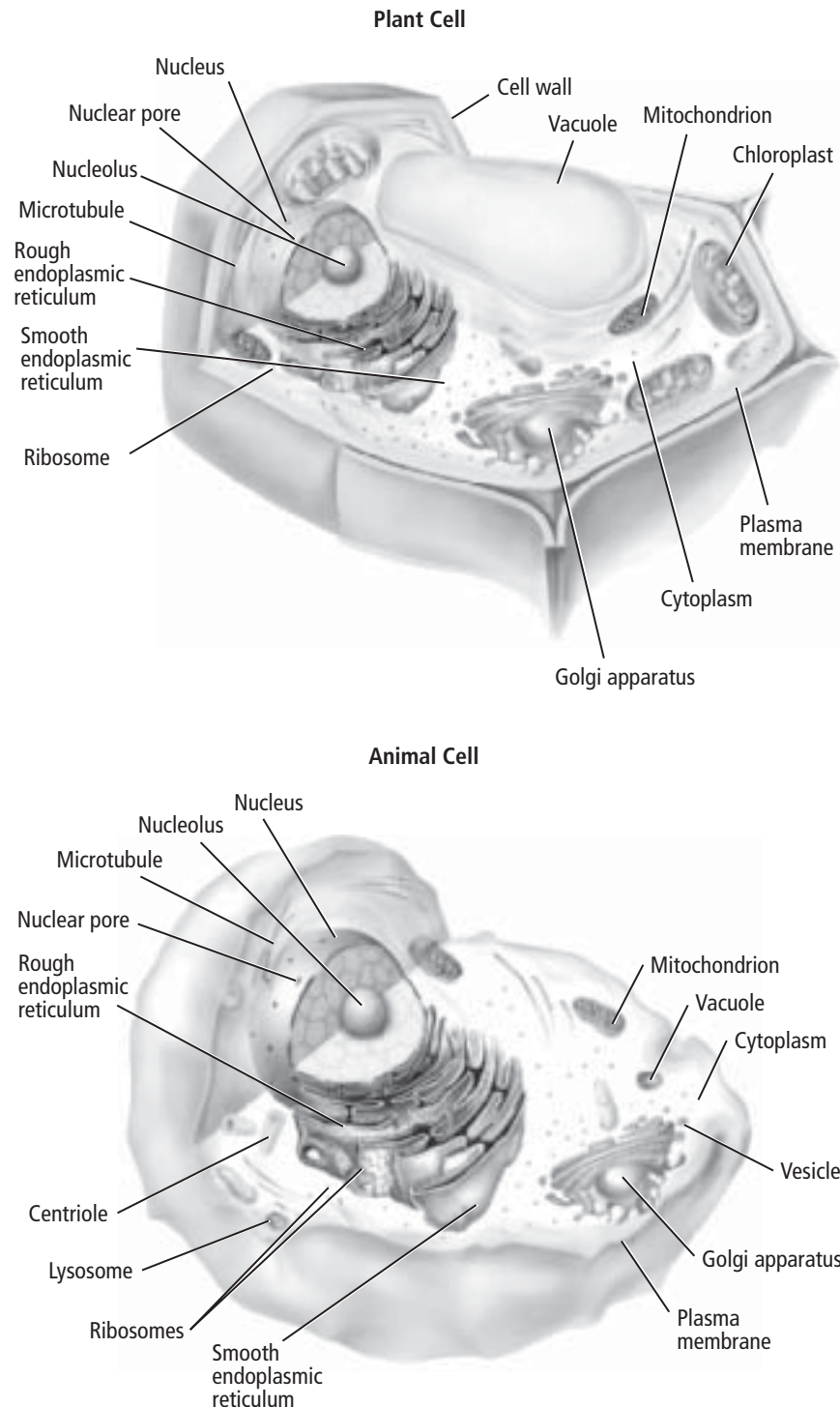
- Name** one cell function that takes place in organelles.

How are plant and animal cells different?

The figure below shows a typical plant cell and a typical animal cell. Note how many organelles are found in both types of cells. Also, note a few differences, such as the chloroplast that appears only in the plant cell. Observe that the vacuole in the plant cell is much larger than the vacuole in the animal cell.

Picture This

2. Highlight the names of structures found in both plant cells and animal cells. Circle the names of structures that are found only in animal cells. Underline the names of structures that are found only in plant cells.



What structure manages cell processes?

The nucleus is the cell's managing structure. Most of the cell's DNA is in the nucleus. DNA defines the cell and controls protein production. A nuclear envelope surrounds the nucleus. Substances pass through the nuclear envelope to move in and out of the nucleus. ✓

Which organelle produces proteins?

Ribosomes produce proteins and are made of two components—RNA and protein. Ribosomes are produced in the **nucleolus**, a structure located inside the nucleus. Some ribosomes float freely in the cytoplasm. They produce proteins that will be used by other cells. Other ribosomes attach to an organelle called the endoplasmic reticulum.

What attaches to rough endoplasmic reticulum?

The **endoplasmic reticulum**, (en duh PLAZ mihk • rih TIHK yuh lum) also called ER, is a membrane system of folded sacs and channels to which ribosomes are attached. There are two types of ER. The first type is called rough endoplasmic reticulum. This is the area where ribosomes attach to the ER's surface. The ribosomes appear to create bumps or rough places on the membrane. The second type, smooth endoplasmic reticulum, has no ribosomes attached. Smooth ER produces complex carbohydrates and lipids.

What is the purpose of the Golgi apparatus?

Once proteins are created, they move to another organelle, the Golgi (GAWL jee) apparatus. The **Golgi apparatus** modifies, sorts, and packs the proteins into sacs called vesicles. The vesicles fuse with the cell's plasma membrane. There the vesicles release the proteins, which move through the plasma membrane to the environment outside the cell.

What is stored in vacuoles?

Cells have vesicles called **vacuoles** that act as temporary storage for materials in the cytoplasm. Vacuoles can store food and other material needed by a cell. They can also store wastes. Plant cells normally have one large vacuole. Animal cells might or might not have a few small vacuoles.

What are lysosomes?

Lysosomes are vesicles that contain substances that digest excess or worn-out organelles and food particles. Lysosomes also digest bacteria and viruses that enter the cell.

✓ Reading Check

3. Explain What is the role of DNA?

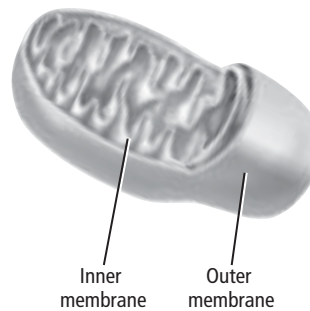
What makes up a centriole?

Centrioles are organelles made of microtubules that function during cell division. They usually are found near the nucleus of the cell. Plant cells do not contain centrioles.

Which organelle produces energy?

Cells need energy to survive. The organelles that convert fuel particles such as sugars into usable energy are called **mitochondria** (mi tuh KAHN dree uh). A mitochondrion has an outer membrane and an inner membrane with many folds, as shown in the figure below. The membrane provides a large surface area for breaking the bonds of sugar molecules. Energy is produced when the bonds are broken.

Mitochondrion



Picture This

4. Explain why the inner membrane has many folds.

How do plant and animal cells differ?

In addition to mitochondria, plant cells contain chloroplasts. **Chloroplasts** are organelles that capture light energy and convert it to chemical energy through a process called photosynthesis. Plants can use light energy from any light source—usually solar. Animal cells do not have chloroplasts and cannot use the Sun’s energy as fuel for cell processes.

Plants also have cell walls. The **cell wall** is a mesh of fibers that surrounds the plasma membrane. It protects and supports the cell. Plant cell walls are made of a carbohydrate known as cellulose.

What are cilia and flagella?

Some animal cell surfaces have cilia or flagella that extend beyond the plasma membrane. **Cilia** are short projections that look like hairs. They move back and forth, similar to the motion of the oars of a rowboat. **Flagella** are longer projections that move in a whiplike motion. Both cilia and flagella are composed of microtubules. They move cells through their watery environments. Cilia also move substances along the surface of the cell.



Think it Over

5. Recall What is another function of microtubules?

Comparing Cells

The table below summarizes the structures of eukaryotic plant and animal cells. The function of each structure is described. Note that prokaryotic cells lack most of the organelles found in eukaryotic cells.

Picture This

6. **Highlight** the organelle to which ribosomes attach.

Cell Structure	Function	Present in Plant/Animal Cells
Cell wall	protects and supports plant cells	plant cells only
Centriole	important in cell division	animal cells only
Chloroplast	site where photosynthesis occurs	plant cells only
Cilia	aids in moving the cell and moving substances along the surface of the cell	some animal cells
Cytoskeleton	a framework for the cell within the cytoplasm	both
Endoplasmic reticulum (ER)	site of protein synthesis; where ribosomes attach	both
Flagellum	aids in moving and feeding the cell	some animal cells
Golgi apparatus	modifies and packages proteins for distribution outside the cell	both
Lysosome	breaks down excess or worn-out substances in the cell	animal cells only
Mitochondrion	supplies energy to the rest of the cell	both
Nucleus	directs the production of proteins and cell division	both
Plasma membrane	controls the movement of substances in and out of the cell	both
Ribosome	produces proteins	both
Vacuole	stores materials temporarily	plant cell—one large; animal cell—a few small

Organelles at Work

The structures in the cell work together to perform cell functions. The synthesis of proteins is a major cell function, which begins in the nucleus. Protein synthesis continues with the ribosomes on the rough ER and the ribosomes that float freely in the cytoplasm. Most proteins made on the rough ER are sent to the Golgi apparatus. There they are packaged in vesicles and sent to other organelles or out of the cell. Like each member of a soccer team, each cell structure has a specific task to do to make the cell function properly.

Reading Check

7. **Identify** a major cell function.

Cellular Structure and Function

section 4 Cellular Transport

MAIN Idea

Cellular transport moves substances in and out of a cell.

What You'll Learn

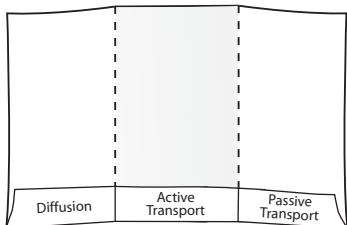
- the process of diffusion, facilitated diffusion, and active transport
- effect of hypotonic, hypertonic, or isotonic solutions on a cell
- how large particles enter and exit a cell

Mark the Text

Create a Quiz As you read this section, write quiz questions based on what you have learned. After you write the questions, answer them.

FOLDABLES™

Record Information Make a three-pocket Foldable from an 11 × 17 sheet of paper. As you read, record information about cellular transport on quarter sheets of notebook paper and store them in the appropriate pocket.



● Before You Read

Describe on the lines below how you would move a large box that weighs more than you do. Then read the section to learn how large particles move in and out of cells.

● Read to Learn

Diffusion

Substances dissolved in water move constantly and randomly. Imagine you place a drop of red ink on the left side and a drop of blue ink on the right side of a dish of water. The ink moves randomly through the water and turns the water purple as the colors mix. The ink has diffused in the water. **Diffusion** is the net movement of particles from an area where there are more particles of the substance to an area where there are fewer particles. Diffusion does not require additional energy because the particles are already in motion.

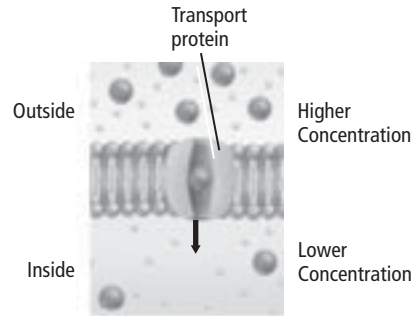
Concentration is the amount of a substance in an area. Diffusion continues until the concentrations are the same in all areas of the water. The dish of water has reached **dynamic equilibrium**, in which the particles continue to move randomly, but the overall concentration does not change.

What affects the rate of diffusion?

Concentration, temperature, and pressure affect the rate of diffusion. Diffusion occurs more quickly when the concentration, temperature, or pressure are high because the particles collide more often. The size and charge of a substance also affects the rate of diffusion.

What is facilitated diffusion?

Water can diffuse across the plasma membrane. However, other ions and molecules that cells need to function cannot diffuse across the plasma membrane. Molecules such as sugars and chlorine need help to move from outside the cell's environment to inside the cell. **Facilitated diffusion** uses transport proteins to help move some ions and small molecules across the plasma membrane. One type of facilitated diffusion is shown in the figure below.



Diffusion of water and facilitated diffusion of ions and small molecules occur without additional energy because the particles are already moving. When no energy is added, the transport is referred to as passive transport.


Osmosis: Diffusion of Water

Water passes in and out of the cell through the plasma membrane. The diffusion of water across a selectively permeable membrane is called **osmosis** (ahs MOH sus). Osmosis helps the cell maintain homeostasis.

What is the result of osmosis?

Most cells undergo osmosis because they are surrounded by watery solutions. These solutions have different concentrations than the inside environment of the cell. Before osmosis, the concentration inside and outside the cell have not reached dynamic equilibrium. After osmosis, the concentrations are the same on both sides of the membrane, and dynamic equilibrium has been reached.

What happens to a cell in an isotonic solution?

A cell in an **isotonic solution** has the same concentration in its cytoplasm as its surrounding watery environment. Water continues to move through the plasma membrane, but water enters and leaves the cell at the same rate. The cell is at equilibrium with its surrounding environment. 

Picture This

- 1. Explain** Use this figure to explain facilitated diffusion to a partner.

Reading Check

- 2. Explain** Why is the cell at equilibrium in an isotonic solution?

✓ Reading Check

3. Analyze Why does water move into a cell placed in a hypotonic solution?

How do hypotonic solutions and hypertonic solutions differ?

If a cell is placed in a solution that has a lower concentration of dissolved substances, the cell is in a **hypotonic solution**. There is more water outside the cell than inside the cell. Osmosis moves water into the cell. ✓

As water moves into an animal cell, the plasma membrane swells. If the solution is too hypotonic, pressure builds inside the cell, and it might burst.

In a plant cell, the cell wall keeps it from bursting. As the central vacuole fills with water, the plasma membrane pushes against the cell wall. The plant cell becomes firmer.

In a **hypertonic solution**, the concentration of dissolved substances outside the cell is higher than inside. There is more water inside the cell. During osmosis, more water moves out of the cell than into it. Animal cells shrink in hypertonic solutions. The loss of water in plant cells causes wilting.

Active Transport

Substances might need to move from an area of lower concentration to an area of higher concentration. Transport proteins help move substances across the plasma membrane against the normal flow. This movement against the normal flow requires energy and is called **active transport**.

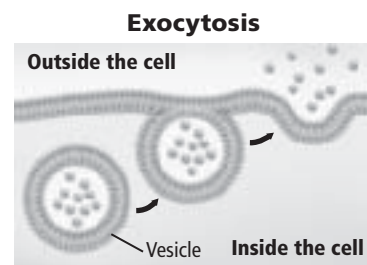
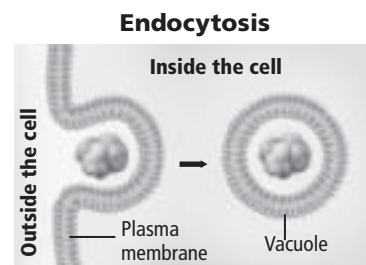
Transport of Large Particles

Some substances are too large to move by diffusion or active transport. **Endocytosis** is the process by which a cell surrounds a substance in the outside environment with a portion of the plasma membrane, then pinches off the substance, leaving it inside the cell.

Exocytosis is the process by which large substances exit the cell. Both processes, as shown in the figure below, require energy. As with other forms of transport, endocytosis and exocytosis help cells maintain homeostasis.

Picture This

4. Label the cell structure through which substances pass as they leave the cell during exocytosis.



Cellular Energy

section 1 How Organisms Obtain Energy

● Before You Read

Think about the objects in your home that use energy. On the lines below, describe the ways that these objects get energy. Then read about how organisms obtain energy.

MAIN Idea

All living organisms use energy to carry out all biological processes.

What You'll Learn

- the two laws of thermodynamics
- the difference between autotrophs and heterotrophs
- how ATP works in a cell

● Read to Learn

Transformation of Energy

Cells need energy. They need energy to move molecules across membranes and to make and break down molecules.

Energy is the ability to do work. **Thermodynamics** is the study of how energy flows and changes in the universe.

What are the laws of thermodynamics?

Two laws of thermodynamics explain the flow of energy. The first law of thermodynamics states that energy can change form, but it cannot be created or destroyed. For example, your body changes the energy in food into chemical energy. Also, when you run, your body changes the energy into mechanical energy. ☑

The second law of thermodynamics states that systems change from states of order to states of disorder on their own. This disorder is known as entropy (EN truh pee). Entropy is always increasing. This means that when your body changes forms of energy, some of the energy is lost as heat. The energy is still present, but it can no longer be used.

Nearly all the energy for life on Earth comes from the Sun. Some organisms make their own food. Some autotrophs use inorganic substances as a source of energy. Other autotrophs change light energy from the Sun into chemical energy. Plants and some bacteria are autotrophs.

Study Coach

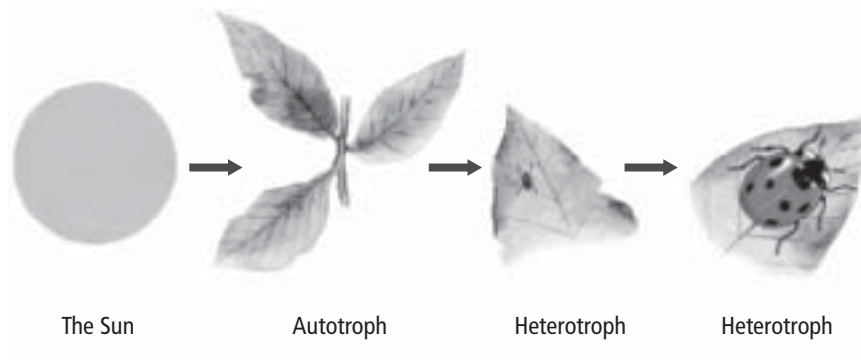
Create a Quiz After you read this section, create a quiz based on what you have learned. Then be sure to answer the quiz questions.

Reading Check

1. **State** the first law of thermodynamics.

Picture This

2. **Circle** the name of the organism that makes its own food.



Metabolism

All of the chemical reactions that go on inside a cell are known as the cell's **metabolism**. A series of reactions in which the product of one reaction becomes the reactant for the next reaction is called a metabolic pathway.

What are the two metabolic pathways?

There are two types of metabolic pathways: catabolic (ka tuh BAH lik) pathways and anabolic (a nuh BAH lik) pathways. In catabolic pathways, energy is released by breaking larger molecules into smaller molecules. In anabolic pathways, the energy released by catabolic pathways is used to build larger molecules from smaller molecules.

Energy flows between the metabolic pathways of organisms in an ecosystem. Photosynthesis is an anabolic pathway. Cellular respiration is a catabolic pathway. These pathways work together to meet the energy needs of cells.

How is energy changed during photosynthesis?

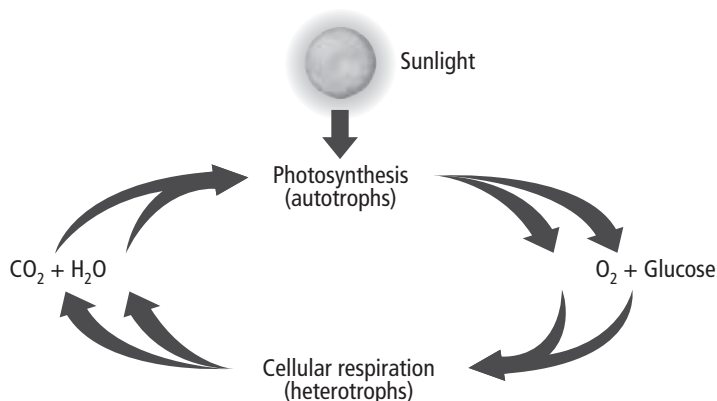
Photosynthesis is a series of reactions that change light energy from the Sun into chemical energy that can be used by the cell. During photosynthesis, light energy, carbon dioxide, and water are changed into organic molecules and oxygen. The energy stored in organic molecules made during photosynthesis can be passed to other organisms. When an animal eats a plant, the plant's stored energy is passed to the animal.

Reading Check

3. **Compare** the energy usage in anabolic and catabolic pathways.

What happens during cellular respiration?

Cellular respiration is a series of reactions that break down organic molecules into carbon dioxide, water, and energy. The energy is used by the cell. The processes of cellular respiration and photosynthesis form a cycle, which is shown in the figure below. The products of photosynthesis are the reactants for cellular respiration, and the products of cellular respiration are the reactants for photosynthesis.



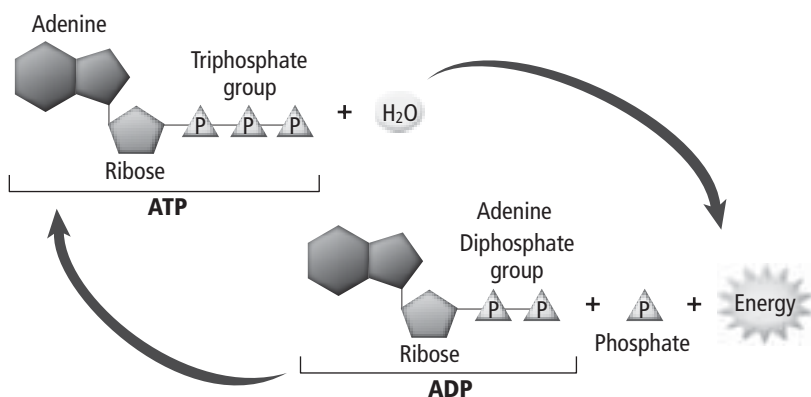
ATP: The Unit of Cellular Energy

Cells store chemical energy in biological molecules. The most important biological molecule is **adenosine triphosphate** (uh DEN uh seen • tri FAHS fayt), or **ATP**.

How does ATP store energy?

ATP is the most abundant energy-storing molecule. It is found in all kinds of organisms. The structure of ATP is shown below. It is made of an adenine base, a ribose sugar, and three phosphate groups.

ATP releases energy when the bond between the second and third phosphate groups is broken, forming a molecule called adenosine diphosphate (ADP). ADP can be changed back into ATP by adding a phosphate group.



Picture This

4. Identify Circle the step in the pathway where energy is captured.

Picture This

5. Identify Circle the high-energy bond that is broken when ATP is converted to ADP.

Cellular Energy

section 8 Photosynthesis

MAIN Idea

Light energy is trapped and converted into chemical energy during photosynthesis.

What You'll Learn

- the two phases of photosynthesis
- how a chloroplast works during light reactions
- how electron transport works

Mark the Text

Identify Details As you read, highlight or underline the events of each stage of photosynthesis.

Reading Check

1. **Identify** one way cells can use glucose.

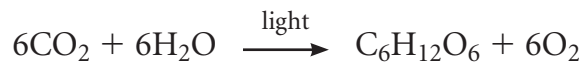
Before You Read

Plants change energy from sunlight into energy that is used by other living things. Describe on the lines below what would happen to life on Earth if plants suddenly disappeared. Then read about how plants use the Sun's energy.

Read to Learn

Overview of Photosynthesis

Photosynthesis is the process in which light energy from the Sun is changed into chemical energy. Nearly all life on Earth depends on photosynthesis. The chemical equation for photosynthesis is shown below.



Photosynthesis occurs in two phases. In phase one—the light-dependent reactions—light energy is absorbed and changed into chemical energy in the form of ATP and NADPH.

In phase two—the light-independent reactions—the ATP and NADPH that were formed in phase one are used to make glucose. Glucose can then be joined with other simple sugars to form larger molecules such as complex sugars and carbohydrates. Sugar can also be changed into other molecules needed by the cell, such as proteins, lipids, and nucleic acids.

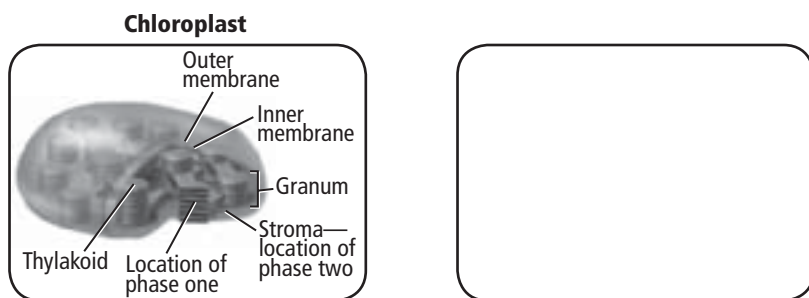
Phase One: Light Reactions

Plants have special organelles called chloroplasts to capture light energy. Photosynthesis begins when sunlight is captured. The captured energy is stored in two energy storage molecules—ATP and NADPH—that will be used in light-independent reactions.

What happens in chloroplasts?

Chloroplasts are large organelles that capture light energy from the Sun. They are found in plants and other photosynthetic organisms. The figure below shows a chloroplast.

A chloroplast is a disc-shaped organelle that contains two compartments. **Thylakoids** (THI la koyds) are flattened saclike membranes. The thylakoids are arranged in stacks called **grana**. The fluid-filled space outside the grana is the **stroma**. Phase one takes place in the thylakoids. Phase two takes place in the stroma.



What is the role of pigments in photosynthesis?

Thylakoids contain light-absorbing colored molecules known as **pigments**. Different pigments absorb different wavelengths of light. Chlorophylls are the major light-absorbing pigments in plants. They absorb energy from violet-blue light and reflect green light, giving plants their green color.

Accessory pigments help plants absorb additional light. For instance, carotenoids (kuh ROH tuh noyds) absorb blue and green light and reflect yellow, orange, and red light. Carotenoids give carrots and sweet potatoes their orange color.

Accessory pigments are the reason leaves change colors in autumn. In green leaves, there is so much chlorophyll that it masks the other pigments. In autumn, as trees prepare to lose their leaves, the chlorophyll molecules break down, revealing the colors of other pigments. The colors red, yellow, and orange can be seen. ✓



Think it Over

- 2. Name** Which organism has chloroplasts? (Circle your answer.)
- mushroom
 - oak tree
 - earthworm

Picture This

- 3. Illustrate** In the box, draw a picture of the thylakoid, grana, and stroma. Label the parts of your picture.

Reading Check

- 4. Explain** Why do the leaves of some trees change colors in autumn?

Reading Check

5. Describe Of what are photosystem I and photosystem II made?

Picture This

6. Identify On the figure, highlight the path that electrons follow. What molecule is the electron's final destination?

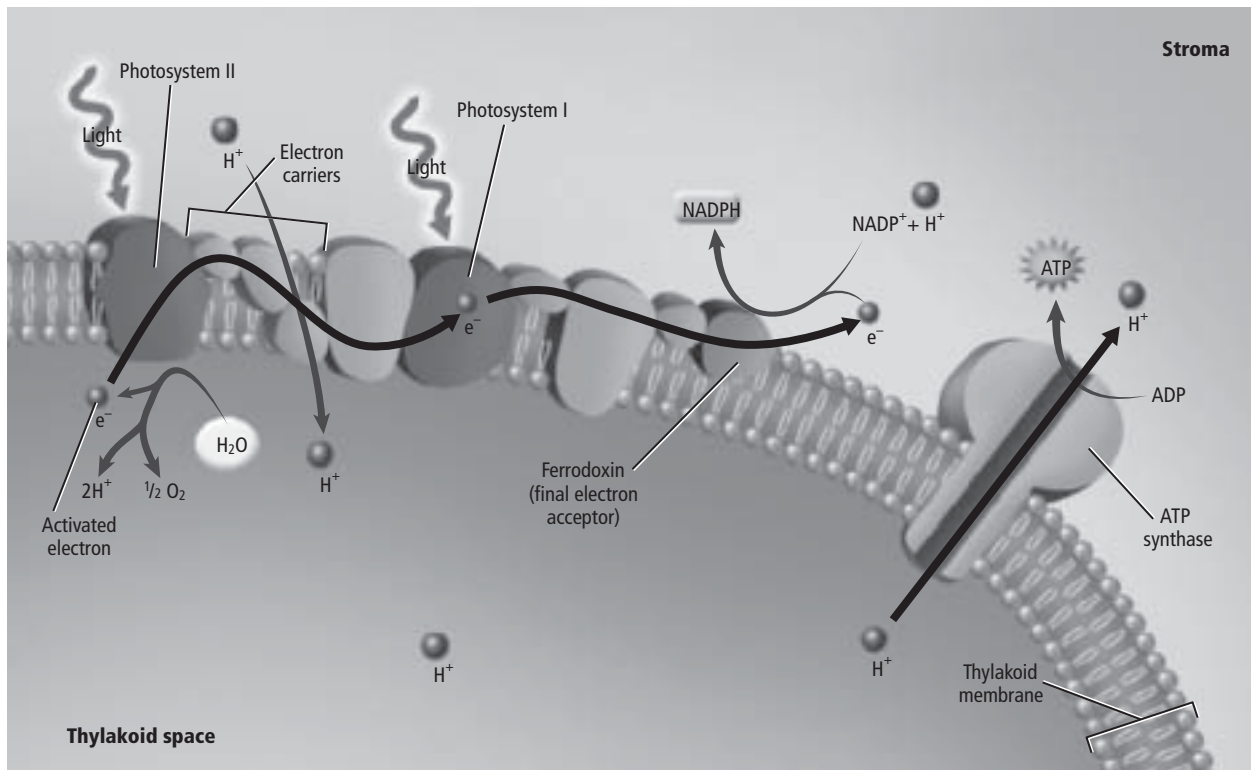
How does electron transport work?

Photosystem I and photosystem II are made of pigments that absorb light and proteins that are important in light reactions. They are in the thylakoid membrane. Follow along in the figure below as you read about their role in photosynthesis.

Photosynthesis begins when light energy causes electrons in photosystem II to go into a high energy state. The light energy also causes a water molecule to split, releasing an electron into the electron transport system, a hydrogen ion into the thylakoid space, and oxygen as a waste product. The excited electrons move from photosystem II and move along a series of electron-carriers to photosystem I. Photosystem I absorbs more light, and the excited electrons move along electron-carriers again. Finally, the electrons are moved to NADP⁺, forming the energy-storage molecule NADPH.

How is ATP made during photosynthesis?

ATP is made when light energy causes the water molecule to split into oxygen and two hydrogen ions (H⁺), or protons. Protons build up inside the thylakoid. Protons diffuse through ion channels into the stroma where the concentration is lower. These channels are enzymes called ATP synthases. As protons move into the stroma, ATP is formed.



Phase Two: The Calvin Cycle

NADPH and ATP are temporary storage molecules. During phase two, also known as the **Calvin cycle**, the energy in these molecules is stored in organic molecules, such as glucose.

What happens in the Calvin cycle?

The Calvin cycle builds sugars out of carbon dioxide and water using the energy stored in ATP and NADPH. The Calvin cycle's reactions do not require sunlight, which is why they are also referred to as light-independent reactions.


In the Calvin cycle, carbon dioxide molecules combine with six 5-carbon compounds to make twelve 3-carbon molecules. The chemical energy stored in ATP and NADPH is passed to the 3-carbon molecules. Two 3-carbon molecules leave the cycle to be used to make glucose and other organic compounds. The enzyme **rubisco** changes ten 3-carbon molecules into 5-carbon molecules to continue the cycle. Because rubisco changes carbon dioxide molecules into organic molecules that can be used by the cell, it is considered one of the most important enzymes. Sugar formed in the Calvin cycle can be used as energy and as building blocks for complex carbohydrates, such as starch.

Alternative Pathways

Photosynthesis might be difficult for plants that grow in hot, dry environments. Many plants in extreme climates have evolved other photosynthesis pathways.

Tropical plants such as sugar cane and corn use the C_4 pathway. Instead of the 3-carbon molecules of the Calvin cycle, C_4 plants fix carbon dioxide into 4-carbon molecules. Less water is lost in the C_4 pathway. These plants keep their stomata closed during hot days to minimize water loss.

What are CAM plants?

Another alternative pathway is called the CAM pathway. CAM plants live in deserts, salt marshes, and other environments where access to water is limited. Cacti and orchids are CAM plants. Carbon dioxide enters the leaves of CAM plants only at night, when the atmosphere is cooler and more humid. The plants also fix carbon dioxide into organic compounds at night. During the day, carbon dioxide is released from organic compounds in the plants. The carbon dioxide enters the Calvin cycle at that point. The CAM pathway minimizes water loss, while allowing for adequate carbon uptake. 



Think it Over

7. **Name** the main energy-storing products of each phase of photosynthesis.

Reading Check

8. **Name** two places where CAM plants live.

MAIN Idea

Living organisms obtain energy during cellular respiration.

What You'll Learn

- the role of electron carriers in cellular respiration
- the difference between alcoholic fermentation and lactic-acid fermentation

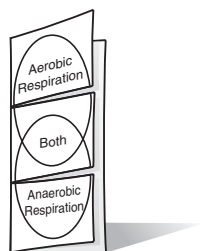
Mark the Text

Identify Main Ideas

As you read, underline or highlight the main ideas in each paragraph.

FOLDABLES™

Compare Make a three-tab Venn diagram Foldable from one sheet of paper to compare and contrast aerobic and anaerobic respiration.



● Before You Read

The energy your body uses comes from the Sun. On the lines below, explain how energy from the Sun is passed to you.

● Read to Learn

Overview of Cellular Respiration

Organisms get energy through cellular respiration. Electrons from carbon compounds such as glucose are collected, and the energy is used to make ATP. ATP is used by cells. The equation for respiration, shown below, is the opposite of the equation for photosynthesis.



Cellular respiration begins with glycolysis, a process in which glucose is broken down into pyruvate. Glycolysis is an **anaerobic process**, meaning it does not need oxygen. Glycolysis is followed by **aerobic processes**, which require the presence of oxygen. During **aerobic respiration**, pyruvate is broken down and ATP is made. Aerobic respiration occurs in two parts: the Krebs cycle and electron transport.


Glycolysis

During **glycolysis**, two phosphate groups are joined to glucose, using two molecules of ATP. The 6-carbon molecule is then broken down into two 3-carbon compounds. Two phosphates are added, and electrons and protons combine with two NAD^+ molecules to form two NADH molecules. The two 3-carbon molecules are changed into two molecules of pyruvate. Four molecules of ATP are made.

Krebs Cycle

Next, the pyruvate, made during glycolysis, is transported into the mitochondria. There it is converted into carbon dioxide in a series of reactions called the **Krebs cycle**.

What are the steps of the Krebs cycle?

Before the pyruvate enters the Krebs cycle, it reacts with coenzyme A (CoA) to form a 2-carbon intermediate called acetyl CoA. Carbon dioxide is released, and NAD^+ is changed to NADH. Acetyl CoA then moves to the mitochondria, where it combines with a 4-carbon molecule to form citric acid. Citric acid is then broken down, releasing two molecules of carbon dioxide and making one ATP, three NADH, and one FADH_2 . Acetyl CoA and citric acid are made, and the cycle continues. Two pyruvate molecules are made during glycolysis, resulting in two turns of the Krebs cycle for each glucose molecule. 

Electron Transport

Electron transport, the final stage of cellular respiration, takes place in the mitochondria. The high-energy electrons and protons from NADH and FADH_2 are used to change ADP to ATP.

Electrons are passed along a series of proteins. Electrons and protons are released from NADH and FADH_2 into the mitochondria. Protons and electrons are transferred to oxygen to make water. Electron transport makes 24 ATP molecules.

Overview of Cellular Respiration			
	Location	Main Activity	High-Energy Molecules Made per Glucose Molecule
Glycolysis		Glucose is converted to pyruvate.	2 ATP, 2 NADH
Krebs cycle		Pyruvate is converted to carbon dioxide.	2 ATP, 8 NADH, 2 FADH_2
Electron transport		Electrons and protons combine with oxygen to make water.	28 ATP

Do prokaryotes use cellular respiration?

Some prokaryotes also undergo aerobic respiration using the cellular membrane instead of the mitochondrial membrane for electron transport. Pyruvate does not move to mitochondria, saving the prokaryotic cell two ATP. Prokaryotes make 38 molecules of ATP from one molecule of glucose.

Reading Check

- 1. Identify** In the Krebs cycle, what is pyruvate converted to?

Picture This

- 2. Identify** Complete the figure by writing the location of each stage of cellular respiration.

Anaerobic Respiration

Anaerobic respiration takes place when oxygen is low. Some prokaryotes that do not need oxygen use anaerobic respiration all the time. Other cells use anaerobic respiration when oxygen levels are low.

How is ATP made during anaerobic respiration?

Anaerobic respiration, or **fermentation**, follows glycolysis when oxygen is absent. Glycolysis makes two ATP from each glucose molecule. Fermentation makes a small amount of ATP and regenerates the cell's supply of NAD^+ so glycolysis can continue. Two important types of fermentation are lactic-acid fermentation and alcohol fermentation.

What are the types of fermentation?

Lactic-acid fermentation changes pyruvate into lactic acid. It takes place in skeletal muscle cells during strenuous exercise, when the body cannot supply enough oxygen. It is also used to make foods like cheese, yogurt, and sour cream.

Yeast and some bacteria undergo a type of fermentation known as alcohol fermentation. These organisms use pyruvate to make ethyl alcohol and carbon dioxide.

Photosynthesis and Cellular Respiration

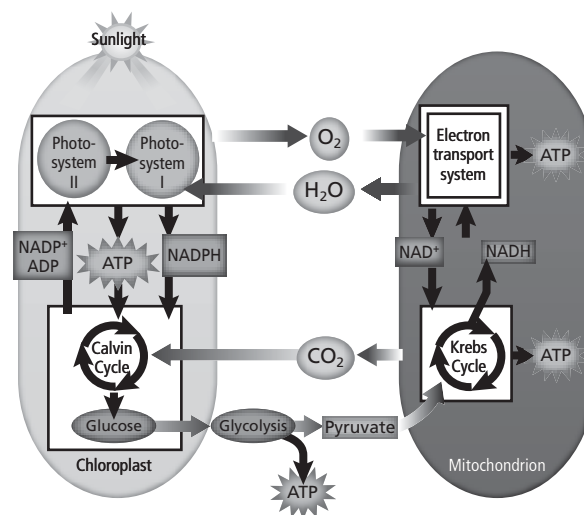
Photosynthesis and cellular respiration are important ways that cells get and use energy. These processes are related in important ways. The products of photosynthesis—oxygen and glucose—are needed for cellular respiration. The products of respiration—carbon dioxide and water—are needed for photosynthesis. The figure below shows this relationship.

Reading Check

3. Define What two processes make up anaerobic respiration?

Picture This

4. Classify What type of organisms have cells that carry out all of the processes shown at the right?



● Before You Read

Think about the life cycle of a human. On the lines below, write some of the stages that occur in the life cycle of a human. In this section, you will learn about the life cycle of a cell.

MAIN Idea

Cells grow until they reach their size limit, then they either stop growing or divide.

What You'll Learn

- why cells are small
- the stages of the cell cycle
- the stages of interphase

● Read to Learn

Cell Size Limitations

Most cells are smaller than the period at the end of this sentence. In this section, you will learn why cells are so small.

What is ratio of surface area to volume?

Recall that all cells are surrounded by a plasma membrane. All substances moving into or out of the cell must cross the plasma membrane. The surface area of the cell is the area covered by the plasma membrane. The volume of a cell is the space taken by the inner contents. Because cells are small, their surface area is high in relation to their volume. This relation is called the ratio of surface area to volume.

To understand this ratio, imagine a cube-shaped bacterial cell with sides measuring one micrometer (μm) in length. Surface area can be calculated as length times width times the number of sides, or $1 \mu\text{m} \times 1 \mu\text{m} \times 6 \text{ sides} = 6 \mu\text{m}^2$. Volume is length times width times height, or $1 \mu\text{m} \times 1 \mu\text{m} \times 1 \mu\text{m}$, which equals $1 \mu\text{m}^3$. The ratio of surface area to volume of this cell is 6:1.

What happens as the cell grows larger? Imagine a cube-shaped bacterial cell that is $2 \mu\text{m}$ per side. The surface area is now $24 \mu\text{m}^2$, and the volume is $8 \mu\text{m}^3$. The ratio of surface area to volume is 3:1. Notice that the ratio of the larger cell is lower than that of the smaller cell.

Mark the Text

Identify Main Ideas

As you read, underline or highlight the main ideas in each paragraph.

Applying Math

1. **Explain** Show the equations used to calculate $24 \mu\text{m}^2$ for the surface area and $8 \mu\text{m}^3$ for the volume of the larger cell.

✓ Reading Check

2. Explain What happens to ratio of surface area to volume as cells grow?

What are the benefits of a high ratio of surface area to volume?

As cells grow in size, the ratio of surface area to volume gets smaller. A low ratio means a cell might have trouble bringing nutrients into and moving wastes out of the cell. ✓

Small cells also have an easier time moving substances around inside the cell. Substances are moved by diffusion or by motor proteins pulling them along the cytoskeleton. Movement of substances over long distances is slow and difficult, so cells remain small.

Cells use signaling proteins to communicate. Signaling proteins move around the cell to relay messages. In larger cells, communication becomes slow because signaling proteins have to move over longer distances.

The Cell Cycle

When a cell reaches its size limit, it will either stop growing or it will divide. Cell division keeps cells from getting too large. It is also the way that cells reproduce. A cell's cycle of growing and dividing is called the **cell cycle**.

The cell cycle has three main stages. They are described in the table below. During **interphase**, the cell grows, carries out cellular functions, and copies its DNA. Interphase is followed by **mitosis** (mi TOH sus), the period when the nucleus divides. Mitosis is followed by **cytokinesis** (si toh kih NEE sis), the period when the cytoplasm divides and two cells are created.

The time it takes a cell to complete the cell cycle varies depending on the type of cell. A typical animal cell takes 12–24 hours to complete the cell cycle. Some cells might complete the cycle in eight minutes. Other cells might take as long as a year to complete one cycle.

Picture This

3. State Complete the table by writing the number of cells present at the end of each stage. The first one has been done for you.

Stage	Description	Number of Cells
Interphase	The cell grows in size, performs normal functions, and copies its DNA.	one cell
Mitosis	The cell nucleus divides, and the chromosomes separate into the two nuclei.	
Cytokinesis	The cytoplasm of the cell divides, forming two daughter cells.	

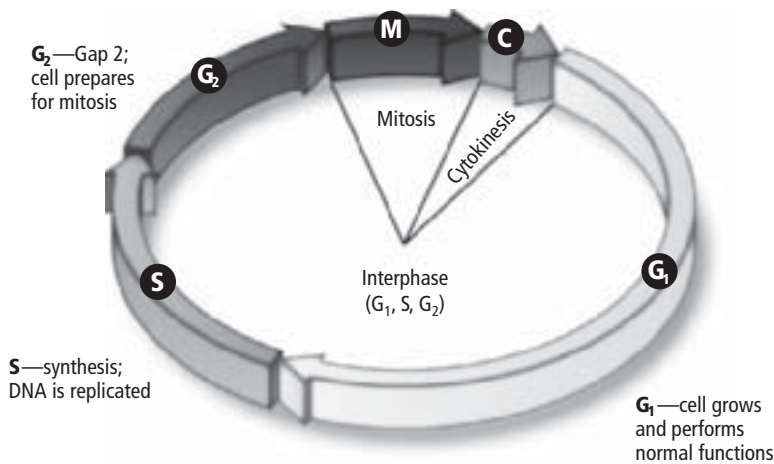
What happens during interphase?

The stages of the cell cycle are shown in the figure below. Most of the cell cycle is taken up by interphase. During interphase the cell grows, performs normal cell functions, and copies its DNA in preparation for cell division. Interphase occurs in three stages: G_1 , S, and G_2 , also called Gap 1, Synthesis, and Gap 2.

As soon as a cell divides, it enters the G_1 stage. During G_1 , a cell grows, performs normal cell functions, and prepares to copy its DNA. Some cells, such as muscles and nerve cells, exit the cycle at this stage and do not divide again.

During the S stage, the cell copies its DNA. **Chromosomes** (KROH muh sohmz) are the structures in the nucleus that contain DNA, the genetic material that is passed from generation to generation of cells. The DNA in chromosomes is tightly wound. **Chromatin** (KROH muh tun) is the relaxed, or unwound, form of DNA and proteins in the nucleus.

The G_2 stage is the period when the cell prepares for the division of its nucleus. When preparations are complete, the cell enters mitosis.



How is the cell cycle completed?

Mitosis and cytokinesis follow interphase. They are described in the next section. At the end of the cell cycle, cell division is complete, and the original cell has become two daughter cells.

How do prokaryotic cells divide?

The cell cycle you have just learned about—interphase, mitosis, and cytokinesis—occurs in eukaryotic cells. As you have learned, prokaryotic cells are simpler cells. They reproduce by a method called binary fission, which you will learn about in Chapter 18.

Picture This

- 4. Label** Circle the stage of interphase during which DNA is copied.

Reading Check

- 5. Name** What is cell division in prokaryotes called?

Cellular Reproduction

section 2 Mitosis and Cytokinesis

MAIN Idea

Eukaryotic cells reproduce by mitosis and cytokinesis.

What You'll Learn

- the events of each stage of mitosis
- the process of cytokinesis

● Before You Read

Recall the last time you got a cut. Skin heals itself with the help of cell division. Skin cells divide, creating new cells to replace the damaged cells. On the lines below, list some other times when your body might need to create new cells. In this section, you will read about two ways that cells reproduce.


Mark the Text

Identify Details As you read, highlight or underline the events of each stage of mitosis.

● Read to Learn

Mitosis

You learned in the last section that the life cycle of a cell has three stages: interphase, mitosis, and cytokinesis. Recall that during interphase, the cell copies its DNA in preparation for cell division. Mitosis follows interphase. During mitosis the two identical copies of DNA separate. Each copy will become part of a new cell, called a daughter cell. Daughter cells are genetically identical because they each have the same DNA.

Mitosis increases the number of cells as a young organism grows to its adult size. Mitosis also replaces damaged cells, such as skin cells that are damaged when you get a cut. 

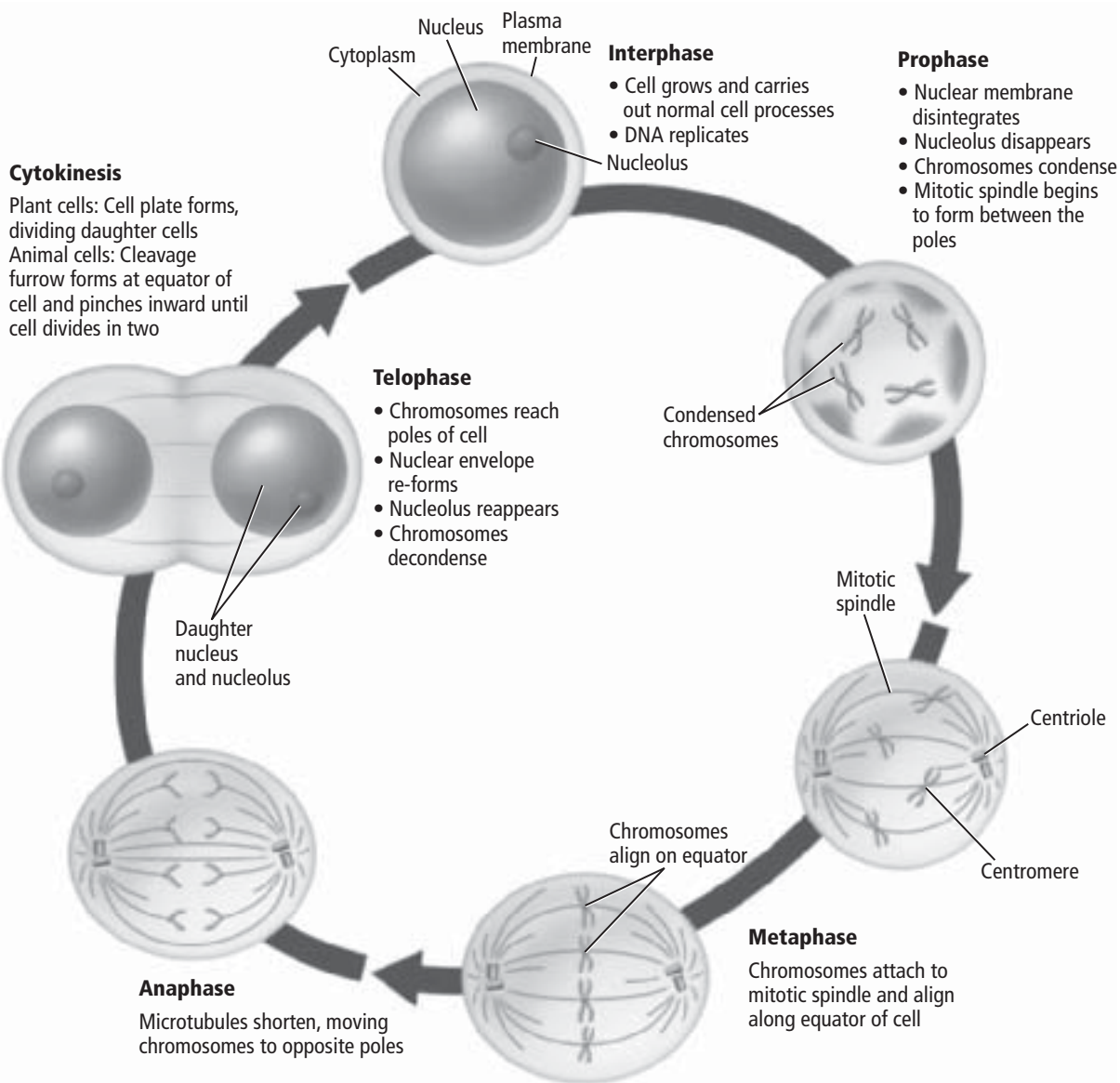
The Stages of Mitosis

Like interphase, mitosis is divided into stages. These four stages are prophase, metaphase, anaphase, and telophase. The figure on the next page shows the four stages of mitosis. Follow the diagram as you read about each stage.

Reading Check

1. Name What is one function of mitosis in a multicellular organism?

Stages of Mitosis



What happens during prophase?

The first and longest stage of mitosis is called **prophase**. Before prophase, DNA is in a relaxed, or unwound, form known as chromatin. During prophase, chromatin becomes tightly wound, or condenses, into chromosomes.

During prophase, each chromosome is X-shaped. The left half of the X is one copy of DNA. The right half is the other identical copy. Each half of the X is a **sister chromatid** containing identical copies of DNA. The sister chromatids are attached at the center of the chromosome by a structure called the **centromere**. The centromere ensures that a complete copy of the DNA copy becomes part of the daughter cell at the end of the cell cycle. ✓

Picture This

2. Label Circle the picture that shows the sister chromatids being pulled to opposite ends of the cell.

Reading Check

3. Identify How are the sister chromatids attached?

What happens at the end of prophase?

As prophase continues, the nucleolus seems to disappear. Structures called spindle fibers form in the cytoplasm. In animal and protist cells, centrioles migrate to the ends, or poles, of the cell. Star-shaped aster fibers come out of the centrioles. Spindle fibers, centrioles, and aster fibers are all made of microtubules. These structures form the **spindle apparatus** which helps move and organize the chromosomes before cell division. Centrioles are not present in plant cells.

As prophase ends, the nuclear envelope disappears. The spindle fibers attach to the sister chromatids of each chromosome on both sides of the centromere and attach to opposite poles of the cell. One spindle fiber connects the centromere to one pole of the cell. The other spindle fiber connects the centromere to the opposite pole of the cell. This ensures that each new cell gets one copy of the DNA.

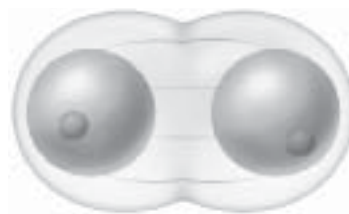
How are the chromosomes arranged?

During the second stage of mitosis, **metaphase**, the chromatids are pulled by motor proteins along the spindle apparatus toward the center of the cell. The chromatids line up in the middle, or the equator, of the cell. If metaphase is completed successfully, each daughter cell will have a copy of each chromosome.

During **anaphase**, the chromatids are pulled apart. The microtubules of the spindle apparatus begin to shorten and pull at the centromere of each sister chromatid to separate into two identical chromosomes. At the end of anaphase, the microtubules move each identical chromosome toward the poles of the cell.

What happens during telophase?

Telophase is the final stage of mitosis. During **telophase**, the chromosomes arrive at the poles of the cell and begin to relax, changing back into chromatin. Two new nuclear membranes form around each set of chromosomes, the nucleoli reappear, and the spindle apparatus is taken apart, as shown below.



Reading Check

4. Describe What happens to the chromatids during metaphase?

Picture This

5. Identify What does the cell still need to do at the end of telophase?

Cytokinesis

Near the end of mitosis, cytokinesis begins. During cytokinesis, the cytoplasm divides. The result of cytokinesis is two daughter cells, each with an identical nucleus.

What is the result of cytokinesis?

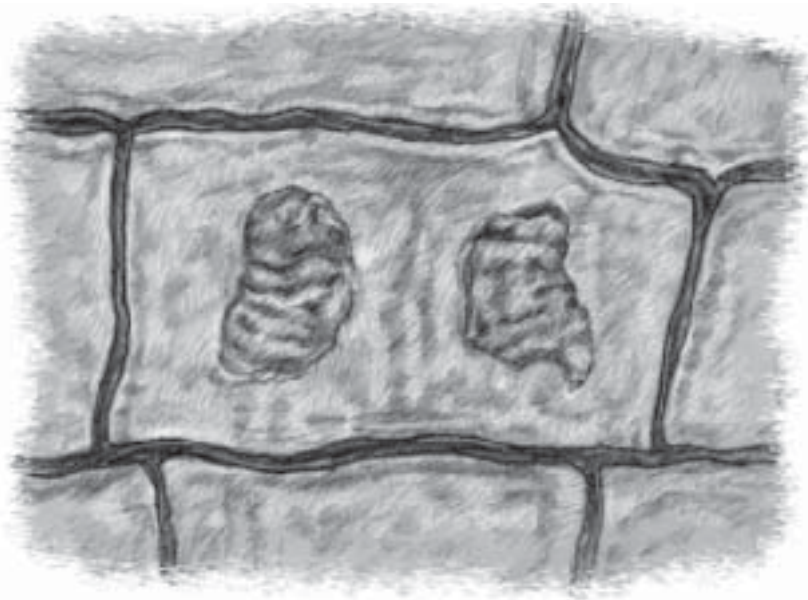
In animal cells, cytokinesis is accomplished by using microtubules to constrict, or pinch, the cytoplasm of the cell in half. The cell splits into two daughter cells. ✓

How is cytokinesis different in plant cells?

Plant cells complete cell division a different way, as shown in the figure below. Recall that plant cells are surrounded by a rigid cell wall. During cytokinesis, plant cells form a new structure, called the cell plate, between the two daughter nuclei. New cell walls then form on either side of the cell plate, dividing the cell into two identical daughter cells.

How is cell division different in prokaryotic cells?

Prokaryotic cells undergo cell division in a different way. Recall that prokaryotic cells divide by a process known as binary fission. When prokaryotic DNA is copied, both identical copies of DNA attach to the plasma membrane. As the plasma membrane grows, the attached DNA molecules are pulled apart. The cell completes fission, producing two new prokaryotic cells.



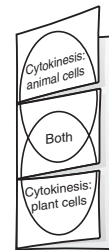
✓ Reading Check

6. **Name** the cell structure that pinches the cytoplasm in half.

FOLDABLES™

Compare and Contrast

Make a Venn diagram Foldable, as shown below. As you read, compare and contrast cytokinesis in plant and animal cells.



Picture This

7. **Identify** What features in the figure can you use to identify this cell as a plant cell?

MAIN Idea

The normal cell cycle is regulated by cyclin proteins.

What You'll Learn

- how cancer relates to the cell cycle
- the role of apoptosis
- the two types of stem cells and their potential uses

Mark the Text

Locate Information

Highlight every heading in the reading that asks a question. Then highlight each answer as you find it.

Picture This

- Name** When are some of the important combinations active?

Before You Read

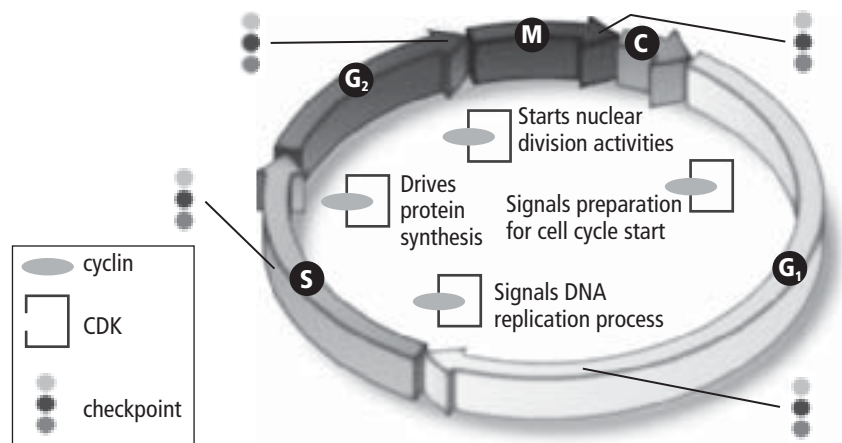
Cancer results when cells lose control of the cell cycle. A healthy lifestyle reduces the risk of cancer. On the lines below, write activities you think might reduce the risk of cancer. Then read to learn about how cancer forms.

Read to Learn

Normal Cell Cycle

The timing and rate of cell division are important to the health of an organism. The rate of cell division varies depending on the type of cell. A mechanism involving proteins and enzymes controls the cell cycle.

The cell cycle in eukaryotic cells is controlled by a combination of two substances that signals the cellular reproduction process. Proteins called **cyclin** bind to enzymes called **cyclin-dependent kinases** (CDKs) in the stages of interphase and mitosis to trigger the various activities that take place in the cell cycle, as shown below.




How do cells use cyclin/CDK combinations?

Cells use different combinations of cyclin/CDK to control activities at different stages in the cell cycle. For instance, in the G₁ stage, one cyclin/CDK combination signals the start of the cell cycle. Other cyclin/CDK combinations signal other activities, including DNA replication, protein synthesis, and nuclear division. Cyclin/CDK combinations also signal the end of the cell cycle.

How do quality control checkpoints work?

The cell cycle has built-in quality control checkpoints that monitor the cell cycle and can stop it if something goes wrong. For instance, near the end of the G₁ stage, the cell monitors its DNA for damage and can stop the cell cycle before entering the S stage of interphase if something is wrong. There are other quality control checkpoints during the S stage and after DNA duplication in the G₂ stage. During mitosis, the cell checks the spindle fibers before it undergoes cytokinesis. If the cell detects a failure, the cell cycle stops.

Abnormal Cell Cycle: Cancer

Sometimes control of the cell cycle fails. When cells do not respond to control mechanisms, cancer results. **Cancer** is the uncontrolled growth and division of cells. 

Cancer cells grow and divide as long as they receive nutrients. They crowd normal cells causing tissues and organs to stop working. Cancer can kill an organism.

What causes cancer?

Cancer is caused by mutations, or changes, in segments of DNA that code for production of proteins, including those that regulate the cell cycle. Often, cells can fix mutations in DNA. If the repair system fails, cancer can result.

Environmental factors can increase the risk of cancer. Substances that are known to cause cancer are called **carcinogens** (kar SIH nuh junz). Tobacco, tobacco smoke, alcohol, some viruses, and radiation are examples of carcinogens.

Avoiding carcinogens can help reduce the risk of cancer. Federal laws protect people from exposure to carcinogens in the workplace and in the food supply. People can reduce their risk of cancer by avoiding all tobacco (including secondhand smoke and smokeless tobacco) and by using sunscreen to protect their skin from ultraviolet radiation from the Sun.

Reading Check

2. Define What is cancer?



Think it Over

3. Identify What is an example of a carcinogen that occurs in nature?



Think it Over

- 4. Identify** Which statement about apoptosis is correct? (Circle your answer.)
- Apoptosis can lead to cancer.
 - Apoptosis can prevent cancer.

Reading Check

- 5. Describe** What are stem cells?

Why does cancer run in families?

Cancer can occur in people of all ages, but older people have a higher risk. This might be because it takes more than one DNA mutation to change an abnormal cell into a cancer cell. Older cells have had more time to accumulate the mutations that lead to cancer.

Cancer runs in some families. People might inherit one or more DNA mutations from their parents, increasing their risk of developing cancer.

Apoptosis

Some cells in an organism are no longer needed. **Apoptosis** (a pup TOH sus) is a natural process of programmed cell death. Cells that are no longer needed are destroyed by apoptosis.

Apoptosis often occurs during embryo development. Apoptosis also occurs in cells that are damaged beyond repair or that could turn into cancer cells. It is also part of the process by which leaves fall from trees in autumn.

Stem Cells

Most cells in a multicellular organism are designed for a special purpose. Some cells might be part of your skin, and other cells might be part of your heart.

Some cells are not specialized. **Stem cells** are unspecialized cells that have the potential to develop into specialized cells. There are two types of stem cells—embryonic stem cells and adult stem cells.

What are embryonic stem cells?

Embryonic stem cells are created after fertilization, when the fertilized egg divides to create 100 to 150 stem cells. Each of these cells has the potential to develop into a wide variety of specialized cells. As the embryo develops, the cells specialize into tissues, organs, and organ systems.

Stem-cell research could lead to the treatment of many human diseases and conditions. Embryonic stem-cell research is controversial. Ethical issues about the source of embryonic stem cells limit their availability to researchers.

Adult stem cells are found in various tissues in the body. They are present in people from birth to adulthood. Adult stem cell research is less controversial because the cells can be obtained with the consent of the donor.

section 1 Meiosis

● Before You Read

Think about the traits that make people unique. Some people are tall, while others are short. People can have brown, blue, or green eyes. On the lines below, list a few traits that make you look different from other people. In this section, you will learn how meiosis rearranges genes.

MAIN Idea

Meiosis produces haploid genes.

What You'll Learn

- how chromosome number decreases during meiosis
- the stages of meiosis
- how meiosis provides genetic variation

● Read to Learn

Chromosomes and Chromosome Number

All students in your class have characteristics passed on to them by their parents. Each characteristic, such as hair color, eye color, and height, is called a trait.

The instructions for each trait are found on chromosomes. Recall from Chapter 7 that chromosomes are found in the nuclei of cells. The DNA on the chromosomes is arranged in sections that control the production of proteins. These DNA sections are called **genes**. Each chromosome has about 1500 genes. Each gene has a role in the characteristics of the cell and how the cell works. Living things have thousands of genes.

Human body cells have 46 chromosomes. Chromosomes come in pairs. You have 23 chromosomes from your father and 23 chromosomes from your mother, making 23 pairs of chromosomes.

Study Coach

Create a Quiz After you have read this section, create a quiz based on what you have learned. After you have completed writing the quiz questions, be sure to answer them.

Applying Math

1. **Calculate** the approximate number of genes humans have. Show your work.

What are homologous chromosomes?

The chromosomes that make up a pair, one from each parent, are called **homologous** (huh MAH luh gus) **chromosomes**. Homologous chromosomes are the same length and have the centromere in the same place. They also carry genes for the same traits at the same place. Look at the picture below, and see if you can spot the homologous pair.

Homologous chromosomes are similar but not identical. For example, the gene for ear shape will be located at the same place on each homologous chromosome. Although these genes code for ear shape, the gene on one chromosome might code for one ear shape. The gene on the other chromosome might code for a different ear shape.



Picture This

2. Identify Circle a pair of homologous chromosomes.

How is chromosome number maintained in a species?

The number of chromosomes does not change from generation to generation. You have the same number of chromosomes as your parents. **Gametes** (GA meets), or sex cells with half the number of chromosomes, ensure the chromosome number stays the same.

The symbol n represents the number of chromosomes. In humans, n is equal to 23. A cell with n number of chromosomes is called a **haploid** cell. Gametes are haploid cells.

The process in which one haploid gamete joins with another haploid gamete is called **fertilization**. After fertilization, the cell has $2n$ chromosomes— n chromosomes from the female parent plus n chromosomes from the male parent. A cell with $2n$ chromosomes is called a **diploid** cell. Notice that n also represents the number of chromosome pairs in an organism.

Reading Check

3. Identify How many chromosomes are in a human gamete? (Circle your answer.)

- a. 46
- b. 23
- c. 10

Take Notes Make a folded table Foldable, as shown below. As you read, take notes and organize what you learn about meiosis I and meiosis II.

	Meiosis I	Meiosis II
Prophase		
Metaphase		
Anaphase		
Telophase		
Result		

Meiosis I

Recall that most cells are formed by mitosis. During mitosis the chromosome number stays the same. Because sex cells need half the number of chromosomes, a different process of cell division is needed. Gametes are formed during a process called meiosis. **Meiosis** is a kind of cell division that reduces the number of chromosomes by half through the separation of homologous chromosomes. Meiosis takes place in the reproductive organs of plants and animals. During meiosis, there are two cell divisions. They are called meiosis I and meiosis II.

What happens during interphase I?

Just as in mitosis, a cell goes through interphase before undergoing meiosis. A cell in interphase carries out a variety of metabolic functions, copies its DNA, and makes proteins.

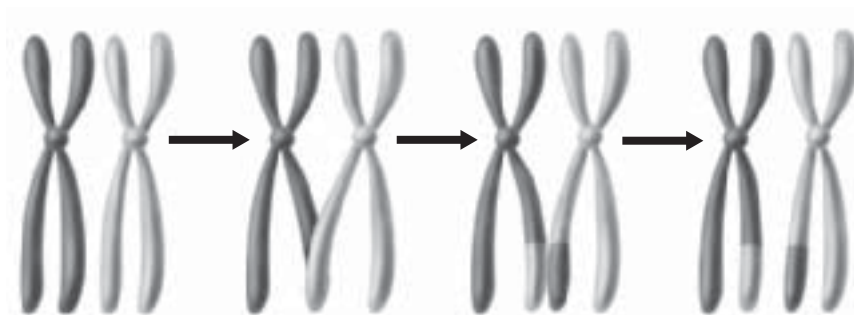
What happens during prophase I?

Meiosis I begins with prophase I. During prophase I, replicated chromosomes, consisting of two sister chromatids, condense. When that happens, the chromosomes become visible under a light microscope.

As the homologous chromosomes condense, they begin to form homologous pairs in a process called synapsis (suh NAP sus). The homologous chromosomes are held tightly together along their lengths by a protein that acts like a zipper. Prophase I continues as the chromosomes move to opposite sides of the cell.

What is crossing over?

During synapsis, the chromosomes often swap pieces of DNA. **Crossing over** occurs when a section of one chromosome changes place with a section of its homologous chromosome. This is shown in the figure below. The centrioles move to the opposite poles of the cell. Spindle fibers form and bind to the sister chromatids at the centromere.



Picture This

4. Label Circle the part of each chromosome that was swapped during crossing over.

What happens during metaphase I?

The next phase is metaphase I. During metaphase I, the pairs of homologous chromosomes line up in the center of the cell. The spindle fibers attach to the centromere of each homologous chromosome.

What happens during anaphase I?

Next is anaphase I. During anaphase I, each homologous chromosome is guided by the spindle fibers toward opposite poles of the cell. When this happens, the chromosome number is reduced from $2n$ to n . Notice that the sister chromatids do not split during meiosis I. Each homologous chromosome still has two sister chromatids. ✓

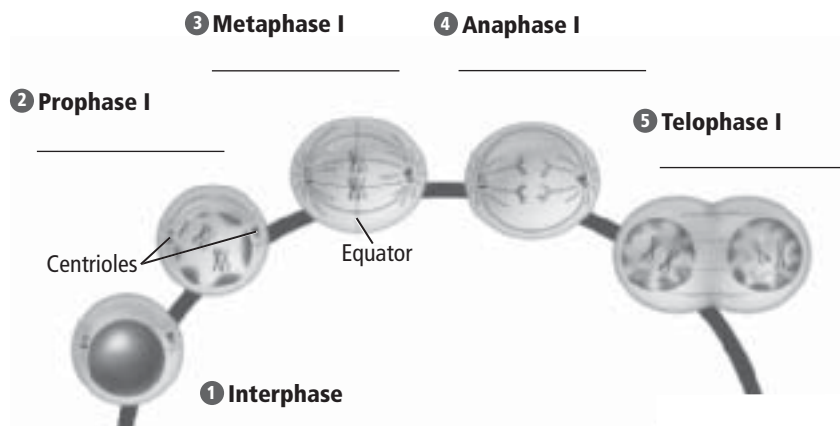
What is the final stage of meiosis I?

The final stage of meiosis I is telophase I. During telophase I, the homologous chromosomes reach opposite poles of the cell. Each pole contains only one member of a pair of homologous chromosomes.

The sister chromatids might not be identical because crossing over might have occurred during synapsis in prophase I. Crossing over is one way that meiosis leads to more genetic diversity. This diversity helps explain how species can change over time.

At the end of telophase I, the cell undergoes cytokinesis, meaning it divides into two cells. The cells then might go into interphase again, but this time, the DNA is not copied during interphase. The events of meiosis I are shown below.

MEIOSIS I



✓ Reading Check

5. Identify During what phase is the chromosome number reduced from $2n$ to n ?

Picture This

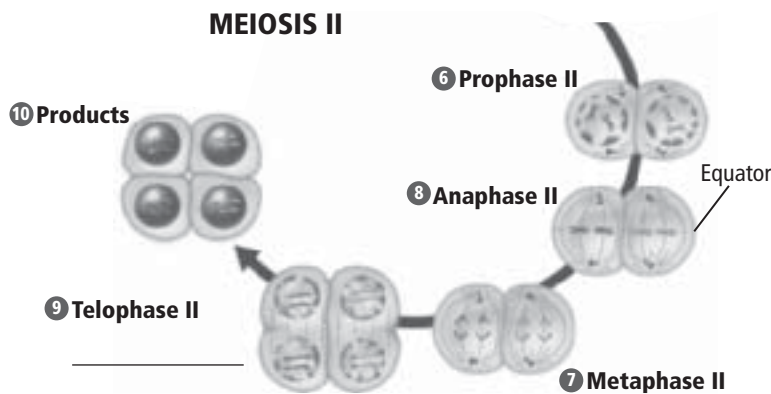
6. Label In the space provided, write the chromosome number ($2n$ or n) for each phase.

Meiosis II

Meiosis is now half finished. To complete meiosis, the cell must go through meiosis II. Meiosis II is similar to mitosis.

What events occur during meiosis II?

During prophase II, the spindle apparatus forms, and the chromosomes condense. During metaphase II, a haploid number of chromosomes lines up near the center of the cell by the spindle fibers. During anaphase II, the sister chromatids are pulled apart at the centromere by the spindle fibers, and the sister chromatids are pulled to the opposite poles of the cell. In telophase II, the chromosomes reach the poles, and the nuclear membrane and nuclei reform. Cytokinesis, or cell division, occurs. The result is four haploid cells, each with n number of chromosomes.



Picture This

7. Label Circle the phase in which the sister chromatids are pulled apart. Count the cells in telophase II, and write the number in the space provided.

The Importance of Meiosis

The figure below shows that meiosis and mitosis have similar steps, but they are different in important ways. An important difference is that mitosis produces two identical diploid daughter cells, while meiosis produces four different haploid daughter cells.

Picture This

8. Compare Fill in the blanks in the table with the number of daughter cells produced.

	Mitosis	Meiosis
Number of cell divisions	one	two
Synapsis of homologous chromosomes	does not occur	occurs during prophase I
Products	_____ identical, diploid cells	_____ nonidentical, haploid cells
Type of cells produced	body cells	reproductive cells
Purpose	growth and repair of body tissues	production of gametes for sexual reproduction

How does meiosis create genetic diversity?

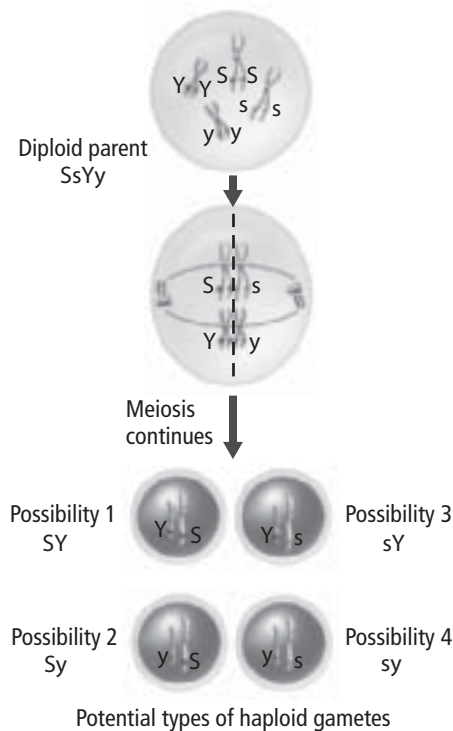
The haploid daughter cells made by meiosis are not identical. Because the daughter cells are different, meiosis results in genetic variation.

One way that meiosis produces non-identical daughter cells occurs during prophase I. When pairs of homologous chromosomes line up at the center of the cell, they do so randomly. This means that each daughter cell gets a different, random assortment of chromosomes. The effect on genetic diversity is illustrated in the figure below.

The other way meiosis creates variation is through crossing over. Fertilization, when two haploid gametes combine, results in even more genetic variation.

Picture This

9. Identify Underline the haploid daughter cells.



Think it Over

10. Compare How is chromosome inheritance different in sexual reproduction?

Sexual Reproduction v. Asexual Reproduction

Asexual reproduction occurs when the organism inherits all of its chromosomes from one parent. The new organism is genetically identical to its parent. Asexual reproduction does not involve meiosis.

Bacteria reproduce by asexual reproduction. Plants and some simple animals can reproduce sexually or asexually. Complex animals only reproduce sexually.

section 2 Mendelian Genetics

● Before You Read

Think about what you have learned about the scientific method. On the lines below, list some of the steps Mendel might have used to learn about the natural world. In this section, you will learn about Gregor Mendel's experiments.

MAIN Idea

Mendel explained how a dominant allele can mask the presence of a recessive allele.

What You'll Learn

- the law of segregation and the law of independent assortment
- how to use a Punnett square

● Read to Learn


How Genetics Began

Gregor Mendel, an Austrian Monk, lived in the 1800s. He experimented with pea plants in the monastery gardens.

Pea plants usually reproduce by self-fertilization. This means that the female gamete is fertilized by a male gamete in the same flower. Mendel discovered a way to cross-pollinate peas by hand. He removed the male gametes from a flower. He then fertilized the flower with the male gamete from a different flower.

Through these experiments, Mendel made several hypotheses about how traits are inherited. In 1866, he published his findings. That year marks the beginning of the science of **genetics**, the science of heredity. Mendel is called the father of genetics.

The Inheritance of Traits

Mendel used true-breeding pea plants—plants whose traits stayed the same from generation to generation. Mendel studied seven traits—flower color, seed color, seed pod color, seed shape, seed pod shape, stem length, and flower position. 

Mark the Text

Check for Understanding

As you read this section, highlight any parts you do not understand. After you have read the section, reread the parts you have highlighted.

Reading Check

1. **Define** What is a true-breeding plant?

What did Mendel find when he crossed pea plants with different traits?

Mendel called the original plants the parent, or P, generation. The offspring were called the F₁ generation. The offspring of the F₁ plants were called the F₂ generation.

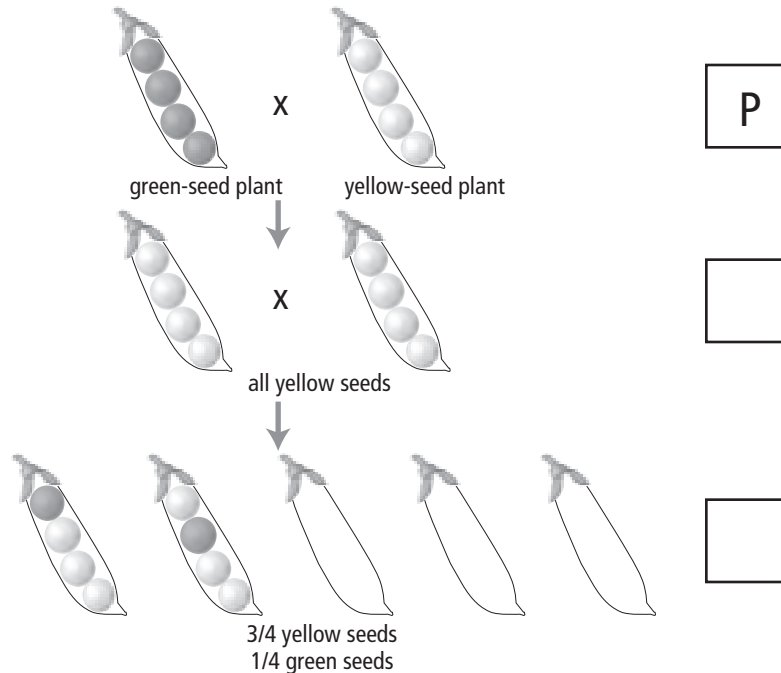
In one experiment, Mendel crossed yellow-seeded and green-seeded plants. All the F₁ offspring had yellow seeds. The green-seed trait seemed to disappear.

Mendel allowed the F₁ plants to self-fertilize. He planted thousands of seeds from these plants. He saw that in these offspring, the F₂ generation, three-fourths of the plants had yellow seeds and one-fourth had green seeds, a 3:1 ratio.

Mendel performed similar experiments for other traits. Each time, he observed the same 3:1 ratio.

Picture This

- 2. Label** Fill in the boxes with the name of each generation of offspring. Draw the peas you would expect to see in the empty pods. Use shading to indicate a green pea.



How did Mendel explain his results?

Mendel proposed that there were two forms of each trait, and each form was controlled by a factor, which is now called an allele. An **allele** (uh LEEL) is a different form of a gene passed from generation to generation. Yellow-seed plants have a different allele than green-seed plants.

Mendel proposed that each trait was controlled by two alleles. The **dominant** form is the version of the trait that appears in the F₁ generation. The **recessive** form is the version that is hidden in the F₁ generation.



Think it Over

- 3. Apply** In Mendel's experiment with green and yellow seeds, what was the dominant trait?

How does dominance work?

When written, the dominant allele is represented by a capital letter. The recessive allele is represented by a lowercase letter.

An organism is **homozygous** (hoh muh ZI gus) if both alleles for a trait are the same. The organism is **heterozygous** (heh tuh roh ZY gus) if the alleles for a trait are different. In heterozygous organisms, only the dominant trait can be seen. Dominant alleles mask recessive alleles.

How do genotype and phenotype differ?

It is not always possible to know what alleles are present just by looking at an organism. A yellow-seed plant could be homozygous (YY) or heterozygous (Yy). An organism's allele pairs are called its **genotype** (JEE nuh tipe). The expression of an allele pair, or the way an organism looks or behaves, is called its **phenotype** (FEE nuh tipe).

What is the law of segregation?

Recall that the chromosome number is divided in half during meiosis. The gametes contain only one of the alleles. Mendel's **law of segregation** states that the two alleles for each trait separate from each other during meiosis and then unite during fertilization. When parents with different forms of a trait are crossed, the offspring are heterozygous organisms known as **hybrids** (HI brudz).

A cross which involves hybrids for a single trait is called a monohybrid cross. Mono means one. The offspring of the cross have a phenotypic ratio of 3:1.

How are two or more traits inherited?

Mendel also performed dihybrid crosses, crossing plants that expressed two different traits. Mendel crossed yellow, round-seed plants with green, wrinkle-seed plants. Round seeds are dominant to wrinkled, just as yellow color is dominant to green. He wondered whether the two traits would be inherited together or separately. Members of the F₁ generation are dihybrids because they are heterozygous for both traits.

Mendel found that the traits were inherited independently. Members of the F₂ generation had the phenotypic ratio of 9:3:3:1—9 yellow round seeds, 3 green round, 3 yellow wrinkled, and 1 green wrinkled. From experiments with dihybrid crosses, Mendel developed the **law of independent assortment**, which states that alleles distribute randomly when gametes are made.



Think it Over

- 4. Predict** What would be the phenotype of a heterozygous, recessive (yy) pea plant?



Think it Over

- 5. Apply** True-breeding yellow-seeded and green-seeded plants are crossed and produce yellow-seeded offspring. Which of these plants is a hybrid?


Reading Check

6. Identify What is one purpose of a Punnett square?

Picture This

7. Define Circle the genotypes in the small squares that will give a yellow-seed phenotype. What will be the phenotypic ratio in the offspring?

Punnett Squares

In the early 1900s, Dr. Reginald Punnett developed a square to predict possible offspring of a cross between two known genotypes. Punnett squares are useful for keeping track of genotypes in a cross. 

What information does a Punnett square contain?

A Punnett square can help you predict the genotype and phenotype of the offspring. The genotype of one parent is written vertically, on the left side of the Punnett square. The genotype of the other parent is written horizontally, across the top. A Punnett square for a monohybrid cross contains four small squares. Each small square represents a possible combination of alleles in the children.

The Punnett square below shows the results of Mendel’s experiment with seed color. The Punnett square shows that four different genotypes are possible—one YY, two Yy, and one yy. The genotypic ratio is 1:2:1.

	<i>y</i>	<i>y</i>
<i>Y</i>	YY	Yy
<i>y</i>	Yy	yy

How is a Punnett square used for two traits?

Punnett squares also can be used to predict the results of a dihybrid cross. A Punnett square for a dihybrid cross is larger. It has 16 boxes to represent 16 allele combinations.

Probability

Genetics follows the rules of probability, or chance. It is like flipping a coin. The probability of flipping heads is one out of two. Because of chance, if you flip a coin 100 times, it might not land heads exactly 50 times, but it will be close.

It is the same in genetics. A cross might not give a perfect 3:1 or 9:3:3:1 ratio. The larger the number of offspring, the more closely the results will match the ratio predicted by the Punnett square.

section ③ Gene Linkage and Polyploidy

● Before You Read

Genetics is like a game of cards. In meiosis, chromosomes are shuffled and sorted. On the lines below, explain the chances of a player getting the same cards two games in a row. In this section, you will learn about the independent assortment of chromosomes that occurs during meiosis.

MAIN Idea

Crossing over of linked genes is a source of genetic variation.

What You'll Learn

- how meiosis produces genetic recombination
- how gene linkage is used to make chromosome maps
- why polyploidy is important

● Read to Learn

Genetic Recombination

During meiosis, genes are combined in new ways. **Genetic recombination** occurs when crossing over and independent assortment produce new combinations of genes.

Recall that independent assortment occurs in meiosis when chromosomes separate randomly. The number of possible gene combinations due to independent assortment can be calculated using the formula 2^n , where n equals the number of chromosome pairs.

Pea plants have 7 pairs of chromosomes. The possible combinations of these chromosomes would be 27, or 2^7 . Fertilization further increases the number of combinations. During fertilization, any possible male gamete can fertilize any possible female gamete. The number of combinations after fertilization would be $2^n \times 2^n$. For peas, this number is $16,384$, or $2^7 \times 2^7$.

In people, the possible combinations of chromosomes are $2^{23} \times 2^{23}$ —over 70 trillion. Crossing over increases genetic recombination even more.

Mark the Text

Main Ideas Highlight the main ideas under each heading. State each main point in your own words.

Applying Math

1. **Calculate** The fruit fly has four chromosome pairs. How many possible combinations of chromosomes can be produced by meiosis and fertilization?

✓ Reading Check

2. Explain What event causes linked genes to separate?

Picture This

3. Identify Which two genes are not likely to cross over? (Circle your answer.)

- a. yellow body color and vermilion eye color
- b. white eye color and vermilion eye color

✓ Reading Check

4. Identify Name two organisms that have polyploidy.

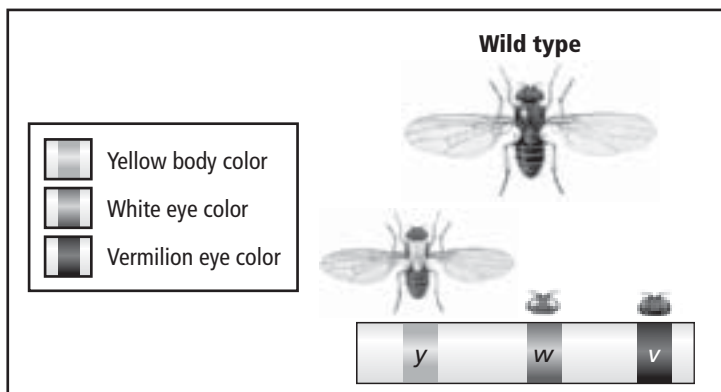
Gene Linkage

Chromosomes contain many genes. Genes that are located close together on the same chromosome are said to be linked. This means they usually travel together during gamete formation. Linked genes do not segregate independently. They are an exception to Mendel's law of independent assortment.

Occasionally, linked genes separate due to crossing over. Crossing over occurs more frequently between genes that are far apart than between genes that are close together. ✓

What does a chromosome map show?

The relationship between crossing over and chromosome distance is very useful. The distance between two genes can be estimated by the frequency of crossing over that occurs between them. Scientists use cross-over data to create a drawing of genes along a chromosome. The drawing, called a chromosome map, shows the order of genes on a chromosome. The first chromosome maps were published in 1913 for fruit-fly crosses. One is shown in the figure below.



Polyploidy

Most organisms have diploid cells—cells with two chromosomes in each cell. Some species have polyploid cells.

Polyploidy (PA lih ploy dee) means the cells have one or more extra sets of all chromosomes. For instance, a triploid organism has three complete sets of chromosomes in each cell. It is designated $3n$.

Polyploidy occurs in only a few animals, such as earthworms and goldfish. It is always lethal in humans. Polyploidy is common in flowering plants. Polyploid plants are often bigger and more vigorous. Many food plants, such as wheat ($6n$), oats ($6n$), and sugarcane ($8n$), are polyploidy. ✓

Complex Inheritance and Human Heredity

section 1 Basic Patterns of Human Inheritance

● Before You Read

A family tree shows how people in a family are related. On the lines below, list people who might appear in a family tree. Then read the section to learn how scientists trace inheritance through several generations of a family.

MAIN Idea

The inheritance of a trait over several generations is shown in a pedigree.

What You'll Learn

- how to determine if an inherited trait is dominant or recessive
- examples of dominant and recessive disorders

● Read to Learn

Recessive Genetic Disorders

During the early 1900s, Gregor Mendel's work on heredity was rediscovered. Archibald Garrod, an English doctor, was studying a disorder that results in black urine and affects bones and joints. Dr. Garrod, with the help of other scientists, discovered that the disorder was a recessive genetic disorder. This finding began the study of human genetics.

Review the table below and recall that a recessive trait is expressed when the person is homozygous recessive for that trait. A person with at least one dominant allele will not express the recessive trait. A person who is heterozygous for a recessive disorder is called a **carrier**.

Term	Description
Homozygous	An organism with two of the same alleles for a particular trait is said to be homozygous for that trait.
Heterozygous	An organism with two different alleles for a particular trait is said to be heterozygous for that trait. When alleles are present in the heterozygous state, the dominant trait will be observed.

Study Coach

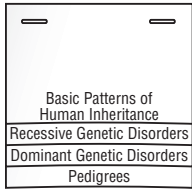
Create a Quiz After you read this section, create a quiz based on what you have learned. Then be sure to answer the quiz questions.

Picture This

1. **Identify** Circle the term that describes the genotype of a person who expresses a recessive trait.



Take Notes Use two sheets of paper to make a layered Foldable, as shown below. As you read, record important information you learn about human inheritance.



Reading Check

2. Explain Why do gangliosides build up in the brain of people with Tay-Sachs disease?

What is cystic fibrosis?

Cystic fibrosis is a recessive genetic trait. Chloride ions are not absorbed into cells but are excreted in sweat. Without the chloride ions in cells, water does not diffuse from cells. This causes the secretion of a thick mucus that affects many areas of the body. The mucus interferes with digestion, clogs ducts in the pancreas, and blocks air pathways in the lungs. Patients with cystic fibrosis often get infections because of excess mucus in their lungs.

Treatment includes physical therapy, medicine, special diets, and replacement digestive enzymes. Genetic tests are used to determine if the recessive gene is present.

What causes albinism?

Albinism is a recessive disorder found in people and animals. In humans, it is caused by the absence of the skin pigment melanin in hair and eyes. People with albinism have white hair, pale skin, and pink eyes. They need to protect their skin from the Sun's ultraviolet rays.

What is Tay-Sachs disease?

Tay-Sachs (TAY saks) disease is a recessive genetic disorder. Tay-Sachs disease (TSD) is more common among Jews whose ancestors are from eastern Europe.

People with TSD are missing an enzyme needed to break down fatty acids called gangliosides. Normally, gangliosides are made and then destroyed as the brain develops. In people with TSD, gangliosides build up in the brain, causing mental deterioration. Children born with TSD usually die by age five. Currently, there is no cure.

What causes galactosemia?

Galactosemia (guh lak tuh SEE mee uh) is a recessive genetic disorder. It causes intolerance of the sugar galactose. Milk contains the sugar lactose. During digestion, lactose breaks down into galactose and glucose, the sugar used by the body for energy. People with galactosemia lack the enzyme needed to break down galactose.

Dominant Genetic Disorders

Not all genetic disorders are recessive. Some are caused by dominant alleles. People who do not have the disorder are always homozygous recessive, meaning they carry two recessive genes for the trait.

What happens in Huntington's disease?

Huntington's disease is a dominant genetic disorder that affects the nervous system. It is rare. Symptoms occur when the person is between 30 and 50 years old. Symptoms are gradual loss of brain function, uncontrollable movements, and emotional disturbances. Genetic tests can tell people whether they have the gene for Huntington's disease, but there is currently no treatment or cure.

What is achondroplasia?

Achondroplasia (a kahn droh PLAY zhee uh) is a dominant genetic disorder that is also known as dwarfism. People with this disorder have a small body size and short limbs. They grow to an adult height of about 1.2 m.

About 75 percent of people with achondroplasia have parents of average size. Because the gene is dominant, parents who are average size do not have the gene. Therefore, when average-sized parents have a child with achondroplasia, the condition occurs because of a new mutation.

Pedigrees

Scientists use a diagram called a **pedigree** to trace inheritance of a trait through several generations. A pedigree uses symbols to illustrate inheritance of the trait.

A sample pedigree is shown in the figure below. In the top row, the two symbols connected by a horizontal line are the parents. Their children are listed below them, oldest to youngest from left to right.

Roman numerals are used to represent generations—I for the parents, II for the children, and so on. Arabic numbers are used to represent the individuals within a generation.

Key to Symbols

○ Normal female

● Female who expresses the trait being studied

◐ Female who is a carrier for the particular trait

| Generation

— Parents

┌┐ Siblings

□ Normal male

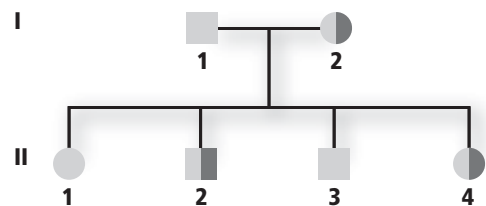
■ Male who expresses the trait being studied

◑ Male who is a carrier for the particular trait

Roman numerals — Generations

Arabic numerals — Individuals in a certain generation

Example Pedigree



Think it Over

3. Explain How can scientists determine if achondroplasia developed from a new mutation?

Picture This

4. Evaluate Circle the carriers in the second generation.

Picture This

5. Calculate What percentage of the children in this family inherited Tay-Sachs disease?

Picture This

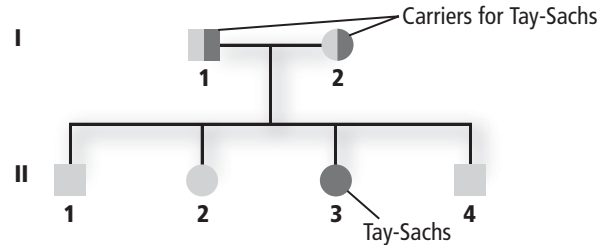
6. Identify Do any of the grandchildren in this family have polydactyly?

Reading Check

7. Explain Why are recessive traits difficult to study?

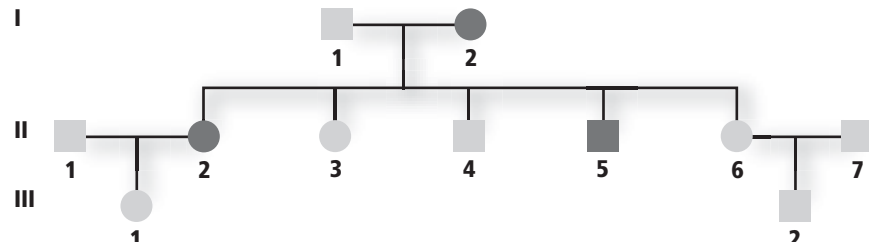
Analyzing Pedigrees

The figure below is a pedigree showing the inheritance of Tay-Sachs disease, a recessive disorder. The pedigree shows that two parents who do not have Tay-Sachs disease can have a child who has the disorder.



How is the inheritance of a dominant disorder shown on a pedigree?

The pedigree below shows the inheritance of the dominant disorder, polydactyly (pah lee DAK tuh lee). People who have polydactyly have extra fingers and toes. A person who has polydactyly could be homozygous or heterozygous for the trait. A person who does not have polydactyly would be homozygous recessive for the trait.



How are genotypes deduced?

A pedigree can be used to learn the genotype of a person. The genotype is determined by observing the phenotypes, or physical traits, of a person.

Genetic counselors use pedigrees to determine if an inherited trait is dominant or recessive. Dominant traits are easy to recognize. Recessive traits are more difficult because people who carry the allele do not always show the trait. ✓

Can genetic disorders be predicted?

Scientists can use pedigrees to predict whether a person in a family will get a genetic disorder. Scientists have to follow several people for many generations to accurately study a disorder. Good record keeping within a family can help scientists predict the inheritance of a disorder.

Complex Inheritance and Human Heredity

section 2 Complex Patterns of Inheritance

● Before You Read

Cats can look different from one another because of differences in their coats. Think about the different kinds of cats you have seen. On the lines below, describe differences you have seen in the coats of cats. Then read the section to learn more about complex inheritance patterns.

MAIN Idea

Complex inheritance of traits does not follow the inheritance patterns described by Mendel.

What You'll Learn

- the difference between sex-linked and sex-limited inheritance
- how environment can influence a trait


● Read to Learn

Incomplete Dominance

Not all traits follow Mendel's rules. Some traits are not dominant or recessive. Sometimes, the heterozygous organism has a mixed phenotype. **Incomplete dominance** occurs when the heterozygous phenotype is an intermediate phenotype between the two homozygous phenotypes.

An example of incomplete dominance occurs in snapdragon flowers. Red-flowered snapdragons (RR) can be crossed with white-flowered snapdragons (rr) to produce offspring with pink flowers (Rr). When heterozygous F_1 generation snapdragon plants (Rr) self-fertilize, the offspring have a 1:2:1 ratio of red, pink, and white flowers.

Codominance

In Mendel's experiments with pea plants, heterozygous pea plants expressed only the dominant allele. **Codominance** occurs when a heterozygous organism expresses both alleles. Sickle-cell anemia is an example of codominance. 

Mark the Text

Highlight each question head. Then highlight the answer to the question.

✓ Reading Check

1. **Define** What is codominance?

✓ Reading Check

2. Describe What effect does sickle-cell anemia have on red blood cells?

What happens in sickle-cell anemia?

Sickle-cell anemia is common in people of African descent. Sickle-cell anemia affects red blood cells and their ability to transport oxygen. Changes in the protein in red blood cells cause those red blood cells to change from a normal disc shape to a sickle or C shape. ✓

Sickle-cell anemia is a codominant trait. People who are heterozygous for the trait make both normal and sickle-shaped cells. The normal cells compensate for the sickle-shaped cells.

Where does sickle-cell anemia occur?

Sickle-cell anemia is found in areas of Africa where malaria occurs. Scientists have discovered that people who are heterozygous for the sickle-cell trait are resistant to malaria. Because the sickle-cell gene helps people resist malaria, they are more likely to pass the sickle-cell trait on to their offspring.

Multiple Alleles

So far you have learned about traits that result from a gene with two alleles. Some traits are controlled by a gene that has **multiple alleles**. Blood groups in humans is an example of a multiple allele trait.

How are blood types produced?

There are four blood types in people: A, AB, B, or O. The four types result from the interaction of three different alleles, as shown below. The allele I^A produces blood type A. I^B produces blood type B. The allele i is recessive and produces blood type O. Type O is the absence of AB alleles. People with one I^A and one I^B allele have blood type AB. Blood types are examples of multiple alleles and codominance.

Rh factors are also in blood. One factor is inherited from each parent. Rh factors are either positive or negative (Rh+ or Rh-); the Rh+ is dominant.

Picture This

3. Evaluate What is the most common blood type?

Genotypes	Resulting Phenotypes
$I^A I^A$	Type A
$I^A i$	Type A
$I^B I^B$	Type B
$I^B i$	Type B
$I^A I^B$	Type AB
ii	Type O

What genes control coat color in rabbits?

The fur color of rabbits is another trait controlled by multiple alleles. In rabbits, four alleles control coat color: C , c^{ch} , c^h , and c . The alleles are dominant in varying degrees. The hierarchy can be written as $C > c^{ch} > c^h > c$.

Allele C is dominant to all other alleles and results in a dark gray coat color. Allele c^{ch} is dominant to c^h , and c^h is dominant to c . Allele c is recessive and results in an albino when the genotype is homozygous recessive.

Multiple alleles increase the possible number of genotypes and phenotypes. Two alleles have three possible genotypes and two possible phenotypes. Four alleles have ten possible genotypes and can have five or more phenotypes.

Epistasis

Epistasis (ih PIHS tuh sus) occurs when one allele hides the effects of another allele. Coat color in Labrador retrievers is a trait controlled by epistasis. Labrador coats vary from yellow to black. Two different genes control coat color. The dominant allele E determines whether the coat will have dark pigment. A dog with genotype ee will not have any pigment. The dominant allele B determines how dark the pigment will be. If the genotype is $EEbb$ or $Eebb$ the coat will be chocolate. If the genotype is $eebb$, $eeBb$, or $eeBB$ the coat will be yellow because the e allele hides the effects of the dominant B allele.

Sex Determination

Each cell in your body contains 23 pairs of chromosomes. One pair, the **sex chromosomes**, determines gender. The other 22 pairs of chromosomes are called **autosomes**.

There are two types of sex chromosomes—X and Y. A person's gender is determined by the sex chromosomes present in the egg and sperm cell. Females inherit two X chromosomes. Males inherit one X and one Y chromosome.

Dosage Compensation

In humans, the X chromosome carries genes needed by males and females. The Y chromosome mainly carries genes needed to develop male characteristics. Because females have two X chromosomes and males have only one, body cells randomly turn off one of the X chromosomes. This is called dosage compensation or X-inactivation.



Think it Over

- 4. Evaluate** What allele is dominant over c^{ch} ?
- c^h
 - c
 - C



Think it Over

- 5. Identify** A person has 22 pairs of autosomes and two X chromosomes. What is the person's gender?
-



Think it Over

6. Draw Conclusions

Why is a recessive sex-linked trait less likely to occur in females than in males?

Picture This

7. Predict Circle the genotype that represents a color-blind person.

- X^B = Normal
- X^b = Red-green color blind
- Y = Y chromosome

	X^B	Y
X^B	$X^B X^B$	$X^B Y$
X^b	$X^B X^b$	$X^b Y$

How is coat color determined in calico cats?

The coat color of calico cats is controlled by the random inactivation of X chromosomes. Orange patches are formed when an X chromosome carrying the allele for black coat color is turned off. Black patches are formed when an X chromosome carrying the allele for orange coat color is turned off.

What are Barr bodies?

Canadian scientist Murray Barr first observed inactivated X chromosomes, now known as Barr bodies. Barr bodies appear as dark objects in the cell nuclei of female mammals.

Sex-Linked Traits

Traits controlled by genes on the X chromosome are called **sex-linked traits** or X-linked traits. Males who have only one X chromosome are affected more than females by recessive sex-linked traits. Females would not likely express a recessive sex-linked trait because one X chromosome will mask the effect of the recessive trait on the other X chromosome.

How is red-green color blindness inherited?

The trait for red-green color blindness is a recessive sex-linked trait. People who are color blind cannot see the colors red and green. About 8 percent of males in the United States are red-green color blind. Examine the Punnett square below to see how red-green color blindness is inherited.

How is hemophilia inherited?

Normally, when a person is cut, the bleeding stops quickly. Hemophilia is a recessive sex-linked disorder that slows blood clotting. Hemophilia is more common in males. Until the discovery of clotting factors in the twentieth century, most men with hemophilia died at an early age. Safe methods of treating the disorder now allow for a normal life span.

Polygenic Traits

So far you have learned about traits that are controlled by one gene with different alleles. **Polygenic traits** develop from the interaction of multiple pairs of genes. Many traits in humans are polygenic, including skin color, height, eye color, and fingerprint pattern. ✓

Environmental Influences

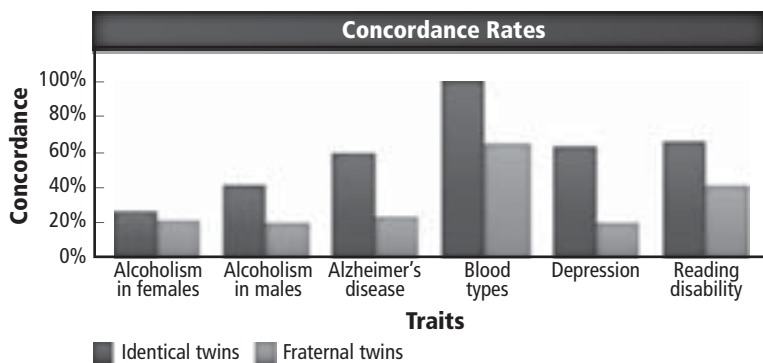
The environment influences many traits. Factors such as sunlight, temperature, and water can affect an organism's phenotype. For example, the gene that codes for the production of color pigment in Siamese cats functions only under cooler conditions. Cooler parts of the cat's body, such as the ears, nose, feet, and tail, are darker. The warmer parts of the body, where pigment production is inhibited, are lighter.

Environmental factors also include an organism's actions. Heart disease can be inherited, but diet and exercise also strongly influence the disease. An organism's actions are considered part of the environment because they do not come from genes.

Twin Studies

Scientists can learn about inheritance patterns by studying twins. Twin studies often reveal how genes and the environment affect phenotype.

Identical twins have identical genes. If a trait is inherited, both identical twins will have the trait. Scientists presume that traits that are different in identical twins are strongly influenced by the environment. The percentage of identical twins who both have the same trait is called a concordance rate, as shown in the graph below. The higher the concordance rate, the stronger the genetic influence.



✓ Reading Check

8. **List** an example of a polygenic trait.

Picture This

9. **Evaluate** Circle the trait that shows the strongest genetic influence.

Complex Inheritance and Human Heredity

section 1 Chromosomes and Human Heredity

MAIN Idea

Chromosomes can be studied using karyotypes.

What You'll Learn

- the role of telomeres
- how nondisjunction leads to Down syndrome and other abnormalities
- the benefits and risks of fetal testing

Mark the Text

Identify Main Ideas

Highlight the main idea of each paragraph.

Picture This

1. **Apply** Examine the karyotype. Are these chromosomes from a male or female?

Before You Read

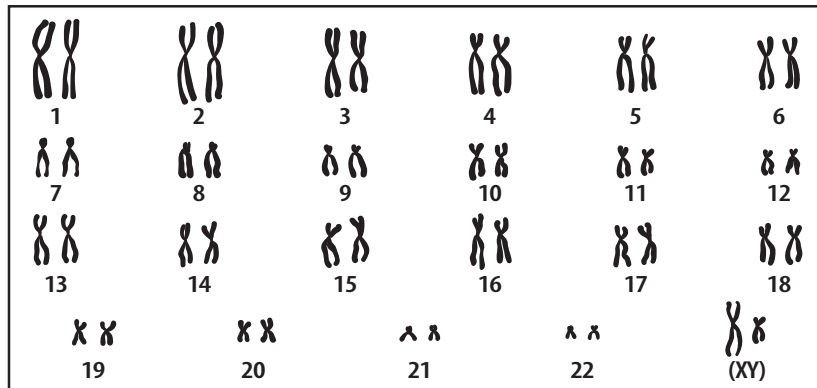
Think about the traits that people in a family might share. On the lines below, list the ways that people in families resemble each other. Then read to learn more about how scientists study genetic material.

Read to Learn

Karyotype Studies

Genetics not only is the study of genes, it is also the study of chromosomes. Images of chromosomes that have been stained during metaphase are studied. The staining bands mark identical places on homologous chromosomes. The homologous chromosomes are arranged, from biggest to smallest, to produce a micrograph called a **karyotype** (KER ee uh tipe). A karyotype is shown in the figure below.

Chromosomes of a human cell




_____ (No. of chromosome pairs) × 2 = _____ (No. of chromosomes)

Telomeres

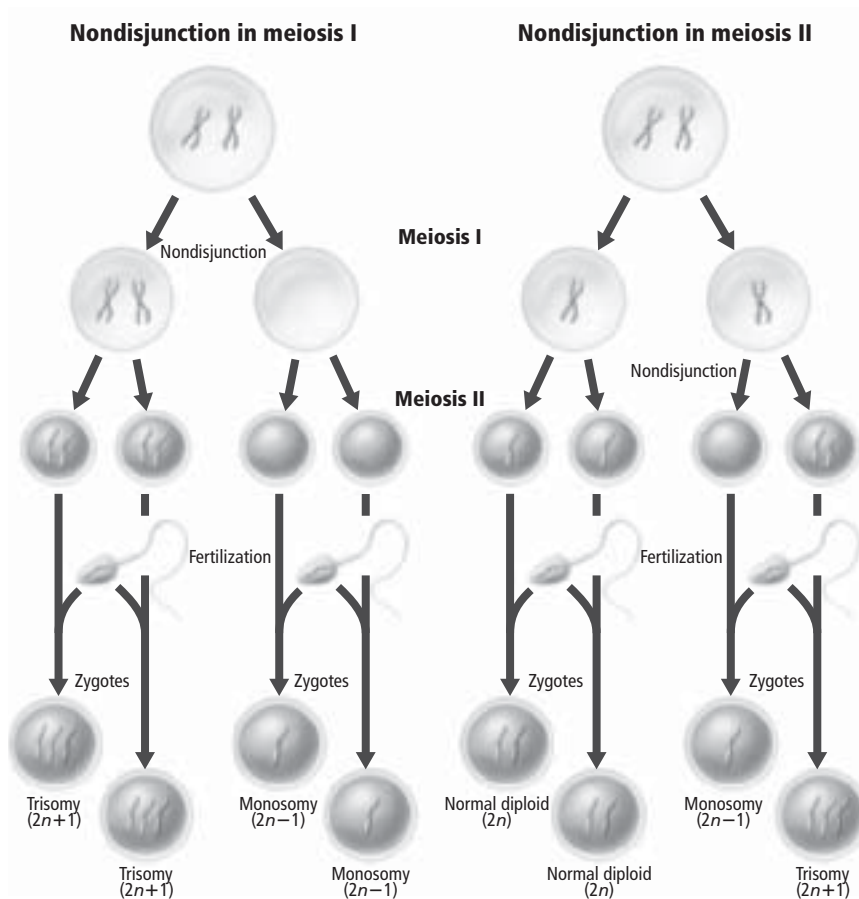
Telomeres are protective caps at the ends of chromosomes. They are made of DNA and proteins. Scientists have discovered that telomeres might be involved in both aging and cancer.

Nondisjunction

During cell division, the chromosomes separate and move to opposite poles of the cell. This ensures that each new cell has the correct number of chromosomes.

Cell division during which sister chromatids do not separate properly is called **nondisjunction**. Nondisjunction does not often occur. 

Nondisjunction during meiosis results in gametes that do not have the correct number of chromosomes. When one of these gametes undergoes fertilization, the offspring will not have the correct number of chromosomes. The figure below shows nondisjunction during meiosis. Trisomy (TRI so me) means having a set of three chromosomes. Monosomy (MAH nuh so me) means having only one copy of a chromosome.



Reading Check

2. Define What happens during nondisjunction?

Picture This

3. Evaluate Does nondisjunction during meiosis produce any normal gametes? Explain.

How does nondisjunction lead to Down syndrome?








Down syndrome is usually the result of an extra copy of chromosome 21. People with Down syndrome have distinctive facial features, are short, and have heart defects and mental disability. Approximately one out of 800 children born in the United States has Down syndrome. Older women have a greater chance of having a child with Down syndrome.

Does nondisjunction occur with sex chromosomes?

People can inherit incorrect numbers of both autosomes and sex chromosomes. The results of nondisjunction in sex chromosomes are shown in the figure below. A female with Turner's syndrome has only one sex chromosome. A male with Klinefelter's syndrome has two X chromosomes and one Y chromosome.

Picture This

4. Label Circle the pictures that show a trisomy in the sex chromosomes.

Nondisjunction in Sex Chromosomes							
Genotype	XX	XO	XXX	XY	XXY	XYY	OY
Example							
Phenotype	Normal female	Female with Turner's syndrome	Nearly normal female	Normal male	Male with Klinefelter's syndrome	Normal or nearly normal male	Results in death

Fetal Testing

A couple with a genetic disorder in the family might want to know if the developing baby, known as a fetus, has the disorder. Older couples might want to know the chromosome number of the fetus. Many fetal tests are available for observation of both the mother and the fetus. Fetal tests can provide important information to the parents and the physician.

Some risk is present in any test or procedure. The physician needs to consider health problems of the mother and the health of the fetus. The physician would not want to perform any tests that might harm the mother or the fetus. Physicians closely monitor the health of the mother and the fetus during testing.

Reading Check

5. State the purpose of fetal testing.

● Before You Read

In 1953, James Watson and Francis Crick discovered the structure of DNA. But they were not the first people to ask, “How is genetic information passed from one generation to the next?” Watson and Crick’s work was possible because of the work of other scientists. On the lines below, identify a task that is possible only because of the work of many people. Then read the section to learn more about how scientists discovered that DNA is the genetic code.

MAIN Idea

The discovery that DNA is the genetic code involved many experiments.

What You’ll Learn


- the basic structure of DNA
- the structure of a eukaryotic chromosome

● Read to Learn

Discovery of the Genetic Material

Mendel’s laws of inheritance became well known to scientists in the early 1900s. Scientists knew that genes were carried on chromosomes. They also knew that chromosomes were made of DNA and protein. For many years, scientists tried to determine which of these two molecules—DNA or protein—carried the genetic information of a cell.

What are smooth and rough bacteria?

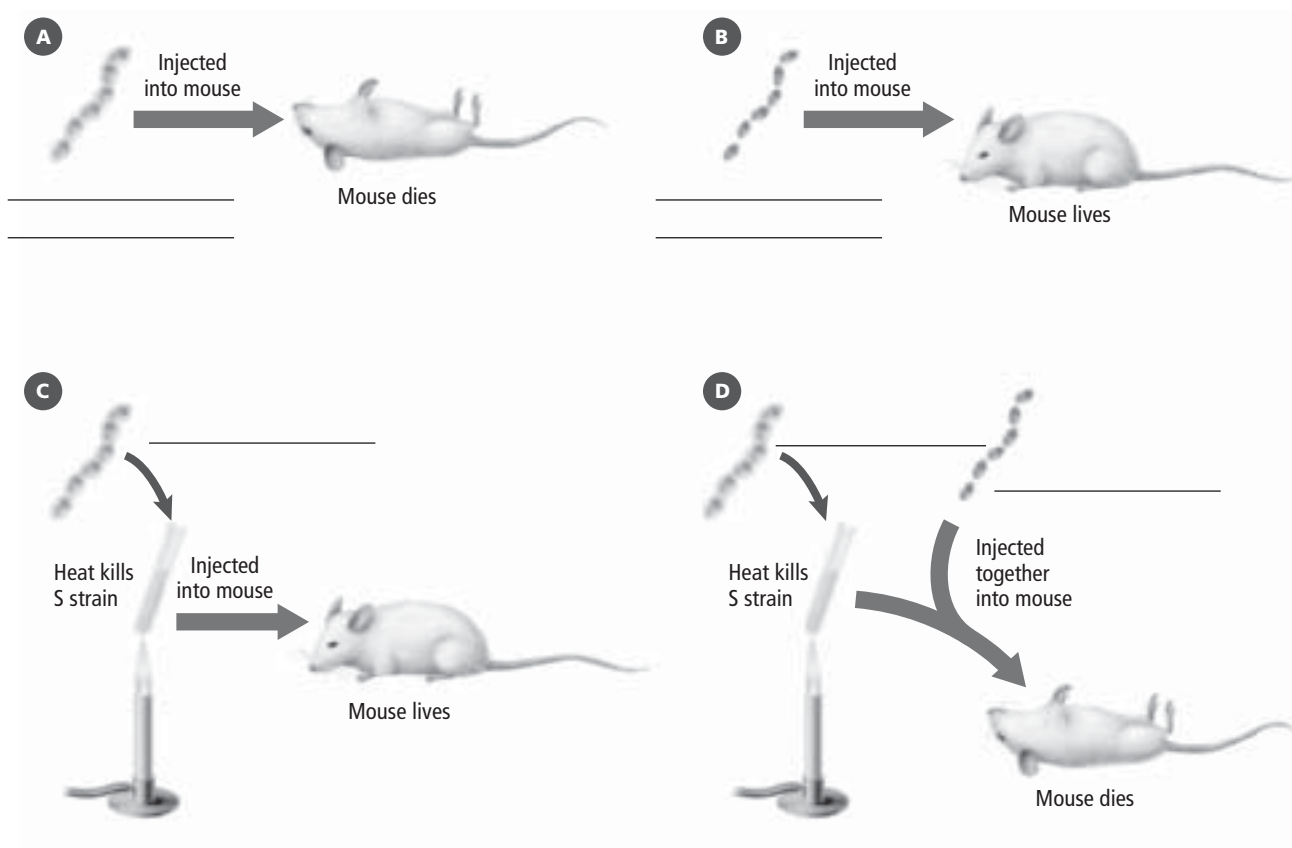
In 1928, Fredrick Griffith conducted an experiment that led to the discovery of DNA as the genetic material. Griffith studied two strains of *Streptococcus pneumoniae*. One strain had a sugar coat and caused pneumonia. It was called smooth (S) because colonies of bacteria appear smooth. Another strain did not have a sugar coat and did not cause pneumonia. It was called rough (R) because its colonies have rough edges. Follow along with Griffith’s study described on the next page. 

Mark the Text

Identify People As you read this section, underline the name of each scientist introduced. Highlight the sentences that explain each person’s contribution to understanding DNA.

Reading Check

1. **Contrast** Name two ways that rough bacteria differ from smooth bacteria.



Picture This

2. Label Write the name of each strain of bacteria (*S* for smooth, *R* for rough) in each of the experiments shown.

Reading Check

3. State what Avery found.

How were bacteria transformed?

When Griffith injected live *S* strain into a mouse, the mouse died. When Griffith injected live *R* strain into a mouse, the mouse did not die. These results are shown above in Parts A and B.

Next, Griffith heated and killed the *S* strain. When injected, the dead *S* strain no longer killed the mouse. This step is shown in Part C above.

Next, Griffith mixed the heat-killed *S* strain with the live *R* strain. As shown in Part D above, when he injected the mixture into a mouse, something unexpected happened—the mouse died. Griffith studied live bacteria from the dead mouse. The smooth trait was visible. He concluded that the live *R* strain had changed into live *S* strain.

How was the transforming factor identified?

In 1931, Oswald Avery, along with other scientists, identified the molecule that transformed the *R* strain into *S* strain. Avery tested DNA, protein, and lipids from heat-killed *S* strain. He found that only DNA was able to change *R* strain into *S* strain.

Who proved that DNA was the genetic material?

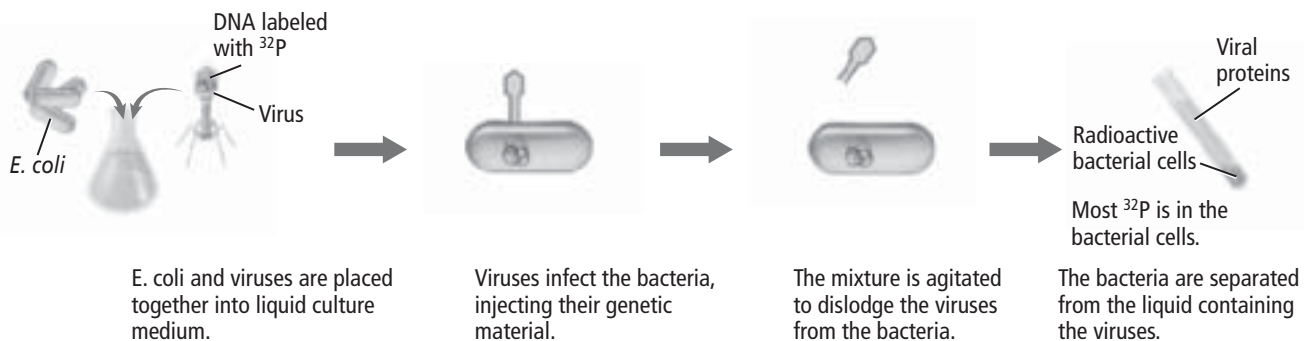
In spite of Avery's result, many scientists still questioned whether proteins or DNA were the genetic material. In 1952, Alfred Hershey and Martha Chase published results of an experiment proving that DNA was the genetic material. Hershey and Chase did an experiment with bacteriophages (bak TIHR ee uh fayjz), a type of virus that infects bacteria. The bacteriophages were made of DNA and protein. They reproduce by attaching to and injecting their genetic material into a living bacterial cell. ✓

Hershey and Chase used radioactive phosphorus (^{32}P) to label the DNA of one set of bacteriophages. They used radioactive sulfur (^{35}S) to label the protein of a second set of bacteriophages.

As shown in the figure below, Hershey and Chase mixed bacteria with viruses from the two groups. The viruses injected their genetic material into the bacteria. The viruses were separated from the bacteria.

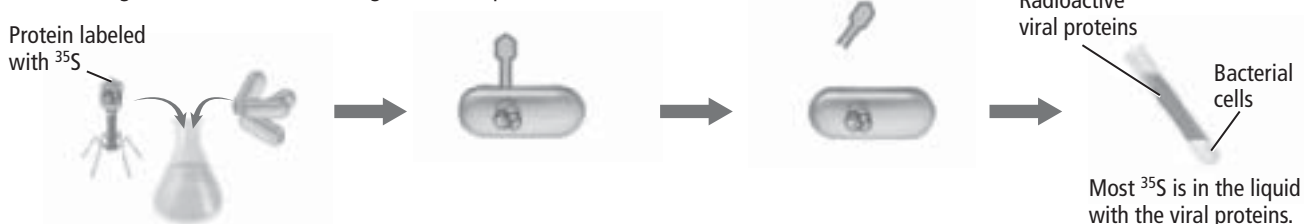
Group 1

Viruses are grown in medium containing ^{32}P to label DNA.



Group 2

Viruses are grown in medium containing ^{35}S to label protein.



What did the viruses inject into bacteria?

Hershey and Chase found that both sets of viruses had replicated inside the bacterial cells. But only the labeled DNA had entered the bacterial cells. The labeled protein remained outside the bacterial cells. This experiment provided evidence that DNA, not protein, was the genetic material.

Reading Check

4. Identify What two molecules make up a bacteriophage?

Picture This

5. Identify Circle the bacterial cells that have radioactive material inside of them.

DNA Structure

DNA is made of nucleotides. In the 1920s, biochemist P.A. Levene showed that each DNA nucleotide contains the sugar deoxyribose (dee ahk sih RI bos), a phosphate group, and one of four nitrogenous bases—adenine (A dun een), guanine (GWAH neen), cytosine (SI tuh seen), or thymine (THI meen).

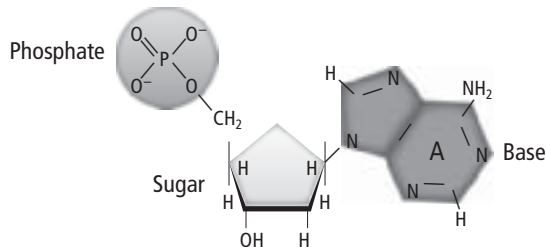
RNA also is made of nucleotides. Each RNA nucleotide contains the sugar ribose, a phosphate, and one of four nitrogenous bases—adenine, guanine, cytosine, and uracil (YOO ruh sihl). The figure below shows the structure of a nucleotide.

Adenine (A) and guanine (G) are double-ringed bases, which are called purine bases. Thymine (T), cytosine (C), and uracil (U) are single-ringed bases, which are called pyrimidine bases.

Erwin Chargaff discovered that the amount of guanine is almost equal to the amount of cytosine, and the amount of adenine is almost equal to the amount of thymine for the DNA of any given species. This finding is known as Chargaff's rule: $C = G$ and $T = A$.

Picture This

6. Identify Is the nucleotide in the picture a DNA nucleotide or an RNA nucleotide? How can you tell?



Who identified the structure of DNA?

After the Hershey-Chase experiment, most scientists thought that DNA was the genetic material. But they still did not know how nucleotides were arranged in a DNA molecule or why DNA followed Chargaff's rule.

Four scientists helped solve the structure of DNA: British scientists Rosalind Franklin, Maurice Wilkins, and Francis Crick and American scientist James Watson.

What did Franklin's picture show?


Franklin worked for Wilkins at King's College in London, England. She took a picture of DNA using X-ray diffraction, a technique that involved aiming X rays at DNA. Franklin's picture, called Photo 51, showed that DNA was a **double helix**, with two strands of nucleotides twisted around each other like a twisted ladder.

Reading Check

7. Identify What technique did Franklin use to take a picture of DNA?

What did Watson and Crick propose?

Watson and Crick saw Franklin's X-ray diffraction picture. They used Franklin's picture and data as well as other mathematical data to determine the specific structure of the DNA double helix.

Watson and Crick built a model of DNA with two outside strands made of deoxyribose alternating with phosphate. The bases were on the inside of the molecule—cytosine paired with guanine, thymine paired with adenine. 

What is the structure of DNA?

Imagine DNA as a twisted ladder. The rails of the ladder are made of alternating deoxyribose and phosphates. The pairs of bases (cytosine—guanine or thymine—adenine) form the rungs. The rungs are always the same width because a purine base always binds to a pyrimidine base.

Now imagine two pencils lying side by side with the point of one pencil next to the eraser of the other. Like these pencils, the two strands of the sugar-phosphate chain of a DNA double helix run in opposite directions. The ends of the sugar-phosphate strands are named 5' (read "five-prime") and 3' (read "three-prime"). One strand runs 5' to 3'. The other strand runs 3' to 5'.


When was the structure of DNA announced?

In 1953, Watson and Crick published a letter in the journal *Nature* suggesting the structure for DNA and a hypothesized method of copying the molecule. In the same issue, Wilkins and Franklin published separate articles that supported Watson and Crick's structure. Scientists had solved some mysteries. However, they still did not know how DNA worked as a genetic code.

Chromosome Structure

The DNA molecule in prokaryotes is contained in the cytoplasm. The DNA forms a ring with its associated proteins.

DNA in eukaryotes is organized into chromosomes. Human chromosomes vary in length from 51 million to 245 million base pairs. The DNA fits into the nucleus of a eukaryotic cell by coiling around a group of beadlike proteins called histones.

Nucleosomes are DNA that are tightly coiled around the histones. Nucleosomes are twisted together into chromatin fibers, which supercoil into a chromosome. 

Reading Check

8. Identify how the DNA bases pair.

Reading Check

9. Define What is a nucleosome made of?

MAIN Idea

DNA replicates by making a complementary strand to each original strand.

What You'll Learn

- the role of enzymes in the copying of DNA
- how leading and lagging DNA strands are made

Mark the Text

Identify Main Ideas

As you read, underline or highlight the main ideas in each paragraph.

Reading Check

1. **List** the three phases of semiconservative replication.

Before You Read

DNA is the instruction manual for a living thing. Each time one of your cells divides, your DNA is copied. That way, each new cell has its own copy of the instruction manual. On the lines below, list some items that come with instructions.

Read to Learn

Semiconservative Replication

Every time a cell divides, it must copy its DNA. That way, each cell has its own copy of the genetic material. When Watson and Crick presented their model of DNA, they also suggested a possible method of replication—semiconservative replication. In **semiconservative replication**, the two strands separate, serve as a pattern, and produce DNA molecules with one strand of the parental DNA and one strand of new DNA. Other scientists, armed with the knowledge of DNA's structure, began to explore ways that cells might copy DNA.

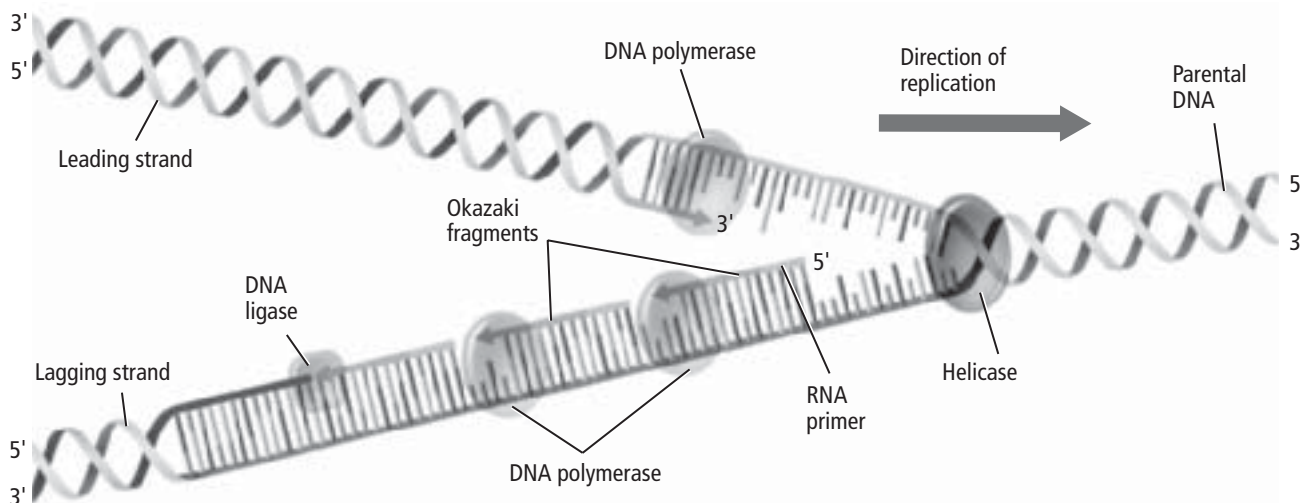
What are the steps of DNA replication?

Recall from Chapters 9 and 10 that DNA replication occurs during interphase of mitosis and meiosis. The process of semiconservative replication happens in three phases: unwinding, base pairing, and joining.

What happens during unwinding?

DNA replication is shown in the figure on the next page. In the first phase, an enzyme called DNA helicase unwinds the double helix. Single-stranded binding proteins hold the two strands apart. The RNA primase enzyme adds a short piece of RNA, called an RNA primer, to each strand of DNA.

Semiconservative Replication



How does base pairing occur?

In the next step, the enzyme **DNA polymerase** helps the addition of nucleotides, bonding a new nucleotide to the parent strand and creating base pairs as it forms new strands.

Recall that one DNA strand runs 3' to 5'. The other runs 5' to 3'. The two strands are copied differently. One strand, called the leading strand, is made longer as the original DNA unwinds and nucleotides are added to its 3' end. The other strand, called the lagging strand, becomes longer as small pieces called **Okazaki fragments** are added in the 3' to 5' direction.

How are the fragments joined?

DNA polymerase removes RNA primers and replaces them with DNA nucleotides. When the last RNA primer has been removed and replaced with DNA nucleotides, the enzyme DNA ligase connects the DNA nucleotides.

Comparing DNA Replication in Eukaryotes and Prokaryotes

Eukaryotic DNA replication occurs at many places at the same time. The sites of DNA replication look like bubbles in the DNA strand.

Prokaryotic DNA is circular. In prokaryotes, the DNA strand is opened at one place on the circle. Replication occurs in both directions, unzipping the circle, until the whole DNA strand is copied.

Picture This

- 2. Identify** Circle the names of the three enzymes involved in the process of semiconservative replication.



Think it Over

- 3. Compare** Name one difference between eukaryotic DNA replication and prokaryotic DNA replication.

MAIN Idea

DNA codes for RNA, which guides protein synthesis.

What You'll Learn

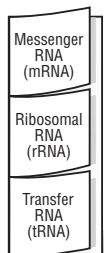
- the different types of RNA involved in transcription and translation
- the role of RNA polymerase in the making of messenger RNA

Study Coach

Create a Quiz Read this section, and create a quiz with answers.

FOLDABLES™

Record Information Make a three-tab Foldable, as shown below, to organize information about the three types of RNA and how each is involved in transcription and translation.



● Before You Read

Computer programmers use a type of language, or code. The computer reads the code and follows the instructions. On the lines below, give other examples of codes. In this section you will learn how DNA, the genetic code, contains instructions for making proteins.

● Read to Learn

Central Dogma

Proteins function as the building blocks of a cell and as enzymes. The instructions for making proteins are found in DNA. The information is read and expressed from DNA to RNA to proteins. This chain of events is called the central dogma of biology: DNA codes for RNA, which guides the making of proteins.

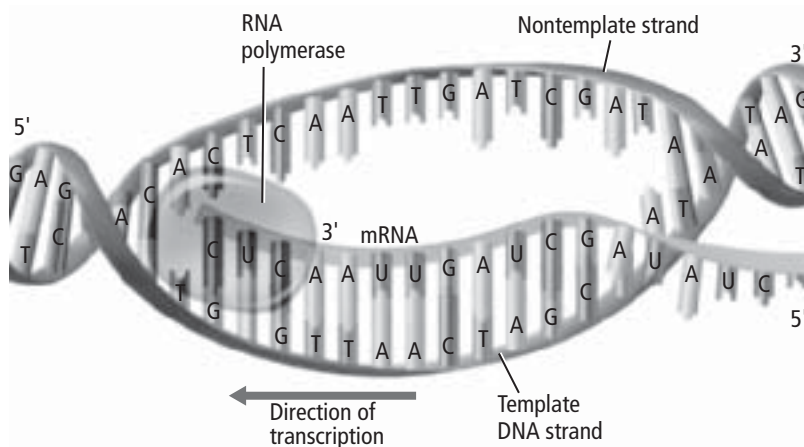
What are the types of RNA?

RNA, like DNA, is a nucleic acid. RNA nucleotides contain the sugar ribose instead of deoxyribose and the base uracil instead of thymine. RNA usually exists in single strands. Cells contain three main types of RNA—messenger RNA, ribosomal RNA, and transfer RNA.

Messenger RNA (mRNA) molecules are long strands of RNA nucleotides that direct ribosomes to make proteins. They travel from the nucleus to the ribosome. Ribosomal RNA (rRNA) molecules make up part of the ribosomes of the cell in the cytoplasm. Transfer RNA (tRNA) molecules transport amino acids to the ribosomes.

What happens during transcription?

During **transcription** (trans KRIHP shun), mRNA is made from DNA. As shown below, the DNA is unzipped in the nucleus. **RNA polymerase** binds where mRNA will be made. RNA polymerase makes mRNA in the 5' to 3' direction. Uracil is added to the mRNA strand instead of thymine, making a complement to the DNA strand. The mRNA strand moves out of the nucleus through nuclear pores into the cytoplasm.



How is mRNA processed?

The mRNA code that is made during transcription has all of the DNA code. Before it leaves the nucleus, the pre-mRNA molecule undergoes processing. First, some of the sequences that interrupt the DNA code, called **introns**, are cut out. The sequences that remain in the mRNA molecule are called **exons**. Exons are the protein-coding sequences. ✓

A protective cap is added to the 5' end of the mRNA strand. A string of adenines, called a poly-A tail, is added to the 3' end.

The Code

The only way DNA varies among organisms is the sequence of bases. There are 20 amino acids that are used to make proteins, so DNA must provide at least 20 codes.

In the 1960s, scientists discovered that the DNA code is a three-base code called a **codon**. Each codon is transcribed into the mRNA code.

The genetic code for all 64 codons is shown in the table at the top of the next page. Three codons—UAA, UAG, and UGA—do not code for an amino acid. They are called stop codons because they stop the transcription process. AUG codes for methionine and is the start codon.

Picture This

1. **Draw** an arrow pointing to the location where the DNA is unzipped and where mRNA is made.

Reading Check

2. **Define** What is the name of the sequences that are removed from mRNA during processing?

Picture This

3. Apply Determine the amino acid chain that would result from the sequence AUG-CCC-GGA-UUA-UAG.

Dictionary of the Genetic Code

First Base	Second Base				Third Base
	U	C	A	G	
U	UUU phenylalanine	UCU serine	UAU tyrosine	UGU cysteine	U
	UUC phenylalanine	UCC serine	UAC tyrosine	UGC cysteine	C
	UUA leucine	UCA serine	UAA stop	UGA stop	A
	UUG leucine	UCG serine	UAG stop	UGG tryptophan	G
C	CUU leucine	CCU proline	CAU histidine	CGU arginine	U
	CUC leucine	CCC proline	CAC histidine	CGC arginine	C
	CUA leucine	CCA proline	CAA glutamine	CGA arginine	A
	CUG leucine	CCG proline	CAG glutamine	CGG arginine	G
A	AUU isoleucine	ACU threonine	AAU asparagine	AGU serine	U
	AUC isoleucine	ACC threonine	AAC asparagine	AGC serine	C
	AUA isoleucine	ACA threonine	AAA lysine	AGA arginine	A
	AUG (start) methionine	ACG threonine	AAG lysine	AGG arginine	G
G	GUU valine	GCU alanine	GAU aspartate	GGU glycine	U
	GUC valine	GCC alanine	GAC aspartate	GGC glycine	C
	GUA valine	GCA alanine	GAA glutamate	GGA glycine	A
	GUG valine	GCG alanine	GAG glutamate	GGG glycine	G

What happens during translation?

After the mRNA is made, it leaves the nucleus and moves to the cytoplasm. There the 5' end of the mRNA connects to a ribosome. The ribosome is where the code is read and translated to make proteins through a process called **translation**.

During translation, tRNA molecules act as interpreters of the mRNA. Each tRNA molecule is folded into a cloverleaf shape. The 3' end attaches to a specific amino acid. At the middle of the folded strand, there is a three-base coding sequence called an anticodon. Each anticodon is complementary to a codon on the mRNA. The anticodon is read 3' to 5'.

What is the role of the ribosome?

You can think of the ribosome as a factory for making proteins. Ribosomes are made of two parts—a large subunit and a small subunit. The subunits are not involved in making protein. The two parts of the ribosome come together and attach to an mRNA molecule to complete the ribosome.

Think it Over

- 4. Name** Where in the cell does translation occur? (Circle your answer.)
- cytoplasm
 - nucleus
 - endoplasmic reticulum

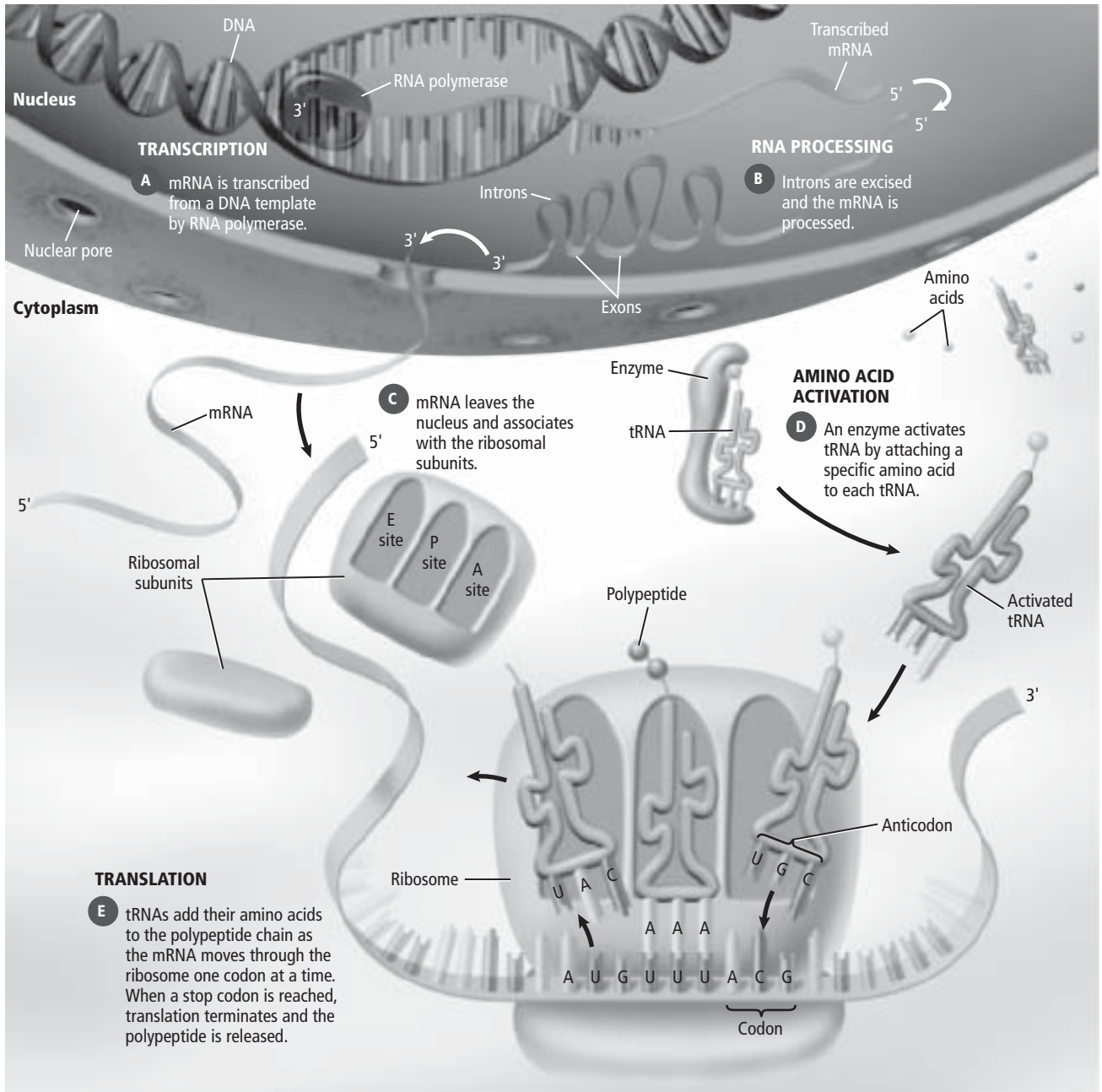
How does translation work?

Transcription takes place in the nucleus. Translation occurs in the cytoplasm.

Follow along with the picture below. You will see how the ribosome translates the mRNA code into a chain of amino acids, called a polypeptide.

Picture This

5. Identify Circle the tRNA in the P site.





Think it Over

6. Identify In what order does a tRNA move through the binding sites on a ribosome? (Circle your answer.)

- a. E site–P site–A site
- b. A site–E site–P site
- c. P site–A site–E site

How is a protein made?

A tRNA molecule with the anticodon CAU carrying a methionine will move in and bind to the mRNA start codon—AUG—on the 5' end.

A tRNA, that is complementary to the mRNA codon, binds to a groove in the ribosome known as the P site. A second tRNA, that is complementary to the second mRNA codon, moves into a second groove called the A site.

The ribosome bonds the new amino acid in the A site and the amino acid in the P site. As the two amino acids join, the tRNA in the P site is released to the third site, called the E site, where it exits the ribosome.

The ribosome then moves along the mRNA molecule, so the tRNA in the A site shifts to the P site. A new tRNA then moves into the A site. The process continues, adding and joining amino acids in the sequence determined by the mRNA.

The ribosome continues moving along the mRNA, linking amino acids together, until it reaches a stop codon. The mRNA is released from the last tRNA by proteins called release factors, and the ribosome subunits come apart, ending protein synthesis.

One Gene—One Enzyme

Scientists still needed to learn the relationship between the genes and the proteins for which they coded. In the 1940s, George Beadle and Edward Tatum conducted experiments on the mold *Neurospora*. The mold spores they studied were mutated by exposure to X rays. Their experiments showed that a gene can code for an enzyme. Based on the results of their experiments, Beadle and Tatum proposed that each gene makes one enzyme, the “one gene—one enzyme” hypothesis.

How has the one gene—one enzyme hypothesis been revised?

Later experiments by other scientists showed that some enzymes contain more than one polypeptide chain. As a result, the hypothesis has been changed to state that each gene codes for one polypeptide.

● Before You Read

Like a DNA codon, the sentence, “The dog ran.” contains only three-letter words. Insert one letter “Z” and the sentence changes to, “ThZ edo gra.” On the lines below, write the sentence that results if you insert two letters, then three letters. Which sentence is easiest to read? In this section, you will read about how mutations affect gene expression.

MAIN Idea

The cell regulates gene expression, and mutations can affect this expression.

What You’ll Learn


- how bacteria can regulate their genes by operons
- how eukaryotes regulate transcription of genes

● Read to Learn

Prokaryote Gene Regulation

Cells use **gene regulation** to control which genes are transcribed in response to the environment. Prokaryotes use operons to control the transcription of genes. An **operon** is a section of DNA that contains the genes for the proteins needed for a specific metabolic pathway. An operon contains an operator, a promoter, and a regulatory gene. The operator is like an on/off switch for transcription. The promoter is where RNA polymerase first binds to the DNA.

How does the *trp* operon work?

The tryptophan (*trp*) operon in the bacteria *Escherichia coli* (*E. coli*) is a repressible operon. Tryptophan synthesis occurs in five steps. Each step is triggered by a specific enzyme. The tryptophan operon contains five genes (*trpA* through *trpE*) needed to make the amino acid tryptophan. When tryptophan levels are low, RNA polymerase binds to the operator, turning on the transcription of the five enzyme genes needed for tryptophan synthesis. 

Mark the Text

Restate the Main Point

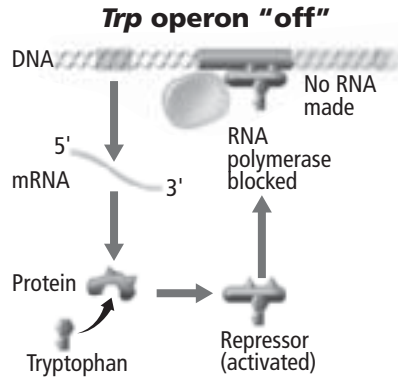
Highlight the main point in each paragraph. State each main point in your own words.

Reading Check

1. **Explain** What triggers each step in the synthesis of tryptophan?

How is the *trp* operon turned off?

The figure below shows what happens when tryptophan is abundant. The cell has no need to make tryptophan. Tryptophan binds to the repressor protein to activate it. The complex binds to the operator, keeping RNA polymerase from binding. The genes needed for tryptophan synthesis are not made.



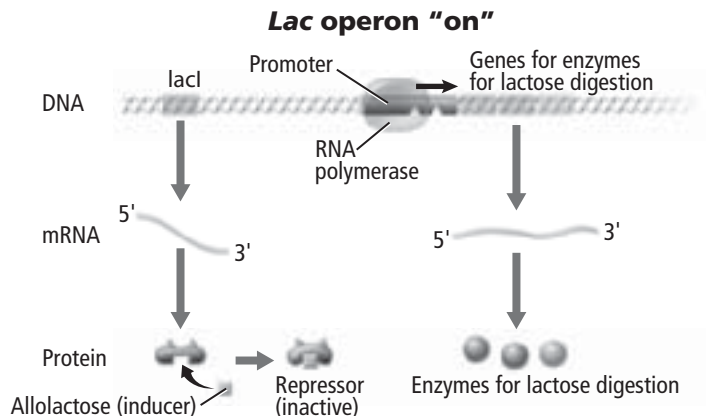
Picture This

- 2. Identify** Circle the operator sequence where the tryptophan-repressor complex is bound.

How does the *lac* operon work?

The *E. coli* lactose (*lac*) operon, an inducible operon, is shown below. The *lac* operon contains a promoter, an operator, a regulatory gene, and three genes that code for enzymes needed to digest the sugar lactose as food. The *lac* operon is switched on by an inducer, a molecule present in food containing lactose. The inducer binds to the *lac* repressor and inactivates it. RNA polymerase can bind to the promoter and transcription proceeds, and the lactose-digesting enzymes are made.

E. coli does not need to make lactose-digesting enzymes when lactose is not available. In that case, an inducer is not present and the regulatory gene makes a repressor protein that binds to the operator and blocks transcription.




Picture This

- 3. Label** Circle the allolactose-repressor complex. How is the *lac* repressor different from the *trp* repressor?

Eukaryote Gene Regulation

Eukaryotes have many more genes than prokaryotes. They also use different, more complex methods of gene regulation.

How do eukaryotes control transcription?

Proteins called transcription factors control when a gene is turned on and how much of that protein is made. Some transcription factors guide the binding of RNA polymerase to a promoter. Other transcription factors control the rate of transcription. 

How do Hox genes work?

Homeobox (Hox) genes code for transcription factors. Hox genes control differentiation, the process through which cells become specialized in shape and function. Hox genes are used during embryo development and are active in different zones of the embryo. They control what body part will develop in different parts of the embryo.


What is RNA interference?

Another way that eukaryotic genes are regulated is RNA interference (RNAi). Interfering RNA molecules are small segments of double-stranded RNA that bind to a protein complex that breaks down one strand of the RNA. The resulting single-stranded interfering RNA and protein complex bind to mRNA sequences and prevent mRNA from being translated.

Mutations

A permanent change in a cell's DNA is called a **mutation**. Mutations that occur in a gene sequence can change the protein that is made. Mutated proteins often do not work.

What mutations involve a single nucleotide?

Point mutations occur when a single nucleotide is changed and can result in a genetic disorder. A substitution is a kind of point mutation that occurs when one base is exchanged for another. A missense mutation is a substitution in which the DNA code is changed so that it codes for the wrong amino acid. A nonsense mutation changes the codon for an amino acid to a stop codon. Nonsense mutations often cause translation to stop early, making a protein that is too short. Muscular dystrophy is an example of a disease caused by a nonsense mutation. 

Reading Check

4. **State** two ways that transcription factors control genes.

Reading Check

5. **Name** What type of mutation occurs when a stop codon replaces an amino acid codon?



Think it Over

6. Evaluate Would a 3-nucleotide insertion result in a frameshift? Why or why not?

Reading Check

7. Explain How does UV light damage DNA?

What are some other types of mutations?

Insertions and deletions occur when a nucleotide is added or lost. Insertions and deletions can cause a frameshift mutation, causing the ribosome to misread the codons. THE BIG FAT CAT ATE THE WET RAT becomes THE BIG ZFA TCA TAT ETH EWE TRA. Cystic fibrosis and Crohn's disease are both caused by frameshift mutations. Some mutations involve large pieces of DNA containing many genes. A piece of a chromosome can be deleted, moved to a different location on the same chromosome, or moved to another chromosome. Such mutations often have serious effects.

In 1991, a new type of mutation was discovered. This mutation happens when repeated sequences, called tandem repeats, increase in number. Fragile X syndrome and Huntington's disease are both caused by this type of mutation.

How do mutations affect protein folding?

Small mutations, like substitutions, can lead to genetic disorders. Changing one amino acid for another can change how a protein folds and, as a result, change how it functions.

What causes mutations?

Some mutations occur simply because DNA polymerase makes a mistake, adding the wrong nucleotide during DNA replication. Other mutations are caused by **mutagens** (MYEW tuh junz), which are chemicals or radiation that can damage DNA.

Some mutagens resemble nucleotides so closely, that DNA polymerase mistakes them for nucleotides and adds the mutagen into the DNA chain. Chemical mutagens are being studied for possible use in treating HIV—the virus that causes AIDS.

UV radiation from the Sun can damage DNA. It can cause thymine bases that are next to each other to bind together. This creates a kink in the DNA, and it cannot replicate.

How are mutations inherited?

Mutations in body cells, or somatic cells, are not passed on to the next generation. Sometimes these mutations do not cause problems for the cell. Other times they kill the cell. Some somatic cell mutations lead to cancer.

Mutations in sex cells are passed on to the organism's offspring. Every cell in the offspring will carry the mutation. Sometimes the mutations do not change how those cells function. Other times the mutations have serious effects.

● Before You Read

Imagine that you could design the perfect dog. What color would it be? Would it be big or small? On the lines below, describe the traits your dog would have. In this section, you will learn how selective breeding produces certain traits.

MAIN Idea

Selective breeding is used to create animals or plants with certain traits.

What You'll Learn

- how inbreeding differs from hybridization
- how to use test crosses and a Punnett square to find the genotypes of organisms

● Read to Learn

Selective Breeding

For thousands of years, people have been breeding animals and plants to have certain traits. For instance, some dogs, such as huskies, have been bred to be strong runners. Other dogs, such as Saint Bernards, have been bred to have a good sense of smell.

People have also bred plants, such as tomatoes, apples, and roses, to taste better, resist disease, or produce fragrant flowers. **Selective breeding** is the process used to breed animals and plants to have desired traits. As a result of selective breeding, desired traits become more common.

What is hybridization?

A hybrid is an organism whose parents each have different forms of a trait. For instance, a disease-resistant tomato plant can be crossed with a fast-growing tomato plant. The offspring of the cross would be a tomato plant that has both traits. The hybrid is disease resistant and grows quickly.

Hybridization is the process of making a hybrid organism. Hybridization is expensive and takes a long time, but it is a good way to breed animals and plants with the right combination of traits.

Study Coach

Create a Quiz After you read this section, create a five-question quiz from what you have learned. Then, exchange quizzes with another student. After taking the quizzes, review your answers together.

Reading Check

1. **Name** an advantage of hybridization.


How is inbreeding used?

Inbreeding is another example of selective breeding. **Inbreeding** occurs when two closely related organisms that both display the desired trait are bred. Inbreeding can be used to ensure that the desired trait is passed on. Inbreeding can also eliminate traits that are not desired.

Purebred animals are created by inbreeding. Clydesdale horses are an example of a purebred animal. Clydesdale horses were first bred in Scotland hundreds of years ago. They were bred for use as farm horses that could pull heavy loads. All Clydesdales have the traits of strength, agility, and obedience.

A disadvantage of inbreeding is that harmful traits can be passed on. Harmful traits are usually carried on recessive genes. Both parents must pass on the recessive genes for the harmful traits to appear in the offspring. Inbreeding increases the chance that both parents carry the harmful traits.

Test Cross

Breeders need a way to determine the genotype of the organisms they want to cross before creating a hybrid. They use test crosses to find out the genotype of an organism. In a **test cross**, an organism whose genotype for a desired trait is unknown is crossed with an organism that has two recessive genes for the trait. 

When are test crosses performed?

An orchard owner might use a test cross to find out the genotype of a white-grapefruit tree. In grapefruits, white color is a dominant trait and red color is a recessive trait. A red-grapefruit tree has two recessive genes (ww). A white-grapefruit tree might have two dominant genes (WW), or it might have one dominant gene and one recessive gene (Ww).

Genotype	Phenotype
Homozygous dominant (WW)	
Homozygous recessive (ww)	
Heterozygous (Ww)	

Reading Check

2. Explain What is the purpose of a test cross?

Picture This

3. Label Fill in the phenotype with the word *white* or *red* for each genotype.

How does a test cross reveal the genotype?

The orchard owner decides to do a test cross to find out the genotype of a white-grapefruit tree. The white-grapefruit tree is crossed with a red-grapefruit tree. The orchard owner uses a Punnett square to understand the results of the cross.

The figure below shows a Punnett square for the test cross if the white-grapefruit tree is homozygous, meaning it has two dominant genes (WW). All the offspring from the test cross will be heterozygous, meaning they will have one dominant and one recessive gene (Ww). All the offspring of the test cross are white-grapefruit trees.

		Homozygous white grapefruit	
		W	W
Homozygous red grapefruit	w	Ww	Ww
	w	Ww	Ww

What if the test cross involved the heterozygous tree?

The figure below shows a Punnett square for the test cross if the white-grapefruit tree is heterozygous (Ww). Half the offspring from the test cross will be white (Ww). Half the offspring from the test cross will be red (ww).

		Heterozygous white grapefruit	
		W	w
Homozygous red grapefruit	w	Ww	ww
	w	Ww	ww

Picture This

4. Evaluate If you planted 100 seeds from this test cross, about how many would be white? How many would be red?

Picture This

5. Calculate If you planted 100 seeds from this test cross, about how many would be white? How many would be red?

MAIN Idea

Genetic engineering manipulates recombinant DNA.

What You'll Learn

- the difference between selective breeding and genetic engineering
- how genetic engineering can be used to improve human health

Mark the Text

Main Ideas As you read, underline or highlight the main ideas in each paragraph.

Reading Check

1. **State** What do scientists have to do to a gene before they can manipulate it?

Before You Read

The tools that a chef uses to prepare food differ from the tools a mechanic uses to fix cars. On the lines below, describe a few of the tools you use at home and school. In this section, you will learn about tools scientists use to study DNA.

Read to Learn

Genetic Engineering

For many years, scientists knew the structure of DNA and knew that information flowed from DNA to RNA and from RNA to proteins. In the last few decades, scientists have learned more about how individual genes work by using genetic engineering. **Genetic engineering** is a way of manipulating the DNA of an organism by inserting extra DNA or inserting DNA from another organism.

One example of genetic engineering uses green fluorescent protein (GFP). GFP is a protein made naturally in jellyfish. GFP causes jellyfish to turn green under ultraviolet light. Scientists have inserted the DNA for making GFP into other organisms. This makes the organisms glow.

DNA Tools

An organism's **genome** is all the DNA present in the nucleus of each cell. Genomes can contain millions of nucleotides in the gene's DNA. In order to study a specific gene, scientists isolate it from the rest of the organism's DNA. Scientists can then manipulate it. To understand how scientists do this, it is helpful to know the DNA tools scientists use.

What are restriction enzymes?

Scientists have found hundreds of restriction enzymes. **Restriction enzymes** are proteins made by bacteria. Each restriction enzyme cuts, or cleaves, DNA at a specific DNA sequence.

How do restriction enzymes work?

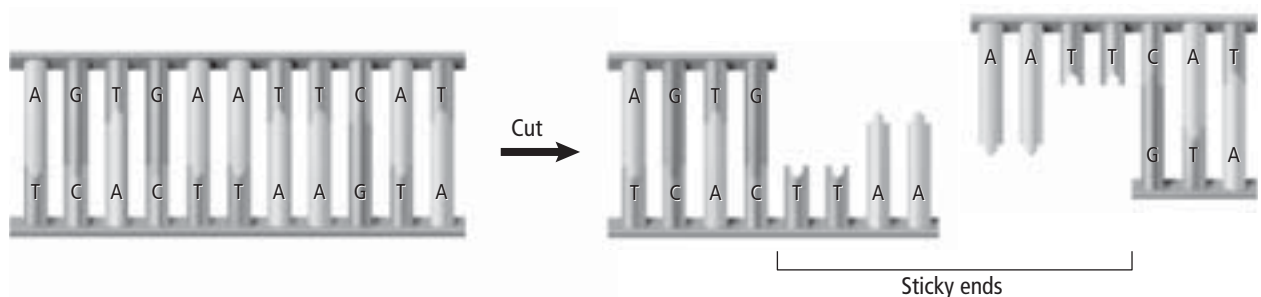
One restriction enzyme that is often used by scientists is called *EcoRI*. *EcoRI* cuts DNA containing the sequence GAATTC. After *EcoRI* cuts DNA, it leaves single-stranded ends, called *sticky ends*, as shown in the figure below. DNA that has been cut with *EcoRI* always has the same sticky ends. DNA fragments with sticky ends can be joined with other DNA fragments with complementary sticky ends.

Not all restriction enzymes leave sticky ends. Some restriction enzymes cut straight across both DNA strands, leaving blunt ends. DNA fragments with blunt ends can be joined to other DNA fragments with blunt ends.

How is gel electrophoresis used to separate DNA fragments?

After DNA is cut with a restriction enzyme, the DNA fragments are different sizes. Scientists use **gel electrophoresis** to separate DNA fragments according to the size of the fragments.

DNA fragments are placed on the negatively charged end of a material called gel. An electric current is applied to the gel. The DNA fragments move toward the positive end of the gel. Smaller fragments move through the gel faster than larger fragments. The unique pattern made by the DNA fragment can be compared to the patterns of known DNA fragments for identification. The figure below shows a gel in which DNA has been separated by electrophoresis.



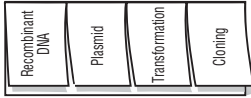
Think it Over

- 2. Explain** Why can two different fragments of DNA cut with *EcoRI* be joined?

Picture This

- 3. Analyze** Use the figure to explain to a partner how gel electrophoresis works.

Take Notes Make a four-tab Foldable, as shown below. As you read, take notes and organize what you learn about recombinant DNA technology.



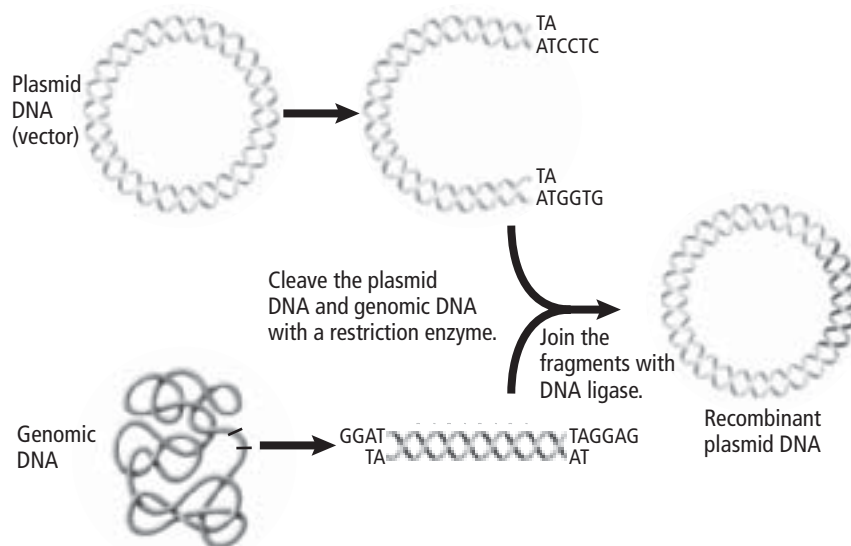
Picture This

4. Identify Circle the carrier in the figure.

Recombinant DNA Technology

Once DNA fragments have been separated using gel electrophoresis, fragments can be removed from the gel. These DNA fragments can then be combined with DNA fragments from another source, as shown in the figure below. This new DNA molecule, with DNA from different sources, is called **recombinant DNA**. Recombinant DNA allows scientists to study individual genes.

Scientists often need to make a lot of recombinant DNA to study it. Scientists use host cells, such as bacteria, to copy the recombinant DNA. A carrier, known as a vector, is used to carry the recombinant DNA into the host cell. One commonly used vector is a small, circular, double-stranded DNA molecule called a **plasmid**. Plasmids can be cut with restriction enzymes. DNA fragments and plasmids cut with the same restriction enzyme can be combined at their sticky ends. An enzyme called **DNA ligase** is then used to join the plasmids and the DNA fragments chemically.



How does transformation occur?

Plasmid DNA can be moved into bacterial cells by **transformation**. Transformation occurs when bacterial cells are heated or given a small electric shock. This creates holes in the plasma membrane of the bacterial cell, enabling the plasmid DNA to enter the bacterial cell.

Plasmids are found naturally in bacteria. When the bacteria reproduce and copy their own DNA, they also copy the plasmid DNA. **Cloning** occurs when bacteria reproduce and copy recombinant DNA molecules.

What is DNA sequencing?

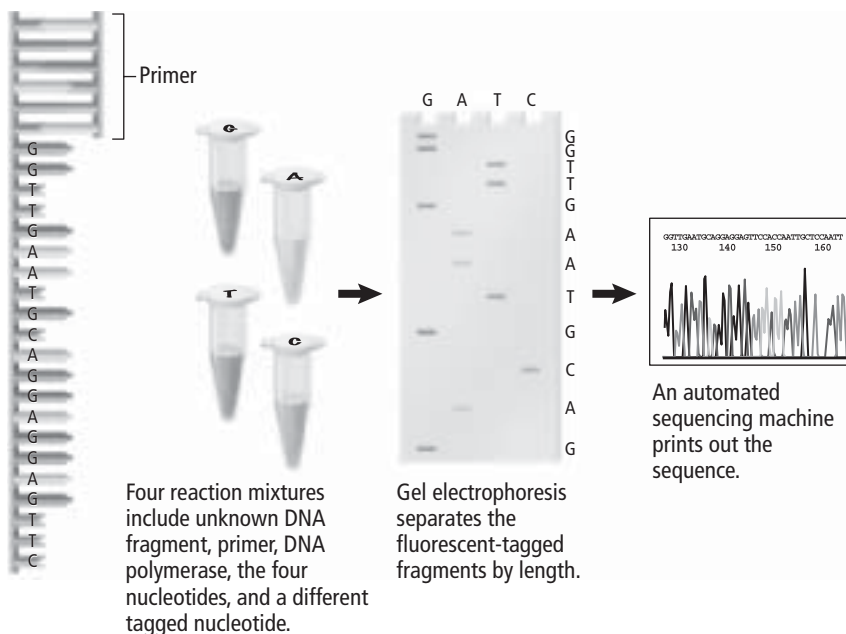
DNA sequencing involves finding out the exact order of the nucleotides that make up an organism's DNA. Knowing the DNA sequence of an organism gives scientists clues about how that organism's genes work. Scientists can compare genes from different organisms. Scientists can also find errors in the DNA. Long DNA molecules must be cut with restriction enzymes before they can be sequenced. ✓

How is DNA sequenced?

The figure below shows how DNA is sequenced. Scientists mix an unknown DNA fragment, DNA polymerase, and the four nucleotides—A, C, G, and T. Then they add a small amount of the four nucleotides, each tagged with a different color of fluorescent dye.

What stops the growth of a DNA strand?

Usually, when DNA polymerase copies the DNA fragment it will put normal nucleotides on the growing strand. However, sometimes a fluorescent-tagged nucleotide will be added to the strand. Every time these tagged nucleotides are added, the new DNA strand stops growing. This produces DNA strands of different lengths. The tagged fragments are separated by gel electrophoresis. An automated DNA sequencing machine is used to detect the color of each tagged nucleotide. The sequence of the original DNA is determined from the order of the tagged fragments.



Reading Check

5. Determine How are restriction enzymes used?

Picture This

6. Identify Which step in the process separates DNA fragments by length?

Reading Check

7. Explain Why is polymerase chain reaction used to make millions of copies of a DNA fragment?

Picture This

8. Identify Underline the two starting points for the DNA copies.

What is polymerase chain reaction?

Polymerase chain reaction (PCR) can be used to make millions of copies of a specific region of a DNA fragment. PCR is so sensitive that it can detect a single DNA molecule in a sample. With PCR, scientists can copy a single DNA molecule many times so they can study it.

PCR is a powerful tool used by scientists. Forensic scientists use PCR to identify suspects and victims of crimes. Doctors use PCR to detect diseases such as AIDS.

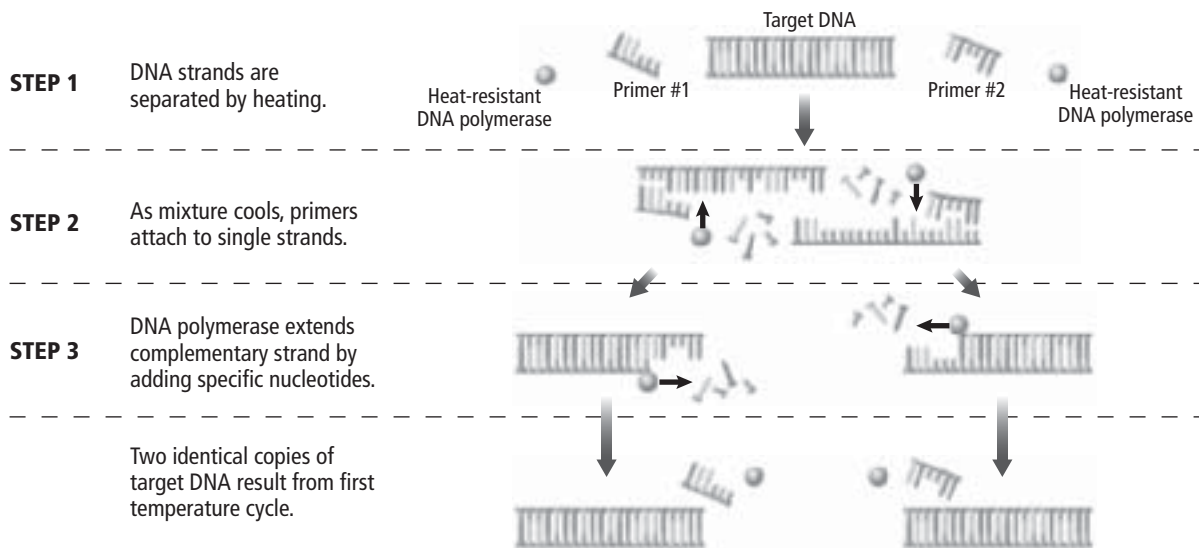
What are the steps of PCR?

Follow the figure below as you read the steps of PCR.

Step 1 Four things are mixed in a small tube: the DNA fragment to be copied, DNA polymerase, the four DNA nucleotides—A, G, C, and T—and two short, single-stranded pieces of DNA called primers. The primers are complements to the ends of the DNA fragment to be copied. The primers are used as starting points for the DNA copies.

Step 2 The tube is placed into a thermocycler. The thermocycler heats and cools the tube over and over again. When the tube is heated, the two strands of the DNA fragment separate. When the tube is cooled, the primers bind to the ends of the separated strands of the DNA fragment.

Step 3 Each primer binds to one strand of the DNA fragment. DNA polymerase then puts the correct nucleotides between the two primers making the copies. The DNA polymerase used in PCR must be able to withstand high heat. It comes from bacteria that live in hot springs, like the ones in Yellowstone National Park.



Biotechnology

Biotechnology is the application of genetic engineering to human problems. Scientists can use biotechnology to produce transgenic organisms. **Transgenic organisms** are organisms that have a gene from a different organism inserted into their DNA. Transgenic animals, plants, and bacteria are used for scientific research, in agriculture, and to treat human diseases.

How are transgenic animals used?

Most transgenic animals are made in laboratories for biological research. Some commonly studied animals are mice, fruit flies, and roundworms. Scientists use these organisms to study diseases and develop ways to treat them.

Transgenic livestock are used to improve the food supply. They also are used to improve health in people. For instance, scientists have engineered goats to make a protein that stops blood from clotting. Doctors use this protein during surgery. Several species of fish have been genetically engineered to grow faster. In the future, transgenic animals might be used as a source of organs for organ transplants in people.

How are transgenic plants used?

Transgenic crops are grown around the world. Farmers in at least 18 countries grow transgenic corn, soybeans, canola, and cotton on millions of acres. Farmers plant these crops because they are resistant to herbicides and insecticides. For example, farmers now plant genetically engineered cotton. The cotton has been engineered to resist bolls, insects that harm cotton plants.

Scientists have developed other transgenic crops. They are testing these crops in fields. One of these crops is a transgenic rice that is more nutritious than normal rice. Scientists hope to use the transgenic rice to decrease malnutrition in Asian countries. Scientists are also testing crops that are designed to survive extreme weather.

Someday, peanuts and soybeans might be developed that do not cause allergic reactions. Transgenic plants might be used to make vaccines or biodegradable plastics.

How are transgenic bacteria used?

Scientists use transgenic bacteria to make insulin, growth hormones, and other medical substances. Transgenic bacteria have been used to protect crops from frost damage and to clean up oil spills. Garbage in some landfills is being decomposed by transgenic bacteria.

Reading Check

9. Identify one way scientists use transgenic animals.

Reading Check

10. Explain What is one trait scientists have engineered into transgenic plants?

MAIN Idea

Genomes contain all of the information needed for an organism to survive.

What You'll Learn

- how forensic scientists use DNA fingerprinting
- how human genome information can help diagnose diseases

Study Coach

Make Flash Cards Make a flash card for each key term in this section. Write the term on one side of the card. Write the definition on the other side. Use the flash cards to review what you have learned.

Applying Math

- 1. Calculate** What percentage of human DNA is not made of genes?

● Before You Read

Scientists now study genes in ways that were not invented 20 years ago. Think of the new technology in your own life. What are some new technologies you use?

● Read to Learn

The Human Genome Project

A genome is all of the genetic information in a cell. The human genome is all of the genetic information in a human cell. The Human Genome Project (HGP) was an enormous project. One goal was to learn the sequence of the billions of nucleotides that make up human DNA. Another goal was to identify all 20,000 to 25,000 human genes.

The HGP was completed in 2003. Scientists will be working for many years to understand the data.

How was the human genome sequenced?

Human DNA is organized into 46 chromosomes. To determine the human genome, each chromosome was cut. Several restriction enzymes were used to make fragments with overlapping sequences. The fragments were combined with vectors and copied. The overlapping sequences were analyzed to generate a continuous sequence.

As scientists studied the sequences in the human genome, they observed that less than 2 percent of all of the nucleotides in the human genome code for all of the proteins in the body. The rest of the DNA is made of long stretches of repeated sequences called noncoding sequences. Scientists do not yet know the function of these sequences.



Think it Over

2. Identify What is most useful for DNA fingerprinting: protein-coding sequences or noncoding sequences? Explain.

How is DNA fingerprinting used?

The protein-coding sections of DNA are almost identical from one person to the next. The long stretches of noncoding sections of DNA are unique to each individual. **DNA fingerprinting** uses gel electrophoresis to observe the patterns that are unique to each person.

Forensic scientists use DNA fingerprinting to identify suspects and victims in a crime. DNA fingerprinting has been used to convict criminals and free innocent people who were wrongly imprisoned. DNA fingerprinting can be used to identify soldiers killed in war and establish paternity.


When only a drop of blood or a single hair is found at a crime scene, the sample does not contain enough DNA for DNA fingerprinting. Forensic scientists use PCR to copy the DNA and make a larger sample. The DNA is then cut with restriction enzymes and separated by gel electrophoresis. The pattern of the fragments from the sample is compared with DNA samples from known sources, such as a suspect or a victim in a crime.

Identifying Genes

Once the genome has been sequenced, the next step is to identify the genes and determine their functions. Organisms, such as bacteria and yeast, do not have noncoding DNA. Scientists look for DNA sequences called open reading frames (ORFs). ORFs are made of codons—groups of three nucleotides that code for amino acids. ORFs begin with a start codon and end with a stop codon. In between the start and stop codons, ORFs contain at least 100 codons. Scientists have identified over 90 percent of genes in yeast and bacteria by looking for ORFs.

In humans and other complex organisms, the long stretches of noncoding sequence make looking for genes more difficult. Scientists use sophisticated computer programs called algorithms to identify genes.

Bioinformatics

The sequencing of DNA from humans and other organisms has created large amounts of data. It has also led to a new field of study. **Bioinformatics** is the study of how to create and use computer databases to store, organize, index, and analyze this data. Scientists are using bioinformatics to discover new ways to locate genes in DNA sequences and to study the evolution of genes. 

Reading Check

3. Explain What is bioinformatics?

Reading Check

4. Define What does it mean to say a gene is expressed?

DNA Microarrays

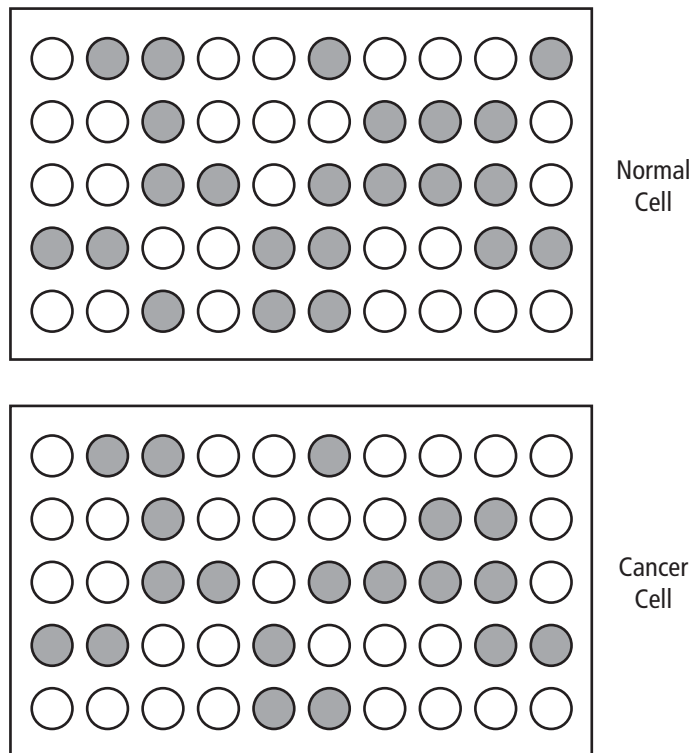
In any cell at any time, some genes are expressed, meaning those genes are making proteins. The rest of the genes are silent. In a different cell or at a different time, other genes will be expressed.

DNA microarrays are tiny microscope slides or silicon chips that contain tiny spots of DNA fragments. One microarray can contain thousands of genes. Scientists use DNA microarrays to study the expression of a lot of genes at once. DNA microarrays are used to study when and where genes are expressed. Microarrays can reveal how gene expression changes under different conditions. Microarrays can be used to compare cancer cells to normal cells. By finding genes that are expressed in cancer cells, scientists can learn more about cancer. They can learn better ways to treat people with cancer.

The figure below shows two DNA microarrays. Each spot represents a different gene. Spots that are white indicate the gene is being expressed. Spots that are black indicate the gene is not being expressed. The top microarray shows the genes that are expressed in a normal cell. The bottom microarray shows the genes that are expressed in a cancer cell.

Picture This

5. Analyze Find the genes that are expressed in the cancer cell but not in the normal cell. Circle the spots that represent those genes.



The Genome and Genetic Disorders

Over 99 percent of all nucleotide sequences are exactly the same from one person to the next. **Single nucleotide polymorphisms**, or SNPs (SNIHPS), are variations in the DNA sequence that occur when a single nucleotide in the genome is changed. A variation is only considered an SNP if it occurs in at least 1 percent of the population.

SNPs can be useful to scientists. Many SNPs do not change how cells function, but SNPs might help scientists find other, nearby mutations that do cause genetic disease. Some SNPs occur near mutations that cause human diseases. Knowing where SNPs occur in the genome might help scientists find mutations that cause diseases.

What is the HapMap project?


A group of international scientists is creating a list of common genetic variations in people. Genetic variations located close together on a chromosome are said to be linked. Linked variations are usually inherited together.

A **haplotype** is a section of linked variations in the human genome. The haplotype map or HapMap project is an international effort to find all the haplotypes. The project will describe what these variations are and show where they are found. The HapMap project will also describe how these variations occur among people within populations and among populations from different areas of the world.

The HapMap project will enable scientists to take advantage of how SNPs and other genetic variations are organized on chromosomes. This will help scientists find genes that cause different types of disease. The HapMap will also help scientists find mutations that affect how a person responds to medicine.

What is pharmacogenomics?

One day people might go to the doctor and have drugs specially prescribed for them based on their genes. **Pharmacogenomics** (far muh koh jeh NAW mihs) is the study of how a person's genes affect his or her response to medicine.

Researchers hope that pharmacogenomics will allow drugs to be custom made for people based on their genetic makeup. Pharmacogenomics might allow doctors to prescribe drugs that are safer, more specific, more effective, and have fewer side effects. Doctors might one day read your genetic code and prescribe drugs made especially for you. 

Applying Math

- 6. Calculate** A single nucleotide variation occurs in 7 of every 1000 people. Is this variation an SNP? Why or why not?

Reading Check

- 7. Define** What is a possible benefit of pharmacogenomics?

How does gene therapy work?

Gene therapy is a way of fixing mutated genes that cause disease. Scientists insert a normal gene into a chromosome to replace the mutated gene. The normal gene can then do the work of the mutated gene.

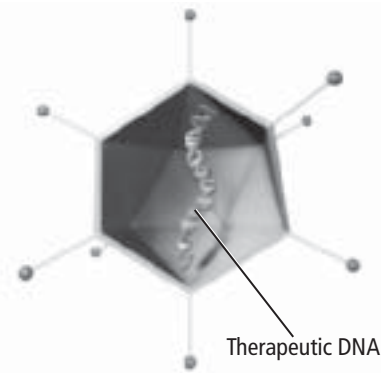
A virus is used as a vector to transfer the normal gene to the cell. The virus releases the recombinant DNA, which contains the normal gene, into the cell. The normal gene inserts itself into the genome and begins functioning.

Gene therapy trials are not currently being conducted in the United States. Researchers need to find nontoxic viral vectors before conducting more gene therapy trials.

Picture This

8. Identify How is a normal gene inserted into a cell? (Circle your answer.)

- a. by a virus releasing recombinant DNA containing the normal gene
- b. by physically removing the mutated gene



Genomics and Proteomics

Genomics is the study of an organism's genome. Following the completion of the human genome sequence in 2003, so much research has become focused on genomics that biologists call this "the genomic era."

Genomics is a powerful strategy for identifying human genes and understanding how they work. Researchers also use genomics to study plants and other organisms, such as rice, mice, fruit flies, and corn, whose genomes have been sequenced.

Genes are important because they are the way cells store information. Proteins are important because they are the machines that make cells run.

Proteomics is the large-scale study and cataloging of the structure and function of proteins in the human body. With proteomics, researchers can study hundreds or thousands of proteins at one time.

Scientists use proteomics to understand human diseases. Scientists expect that proteomics will change the development of medicines to treat diseases such as diabetes, obesity, and atherosclerosis.

Reading Check

9. Define What is proteomics?

The History of Life

section 1 Fossil Evidence of Change

● Before You Read

Throughout Earth's history, many species have become extinct. On the lines below, name some organisms that have become extinct. Then read the section to learn more about how scientists learn about extinct species.

MAIN Idea

Fossils provide evidence of the change in organisms over time.

What You'll Learn

- how a typical fossil is made
- techniques for dating fossils
- the major events using the geologic time scale

● Read to Learn


Earth's Early History

How did life on Earth begin? Because there were no people around to record Earth's earliest history, the answer is a mystery. Scientists who study the beginning of life on Earth must look for clues that were left behind.

Some of the clues are found in rocks. Rocks give us clues about what Earth was like in the beginning and sometimes what species lived during that time. Scientists also study other planets to uncover clues about Earth's past.

What was Earth's early land environment like?

Earth formed about 4.6 billion years ago. At first, Earth was molten—melted rock. Gravity pulled the densest elements to the center of the planet, forming Earth's core. After about 500 million years, a solid crust formed on the surface. The crust was made mostly of lighter elements.

From clues found in rocks, scientists infer that Earth's early surface was hot. Volcanoes erupted and meteorites hit the surface. It is not likely that life could have survived the heat. 

Mark the Text

Identify Definitions

As you read each section, highlight or underline the definition of each underlined term.

Reading Check

1. **Explain** What was Earth's early surface like?

What was Earth's early atmosphere like?

Earth's early atmosphere was probably made up of gases that were expelled by volcanoes. These gases might have been similar to those that are expelled by volcanoes today. Minerals in the oldest known rocks suggest that the early atmosphere had little or no free oxygen. Gases expelled by volcanoes do not include free oxygen.

Clues in Rocks

Earth eventually cooled, and liquid water formed on the surface, forming the first oceans. A short time later, as little as 500 million years ago, life appeared. Rocks provide important clues about Earth's history. The oldest clues about life on Earth date to about 3.5 billion years ago.

Reading Check

- 2. Identify** How old is the oldest evidence of life on Earth?

What is a fossil?

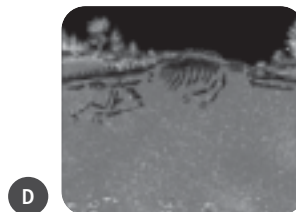
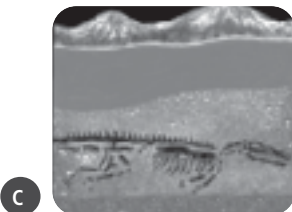
A **fossil** is any preserved evidence of an organism. More than 99 percent of the species that have lived on Earth are now extinct. Only a small percentage of the species are preserved as fossils.

For an organism to be preserved as a fossil, it must be buried quickly in sediment. Organisms that live in water are more likely to form fossils than organisms that live on land because sediment in the water is constantly settling.

First the organism dies. Then sediment covers the organism. Layers of sediment build up over time. In most cases, minerals replace or fill in the pore space of the bones and hard parts of the organism. In some cases, the organism decays, leaving behind an impression of its body. The layers eventually harden into sedimentary rock, such as limestone, shale, or sandstone.

Picture This

- 3. Describe** the events that happen to make a fossil in sedimentary rock.



What can scientists learn from studying fossils?

A **paleontologist** (pay lee ahn TAH luh jist) is a scientist who studies fossils. Paleontologists use fossils as clues to learn what an organism ate and the environment in which an organism lived. Paleontologists can use fossils to put together a picture of extinct communities as if they were alive today.

What dating techniques do scientists use?

Paleontologists have different methods to find out the age of a rock or a fossil. **Relative dating** is a method used to determine the age of rocks by comparing them with rocks in other layers. Relative dating is based on the law of superposition. The **law of superposition** states that sedimentary rock forms in layers, with younger layers of rock deposited on top of older layers. The oldest rocks form the bottom layer and the youngest rocks form the top layer, as shown in the figure below.



What is radiometric dating?

Radiometric dating is a method used to determine the age of rocks using the decay of radioactive isotopes present in the rocks. Recall that an isotope is a form of an element that has the same atomic number but different mass number. The method requires that the **half-life** of the isotope, which is the amount of time it takes for half of the original isotope to decay, is known. The relative amounts of the isotope and its decay product must also be known. ☑

Picture This

- 4. Identify** Label the oldest and the youngest rock layers in the picture.

✓ Reading Check

- 5. Identify** What three things must be known to perform radiometric dating?

Picture This

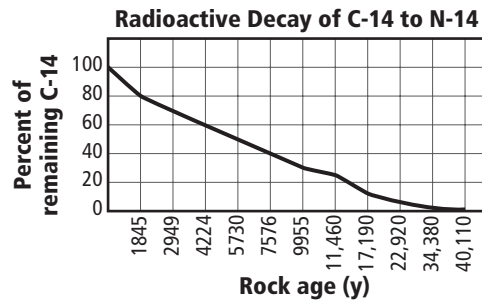
6. Estimate About what percent of carbon-14 is left after 11,460 y?

Reading Check

7. Describe How is radiometric dating used to find the age of sedimentary rock?

How does radiometric dating work?

Carbon-14 is a commonly used isotope. The decay of carbon-14 is shown in the graph below. The half-life of carbon-14 is 5730 years. After 5730 years, half of the original carbon-14 will remain. The other half will have decayed to nitrogen-14. At the half-life, there is a one-to-one ratio, or equal amounts, of carbon-14 and nitrogen-14. Scientists can determine the age of a rock by calculating the ratio of carbon-14 to nitrogen-14 in the rock.



How is radiometric dating used for rocks?

Useful radioactive isotopes are found in igneous or metamorphic rocks but not sedimentary rocks. Often igneous rocks are found in layers closely associated with fossil-bearing sedimentary rocks. Scientists use radiometric dating to determine the age of the igneous rock, and then they infer the age of the fossils in the sedimentary rock that is closely associated with it.

Items such as mummies and frozen mammoths can be dated directly using carbon-14. Only materials less than 60,000 years old can be dated accurately with this isotope. Older materials do not have enough radio-isotope left.

The Geologic Time Scale

The **geologic time scale** is a model that shows the major geological and biological events of Earth's history. These events include changes to Earth and to organisms.

The geologic time scale has two major divisions—Precambrian time and the Phanerozoic (fan eh roh ZOH ihk) eon. An **era** is the next largest division of the geologic time scale. Eras include the Precambrian, Paleozoic, Mesozoic, and Cenozoic. Each era is further divided into one or more **periods**.

It might help to think of the geological time scale as a ribbon that is 4.6 m long. Each meter represents one billion years. Each millimeter represents one million years.

What occurred during the Precambrian?

The first 4 m of the geologic time ribbon makes up the Precambrian (pree KAM bree un). During the Precambrian nearly 90 percent of Earth's history occurred. It began with the formation of Earth, 4.6 billion years ago, and ended about 542 million years ago with the beginning of the Paleozoic era. ✓

Many important events occurred during the Precambrian. Earth formed and life first appeared. Autotrophic prokaryotes, such as bacteria that make organic compounds using carbon dioxide and energy from the sun or inorganic sources, enriched the atmosphere by releasing oxygen. Eukaryotic cells emerged. By the end of the Precambrian, the first animals had appeared.

During the second half of the Precambrian, glaciers might have delayed the further evolution of life. After the glaciers receded, simple organisms lived in marine ecosystems.

How did life change during the Paleozoic era?

A drastic change in the history of animal life on Earth came at the start of the Paleozoic (pay lee uh ZOH ihk) era. In just a few million years, the ancestors of most major animal groups diversified in what scientists call the **Cambrian explosion**. Fish, land plants, and insects appeared. The swampy forests were home to many types of organisms, including huge insects. The first tetrapods—animals that walk on four legs—which were the first land vertebrates, appeared. By the end of the era, reptiles appeared.

What event ended the Paleozoic era?

The Paleozoic era ended with a mass extinction. Recall that a mass extinction is an event in which many species become extinct in a short amount of time. In the mass extinction that ended the Paleozoic era, 90 percent of marine organisms disappeared. Scientists do not know why the mass extinction occurred. Most scientists agree that geological forces, including increased volcano activity, would have disrupted ecosystems or changed the climate. ✓

How did life change during the Mesozoic era?

Life continued to change during the Mesozoic (mez uh ZOH ihk) era. Mammals and dinosaurs appeared. Flowering plants evolved from nonflowering plants. Birds evolved from dinosaurs. Reptiles, including dinosaurs, were the dominate animals.

✓ Reading Check

8. Sequence What marked the beginning of the Precambrian?

✓ Reading Check

9. Identify What type of organisms became extinct during the mass extinction that ended the Paleozoic era?

Reading Check

10. Name the rock layer found between rocks of the Cretaceous period and rocks of the Paleogene period.

What is the evidence of a meteor striking Earth?

Then, a meteorite struck Earth. The evidence for the meteorite comes from a layer of material between rocks of the Cretaceous (krih TAY shus) period and rocks of the Paleogene period. Scientists call this layer of material the **K-T boundary**.

In the K-T boundary, scientists have found high levels of iridium. Iridium is rare on Earth but common in meteorites. Iridium on Earth is evidence of a meteor impact.

How might a meteor strike have led to a mass extinction?

Many scientists think this meteor impact is related to the mass extinction, which eliminated all dinosaurs except birds, most marine reptiles, many marine invertebrates, and many plant species. The meteor itself did not kill these organisms, but the debris from the impact probably stayed in the atmosphere for months or years. The debris would have affected the global climate. Those species that could not adjust to the changing climate disappeared.

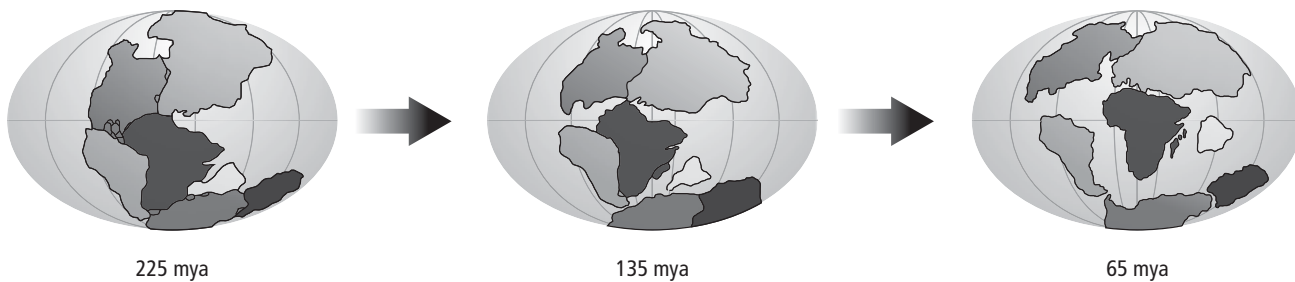
How did Earth change during the Mesozoic era?

Evolution in the Mesozoic era was affected by the massive geological changes of the era. As shown in the figure below, at the beginning of the Mesozoic era, approximately 225 million years ago, the continents were joined into one landmass called Pangaea.

Plate tectonics describes the surface of Earth as being broken into several large plates. Some of the plates contain continents. The plates move over a partially molten layer of rock moving the continents with them. The continents have been moving since they formed. By the end of the Mesozoic era, approximately 65 million years ago, the continents had broken apart, moved, and were in roughly the position they are now.

Picture This

11. Label the landform known as Pangaea.














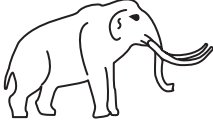

How did life change during the Cenozoic era?

The Cenozoic (sen uh ZOH ihk) era is the most recent era. Mammals became the dominant animals on land. At the beginning of the era, most mammals were small. After the mass extinction, at the end of the Mesozoic era, mammals, including primates, began to become more diverse.

When did present-day humans appear on Earth?

Present-day humans appeared near the end of the geologic time scale. Humans survived the last ice age, but many species of mammals did not. Think back to your time ribbon. The time that humans have lived on Earth takes up about two threads at the end of the ribbon.

The figure below shows the geologic time scale and gives examples of organisms that evolved during each era.

Geologic Era	Time Span	New Organisms
Precambrian	4.6 billion years ago to 544 million years ago	   <p>Unicellular life forms</p> <p>Sponges</p> <p>Jellyfishes</p>
Paleozoic	544 million years ago to 225 million years ago	    <p>Fish</p> <p>Reptiles</p> <p>Amphibians</p> <p>Ferns</p>
Mesozoic	225 million years ago to 65 million years ago	    <p>Small mammals</p> <p>Flowering plants</p> <p>Birds</p> <p>Dinosaurs</p>
Cenozoic	65 million years ago to present	  <p>Large mammals</p> <p>Humans</p>

Applying Math

- 12. Calculate** What percentage of Earth's history has included present-day humans?
-

Picture This

- 13. Label** Circle the era when Pangaea broke apart into individual continents.

The History of Life

section 2 The Origin of Life

MAIN Idea

Evidence indicates that a sequence of chemical events preceded the origin of life on Earth.

What You'll Learn

- differences between spontaneous generation and biogenesis
- events that might have led to cellular life
- the endosymbiont theory

Mark the Text

Identify Scientists

As you read this section, underline the name of each scientist introduced. Highlight the sentences that explain each person's contribution to understanding the history of life.

Reading Check

- 1. Explain** What new device fueled people's belief in spontaneous generation?

Before You Read

You want to make a sandwich but find mold growing on the bread. You don't recall seeing mold on the bread yesterday. On the lines below, explain how you think the mold got there. Then read about early ideas about the origins of life.


Read to Learn

Origins: Early Ideas

There have been many ideas about how life began. Many of these ideas came from people observing the world around them. It was once thought that mice could be created by placing damp hay and corn in a dark corner. This idea that life arises from nonlife is **spontaneous generation**. Spontaneous generation is possibly the oldest idea about the origin of life.

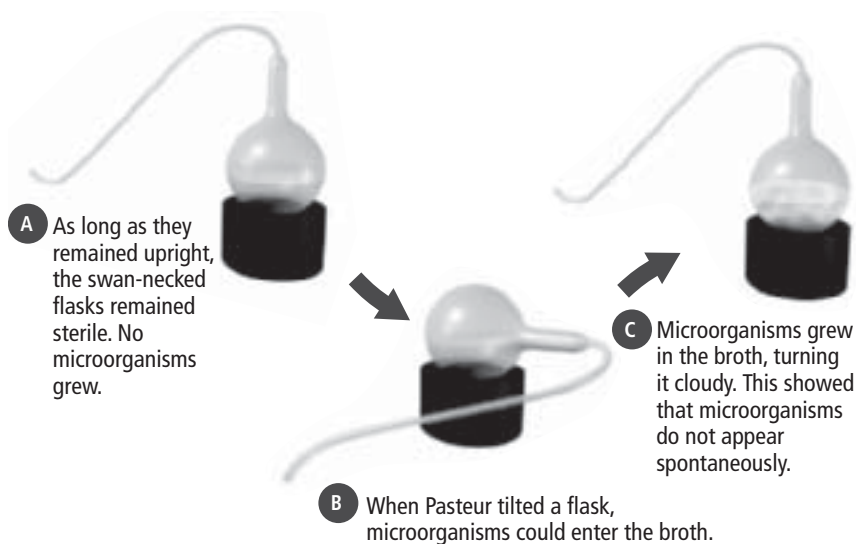
How was spontaneous generation tested?

In 1668, an Italian scientist named Francesco Redi tested the idea that flies arose spontaneously from rotting meat. He hypothesized that flies, not meat, produced other flies. Redi placed rotting meat in flasks that were opened and in flasks that were covered. Redi observed that maggots, the larvae of flies, appeared only in the flasks that were open to flies. The closed flasks did not have flies or maggots.

Despite Redi's experiment, people still believed in spontaneous generation. The microscope was beginning to be used during Redi's time. People knew that organisms too small to be seen were everywhere. Some people thought these microbes must arise spontaneously even if flies do not. 

What idea replaced spontaneous generation?

In the mid-1800s, Louis Pasteur designed an experiment, as shown in the figure below, to prove that the theory of biogenesis was true even for microorganisms. The **theory of biogenesis** (bi oh JEN uh sus) is the idea that living organisms come from other living organisms. Only air was able to enter one flask containing a sterile nutrient broth. Both air and microorganisms were able to enter a second flask containing the sterile nutrient broth. Microorganisms were able to grow in the second flask but not the first flask. After Pasteur's experiment, people rejected spontaneous generation and embraced the theory of biogenesis.



Origins: Modern Ideas

Most biologists agree that life originated through a series of chemical events. During these events, complex organic molecules were made from simpler ones. Eventually, simple metabolic pathways developed. These pathways enabled molecules to be broken down. These pathways might have led to the origin of life. ✓

How did early organic molecules form?

In the 1920s, Russian scientist Alexander Oparin suggested the primordial soup hypothesis explained the origin of life. He thought that if Earth's early atmosphere had a mix of certain gases, organic molecules could have been made from simple reactions involving those gases in the early oceans. UV light from the sun and lightning might have provided the energy for the reactions. Oparin thought that these organic molecules would eventually lead to life.

Picture This

2. Describe What did Pasteur do that allowed microorganisms to enter the flask?

✓ Reading Check

3. Determine Does biogenesis explain the origin of life?

✓ Reading Check

4. Identify Why did Miller and Urey shine UV light on their apparatus?

✓ Reading Check

5. Explain What ocean sediment might have helped protein chains to form?

How was Oparin's hypothesis tested?

In 1953, American scientists Stanley Miller and Harold Urey conducted an experiment showing that simple organic molecules could be made from inorganic compounds. Miller and Urey built a glass apparatus to simulate early Earth conditions. They filled the apparatus with water and gases that they thought had made up the early atmosphere. They boiled the mixture, shined UV light on it to simulate sunshine, and charged it with electricity to simulate lightning. The resulting mixture contained amino acids. Amino acids are the building blocks of proteins. ✓

Later, other scientists found that hydrogen cyanide could be formed from simpler molecules. Hydrogen cyanide can react with itself to eventually form adenine, one of the nucleotides in the genetic code.

Many other experiments have been carried out under a wide variety of conditions similar to those of early Earth. The final products have been amino acids, sugars, and nucleotides. The experiments showed that reactions for the origin of life were possible on early Earth.

What other hypotheses have been proposed?

Some scientists hypothesize that Earth's surface, with its high UV levels and meteorite strikes, was too destructive to have provided a safe place for life. Some scientists suggest that the organic reactions occurred in hydrothermal volcanic vents of the deep sea, where sulfur is the base of a unique food chain. Still others think meteorites might have brought the first organic molecules to Earth.

How were the first proteins made?

Proteins are chains of amino acids. The Miller-Urey experiment shows that amino acids could form on early Earth. Amino acids can bond to one another, but they can separate just as easily. Proteins might have formed when an amino acid stuck to a particle of clay. Clay would have been a common sediment in early oceans. Clay could have provided a framework for protein assembly. ✓


What was the first genetic code?

Another requirement for life is a genetic code—a coding system for making proteins. Many biologists think RNA was life's first coding system. RNA systems are capable of evolution by natural selection.

How do some RNA molecules behave?

Some RNAs can behave like enzymes. These RNA molecules could have carried out some early life processes. Some scientists think clay particles could have been a template for RNA replication and that the resulting molecules developed a replication mechanism.

How did the first cells arise?

Another important step in the evolution of cells is the formation of membranes. Scientists have tested ways to enclose molecules in membranes that allow metabolic and reproductive pathways to develop. However, scientists might never know the steps that led to cell formation. 

Cellular Evolution


Although scientists don't know what the earliest cells were like, chemicals found in rocks suggest life was present 3.8 billion years ago even though no fossils remain. In 2004, scientists discovered what appeared to be fossilized microbes in volcanic rock that is 3.5 billion years old. This suggests that cellular activity had become established. It also suggests that early life might have been linked to volcanic environments.

Scientists think the first cells were prokaryotes, which lack a defined nucleus and most other organelles. Many scientists think prokaryotes called archaea (ar KEE uh) are the closest relatives of Earth's first cells. These microbes live in extreme environments such as hot springs and volcanic vents in the deep sea. These environments are similar to those of early Earth.

When did photosynthetic organisms appear?

Archaea are autotrophs that get their energy from inorganic compounds such as sulfur. Archaea also do not make oxygen.

Scientists think oxygen was not present in Earth's early atmosphere until about 1.8 billion years ago. Any oxygen that appeared earlier probably bonded with free iron ions. Scientists hypothesize that eventually early Earth's free iron was bonded with oxygen so oxygen could accumulate in the environment.

Scientists think that prokaryotes, called cyanobacteria, that could perform photosynthesis evolved about 3.5 billion years ago. These organisms released oxygen into the atmosphere and eventually produced enough oxygen to support an ozone layer. The ozone layer provided a shield from the Sun's damaging ultraviolet radiation and made conditions right for eukaryotes. 

Reading Check

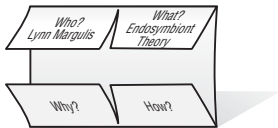
6. State What functions must a membrane allow?

Reading Check

7. Sequence What came first: photosynthetic organisms or eukaryotic cells?

FOLDABLES™

Take Notes Make a four-door Foldable, as shown below. As you read, take notes and organize what you learn about the endosymbiont theory.



Picture This

8. Highlight the name of the structure that cyanobacteria became.

When did eukaryotic cells evolve?

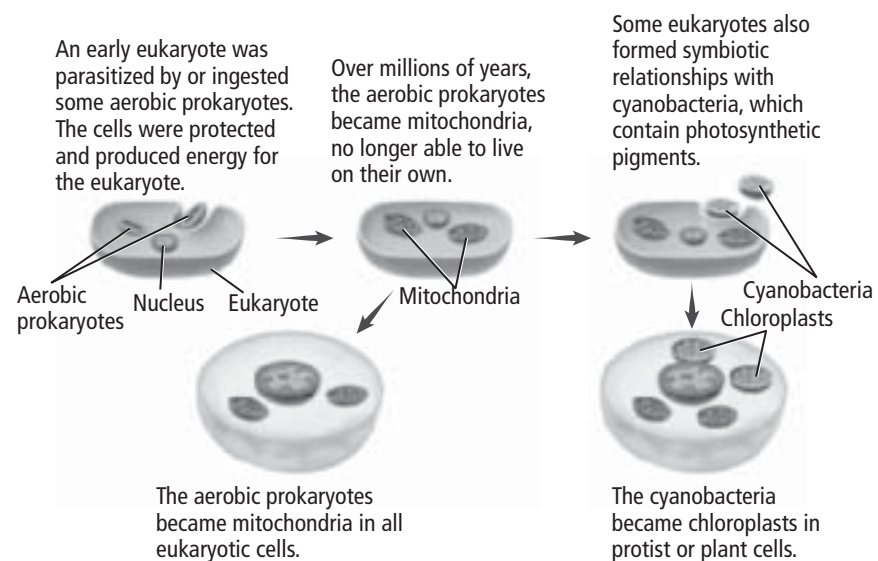
Eukaryotic cells appeared about 1.8 billion years ago. They are larger than prokaryotes and have complex internal membranes, which enclose many organelles including the nucleus.

What is the endosymbiont theory?

American biologist Lynn Margulis proposed the **endosymbiont theory** which states that ancestors of eukaryotic cells lived together in association with prokaryotic cells. In some cases, prokaryotes might even have lived inside eukaryotes. Prokaryotes might have entered eukaryotes as undigested prey, or they might have been internal parasites. Eventually, the relationship benefitted both cells and the prokaryotes became organelles inside the eukaryotic cells, as shown in the figure below.

Evidence suggests that mitochondria and chloroplasts formed by endosymbiosis. Mitochondria and chloroplasts contain their own DNA arranged in circular patterns like the DNA of prokaryotes. Mitochondria and chloroplasts have ribosomes that are more similar to the ribosomes in prokaryotes than to those in eukaryotes. Like prokaryotic cells, mitochondria and chloroplasts reproduce by fission independent from the rest of the cell.

Scientists do not know the early steps that led to life or to its evolution. Scientists continue to test theories and evaluate new evidence as they seek answers to understand what led to life on Earth.



section 1 Darwin's Theory of Natural Selection

● Before You Read

In this section you will learn about Charles Darwin and his theory of natural selection. Read the first paragraph of the *Read to Learn* section. On the lines below, write the ideas about life on Earth that were common during Charles Darwin's lifetime.

MAIN Idea

Charles Darwin developed a theory of evolution based on natural selection.

What You'll Learn

- the evidence that led Darwin to conclude species could change over time
- the four principles of natural selection

● Read to Learn

Developing the Theory of Natural Selection

When Charles Darwin boarded the HMS *Beagle*, people believed that the world was only a few thousand years old. Most people believed the plants and animals they saw had not changed. Darwin believed these things too.

What did Darwin do on the HMS *Beagle*?

The mission of the *Beagle* was to survey the coast of South America. Darwin's original role on the ship was as the captain's companion. He was someone the captain could talk to during the long voyage. Darwin also served as the ship's naturalist. His job was to collect rocks, fossils, plants, and animals from the places he visited.

During the five-year voyage, Darwin read *Principles of Geology*, by Charles Lyell. Lyell's book proposed that Earth was millions of years old. The book influenced Darwin's thinking as he found fossils of marine life high in the Andes mountains. He also found fossils of giant versions of smaller living mammals. He observed how earthquakes could quickly lift rocks great distances.

Mark the Text

Identify Main Ideas

Highlight every heading in the reading that asks a question. Then highlight each answer as you find it.

Reading Check

- 1. Name** an observation Charles Darwin made.

✓ Reading Check

2. Identify Where are the Galápagos Islands?

Picture This

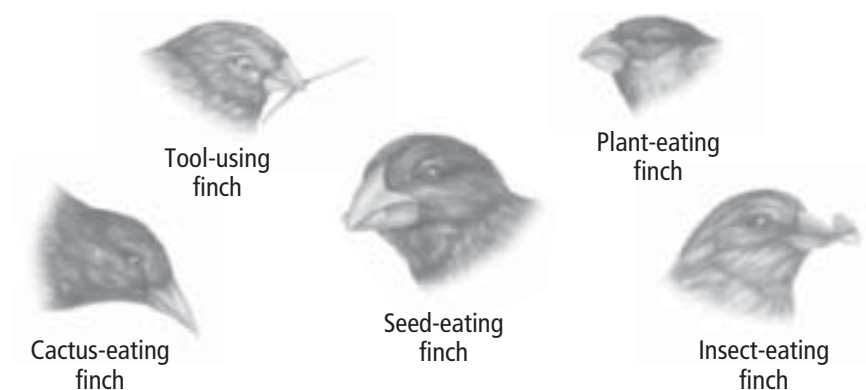
3. Explain Each of the Galápagos islands had different types of plants. How might this explain the differences in beak shape in finches?

What did Darwin find on the Galápagos Islands?

One of the places the *Beagle* sailed was the Galápagos (guh LAH puh gus) Islands off the coast of Ecuador. Darwin noticed that mockingbirds on one island were slightly different from mockingbirds on the other islands. He took careful collections of these birds. Darwin thought that the finches he saw were not related to one another and probably had representatives on mainland South America. Although he noted the differences, he did not think much about these differences at the time. Darwin also did not notice that tortoise shells were different on each island. ✓

When Darwin returned home, he showed his specimens to naturalist John Gould. Gould told Darwin that the mockingbirds from different islands were different species. Gould also determined that the Galápagos finches did not live anywhere else in South America. They were different species too. A few of Darwin's finches are shown in the picture below. Notice the difference in beak size and shape.

The Galápagos finches most closely resembled finches from the closest mainland in South America. Darwin suspected that populations from the mainland changed after reaching the Galápagos.



What did Darwin learn from artificial selection?

Darwin suspected that small, gradual changes might lead to new species. Darwin knew that people could create new breeds of plants and animals by breeding plants and animals that express the desired traits. Darwin called this selective breeding **artificial selection**.

Darwin thought that if people could change species by artificial selection, perhaps species could also change in the natural world. Darwin reasoned that, given enough time, gradual change could produce new species.

What principles did Darwin use?

Darwin developed a theory for how one species could change to become multiple new species. Darwin based his theory on four principles.

Principle 1 Individuals in a population show differences, even among the same species. Differences among you and your classmates support this principle.

Principle 2 The differences between individuals are inherited. Traits are passed down from parents to their offspring.

Principle 3 Animals have more young than can survive on the resources in their environment. For example, the average female cardinal lays nine eggs in a summer. If each of the offspring lives one year and reproduces, in eight years the offspring would produce a million cardinals. The population of cardinals would quickly outgrow the food supply.

Principle 4 Some differences increase an organism's reproductive success, or its chance of having living offspring. Any difference that increases reproductive success will be inherited by offspring and will be more common in the next generation. For example, pigeons with fan-shaped tails have more reproductive success than pigeons without fan-shaped tails. As a result, more pigeons in the next generation will have fan-shaped tails.

These principles formed the basis of Darwin's theory of evolution by **natural selection**, which explains how traits of a population can change over time. Darwin reasoned that given enough time, natural selection could produce a new species.

The Origin of Species

Darwin began writing a book describing how natural selection could produce new species. In 1858, he learned that Alfred Russel Wallace, another English naturalist, had reached similar conclusions about natural selection. In 1858, both Wallace and Darwin presented their findings at a scientific meeting. In 1859, Darwin published his book, *On the Origin of Species by Means of Natural Selection*.

Darwin did not use the word "evolution" until the last page of his book. Today, biologists use **evolution** to describe the way a species changes over time. Darwin's theory of natural selection explains how evolution can occur.



Think it Over

- 4. Identify** Name a resource that could limit the survival of animals within a population.



Think it Over

- 5. Contrast** How does natural selection differ from evolution?

section 2 Evidence of Evolution

MAIN Idea

Multiple lines of evidence support evolution.

What You'll Learn

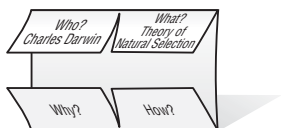
- how fossils provide evidence of evolution
- evidence of evolution from morphology
- how physiology and biochemistry provide evidence of evolution

Mark the Text

State Main Ideas As you read, stop after every few paragraphs and put what you have just read into your own words. Then highlight the main idea in each paragraph.

FOLDABLES™

Take Notes Make a four-door Foldable, as shown below. As you read, take notes and organize what you learn about Charles Darwin and the development of the theory of natural selection.



Before You Read

To learn how different organisms might be related, scientists look for similarities and differences between the organisms. On the lines below, compare a cat and a frog. What physical features are the same? What physical features are different?

Read to Learn

Support for Evolution

Science uses theories that provide explanations for how some aspects of the natural world operate. Any theory should explain available data and suggest further areas for experiments. Darwin's theory of evolution by natural selection explains the patterns scientists see in past and present organisms.

In most cases, people cannot observe evolution directly because it happens over millions of years. Fossils help us understand evolution because they are a record of species that lived long ago. The fossil record shows that some species from long ago are extinct today. Other species alive today are similar to those in fossils.

What did Darwin predict about the fossil record?

Darwin predicted that scientists would find fossils that would show organisms that were intermediate between different species. Darwin's prediction has come true. Scientists have found intermediate species for the evolution of mollusks, modern horses, whales, and humans.

What are two classes of traits?

Scientists have found fossils of *Archaeopteryx*, a dinosaur that has the teeth, claws, and a bony tail of a reptile and feathers and the ability to fly like a bird. *Archaeopteryx* is likely an intermediate organism and is evidence that birds evolved from dinosaurs.

Scientists divide traits into two classes. **Derived traits** are newly evolved traits that have not appeared in common ancestors. **Ancestral traits** are traits that are shared by species with a common ancestor. In *Archaeopteryx*, teeth are an example of an ancestral trait.

What does anatomy reveal about evolution?

The limbs of vertebrates perform different functions, but they have similar anatomy. Wings and legs have similar structures because birds and animals evolved from the same ancestor. **Homologous structures** are similar structures inherited from a common ancestor. Darwin's theory of evolution by natural selection predicts that new structures are more likely to be modifications of ancestor's structures than entirely new features. The figure below shows the homologous forelimbs of three different animals.



What are vestigial structures?

In some cases, a functioning structure in one species is smaller or doesn't function in a closely related species. **Vestigial structures** are features that are reduced forms of functional structures in other organisms. Vestigial structures are reduced when structures are no longer needed. The structures become smaller over time and might eventually disappear.

Picture This

- 1. Identify** On the blank lines in the figure, write the function of the forelimbs in each animal.

Reading Check

- 2. Define** What are vestigial structures?

Picture This

3. Name What analogous structure is found in both birds and insects?

What are analogous structures?

Two organisms can have similar structures without being closely related. **Analogous structures** have the same function but different construction because they are not inherited from a common ancestor. Bird wings and insect wings are analogous structures. They have the same function but different anatomy.



What do embryos reveal about evolution?

An **embryo** is an early stage of development in organisms. Embryos of fishes, birds, reptiles, and mammals have several homologous structures that are not present when the organisms are adults. These structures suggest that vertebrates evolved from a common ancestor.

What do molecules reveal about evolution?

The metabolism of different organisms is based on the same complex molecules: DNA, RNA, ATP, and many enzymes. These molecules are similar because the organisms have a common ancestor.

The more closely related two organisms are, the more similar their molecules will be. Scientists have observed this pattern for DNA and RNA sequences, as well as for the amino acid sequences of proteins. Scientists now use similarities in DNA and RNA sequences to determine evolutionary relationships between species.


What does biogeography predict?

Darwin's theory of evolution by natural selection predicts that species respond to similar environments in similar ways. **Biogeography** is the study of how plants and animals are distributed on Earth. Biogeography provides evidence that similar environments can lead to the evolution of similar animals, even if the environments are far apart. ✓

✓ Reading Check

4. Define What is biogeography?

Adaptation


Some traits contribute greatly to an organism's survival or reproduction. Traits that enable organisms to survive or reproduce better than organisms without those traits are called adaptations. 

Fitness is one way to measure the effectiveness of traits. **Fitness** is a count of offspring born to organisms with a trait compared to offspring born to organisms without that trait. Traits that enable organisms to survive or reproduce better than organisms without those traits are adaptations.

Camouflage (KA muh flahj) is an adaptation that allows an organism to blend with its surroundings. Camouflage increases fitness because it allows the organism to hide from predators.

Mimicry is an adaptation that occurs when one species looks like another species. In one form of mimicry, a harmless species evolves to look like a dangerous one. In another form of mimicry, two or more harmful species resemble one another. In both cases, predators cannot tell the species apart, so they avoid both. Mimicry increases the chance that a species will survive and reproduce.

Do all traits evolve slowly?

Bacteria that were originally killed by antibiotics such as penicillin have quickly evolved into populations of resistant bacteria. For most antibiotics, at least one species of resistant bacteria exists. Some diseases, such as tuberculosis, that doctors once believed could be controlled with antibiotics have now come back. The forms of these diseases are more harmful than the forms that were treated with antibiotics. These new forms resist treatment with today's antibiotics. 

Do all traits increase fitness?

Not all features of organisms are adaptations that increase fitness. Some features arise because they are unavoidable consequences of other evolutionary changes.

For example, human babies are born helpless at an earlier stage of development than other primates. Many scientists believe that early birth is not an adaptation but is a consequence of evolution. Human babies must be small in order to squeeze through a narrow birth canal. The birth canal is narrow because human females have a narrow pelvis. The shape of the pelvis is an adaptation that enables people to walk on two legs instead of four.

Reading Check

5. Explain What is an adaptation?

Reading Check

6. Name a problem with the rapid evolution of antibiotic-resistant bacteria.

section 1 Shaping Evolutionary Theory

MAIN Idea

The theory of evolution is being refined as scientists learn new information.

What You'll Learn

- factors that influence how new species originate
- about gradualism with punctuated equilibrium

Study Coach

Make Flash Cards Write the underlined words on one side of a flash card. Write the definition on the other side of the card.

Reading Check

1. Explain What happens when a population is in genetic equilibrium?

Before You Read

In this section, you will learn how our understanding of evolution has changed in the last 150 years. Other aspects of science have also changed. On the lines below, name several other scientific advances that have happened since the mid-1800s.

Read to Learn

Mechanisms of Evolution

Natural selection helps explain how one or two ancestors became today's diversity. Natural selection is one way that species evolve, but it is not the only way.

In the 150 years since Darwin published his findings on natural selection, scientists have learned much about evolution. They have uncovered other ways that species can change. To understand the other mechanisms for evolution, it is important first to learn about population genetics.

What is the Hardy-Weinberg principle?

In 1908, English mathematician Godfrey Hardy and German physician Wilhelm Weinberg each arrived at the same conclusion about how the laws of inheritance work in a population. The Hardy-Weinberg principle states that the frequency of alleles in populations does not change unless the frequencies are acted on by some factor that causes change. When the frequency of alleles remains the same, the population is in genetic equilibrium. A population in genetic equilibrium does not evolve.

How does the Hardy-Weinberg principle work?

The Hardy-Weinberg principle helps us understand when evolution can occur. Evolution occurs only when a population is not in genetic equilibrium.

Genetic equilibrium occurs when five conditions, listed in the table below, are met. When one or more of the conditions is violated, the population can change or evolve.

Populations can meet some of these requirements for long periods of time. Many populations are large enough to maintain genetic equilibrium. Other conditions do not often occur in nature. For example, one condition is that mating must be random across an entire population. But mating is rarely random. It usually occurs between closest neighbors. Because all five conditions do not usually occur in nature, most populations are able to evolve.

Conditions for Genetic Equilibrium		
Condition	Violation	Consequence
The population is large.	Many populations are small.	Chance events can change population traits.
There is no immigration or emigration.	Organisms move in and out of the population.	The population can lose or gain traits with movement of organisms.
Mating is random.	Mating is not random.	New traits do not pass as quickly to the rest of the population.
Mutations do not occur.	Mutations occur.	New variations appear in the population with each new generation.
Natural selection does not occur.	Natural selection occurs.	Traits in a population change from one generation to the next.

How does genetic drift lead to evolution?

Genetic drift is the random change in the frequency of alleles in a population. Genetic drift usually affects small populations. Genetic drift occurs because chromosomes are sorted randomly during meiosis. The one of a parent's two alleles that passes to the offspring is determined by chance. Genetic drift is another way that a population can evolve.

Unlike natural selection, the adaptations that result from genetic drift are not always the best ones for the environment. Sometimes, important adaptations can be lost by genetic drift.

Picture This

2. Explain White rabbits blend in with the snow. Brown rabbits are more likely to be eaten by predators. Is the population of rabbits in genetic equilibrium? Explain your answer.



Think it Over

3. Draw Conclusions

What population would be most likely to experience genetic drift? (Circle your answer.)


- 4000 mice living in a meadow
- 30 rabbits living on a mountaintop
- five million people living in a city

What is the founder effect?

The **founder effect** can occur when a few individuals are separated from the rest of the population. The few individuals carry a random subset of the genes in the original population. The frequency of alleles in the subset might be different from the frequency of alleles in the original population. The founder effect is a random way that species can evolve. Unlike natural selection, the traits that result might or might not be the best available for the environment.

The founder effect often occurs on islands. New species can result from a few founders of the original population. The founder effect also occurs in people. Amish and Mennonite people live in the United States but do not usually marry outside their communities. They have many unique genes.

What happens in a genetic bottleneck?

When a large population declines in number then rebounds to a large number again, a **bottleneck** occurs. Bottlenecks reduce the total alleles in a population. The genes of the resulting population can be unusually similar. 

Cheetahs in Africa might have gone through a bottleneck a few thousand years ago. Cheetahs are genetically similar and appear to be inbred. Inbreeding reduces fertility and can eventually cause extinction.

What is gene flow?

A population in genetic equilibrium experiences no gene flow. No new genes enter the population and no genes leave the population. However, few populations are isolated. Gene flow occurs when individuals move among populations. This movement increases the variations in genes and reduces the differences among populations.

With whom do organisms mate?

Mating in a population is usually nonrandom. Individuals tend to mate with other individuals that live near them. This promotes inbreeding. Nonrandom mating might favor individuals that are homozygous for particular traits.

How do mutations affect genetic equilibrium?

The cumulative effect of mutations might change the allelic frequencies in a population and violate genetic equilibrium. Occasionally, a mutation provides an advantage for an organism. The mutation will become more common in future generations. Mutations are the raw material in which natural selection works.

Reading Check

4. Define What happens in a bottleneck?

Think it Over

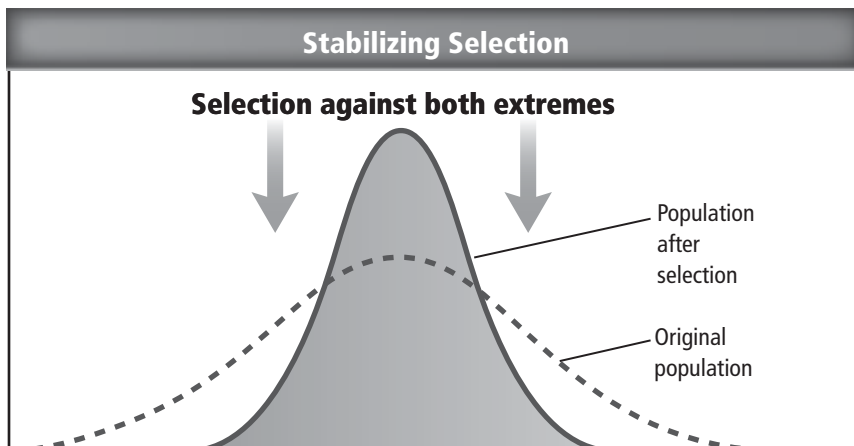
5. Evaluate What is a problem with inbreeding?

What are the different types of natural selection?

Recall that natural selection changes organisms to better fit their environment. There are three different ways (stabilizing, directional, and disruptive selection) that natural selection can change populations.

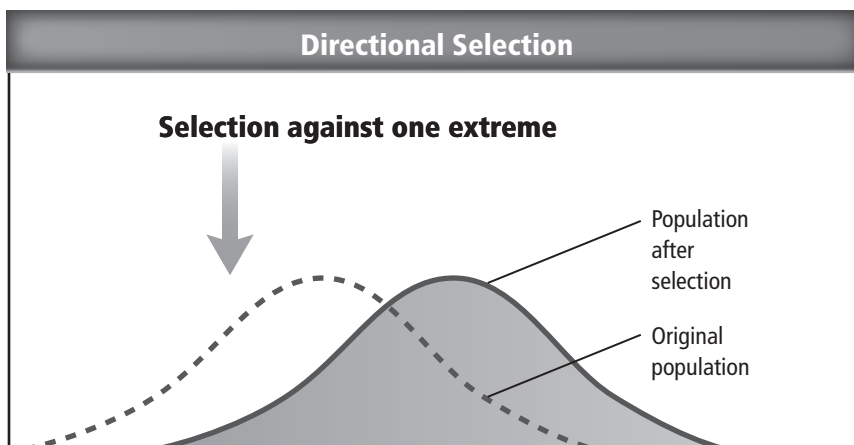
Stabilizing selection removes organisms with extreme forms of a trait. It is the most common form of selection. Stabilizing selection favors the average value of a trait, as shown in the figure below.

For example, human babies born with below-normal or above-normal birth weights are less likely to survive than babies born at average weights. Therefore, the average birth weight in humans remains about the same.



What is favored in directional selection?

Directional selection favors the extreme form of a trait. When an extreme form of a trait results in higher fitness, **directional selection** shifts the populations toward the beneficial trait. Directional selection is shown in the graph below.



Picture This

6. Highlight the curve representing the population in which the extreme forms of a trait have been removed.

Picture This

7. Highlight the curve representing a population before it has undergone directional selection.


 **Reading Check**

8. Evaluate In this example, what causes directional selection to occur?

 **Reading Check**

9. Identify What are two types of isolating mechanisms?

What is an example of directional selection?

American biologists, Peter and Rosemary Grant have observed directional selection in Galápagos finches. In years with little water, food supplies decrease. The remaining foods are hard seeds. Birds with small beaks starve because they are unable to crack the seeds. Birds with larger beak sizes can more easily crack the seeds and survive. In years with little water, average beak size increases. When rain returns, average beak size decreases because smaller beak size is a better fit for the environment. 

What is disruptive selection?


Disruptive selection removes individuals with the average form of a trait. It creates two populations with extreme forms of a trait. Disruptive selection occurs in water snakes on the shores of Lake Erie. Mainland snakes live in grass habitats and have brown skin. Island snakes live on rocky shores and have gray skin. The color of both snakes helps them blend in with their habitat. Snakes that have an intermediate color would be obvious to predators.

What is sexual selection?

Sexual selection occurs when certain traits are inherited because they increase the chance of attracting a mate. This type of selection is often found in populations where males and females look different. Notice that in natural selection, traits best for survival in the environment are selected. In sexual selection, the traits selected are not necessarily those that are best for survival in the environment.

Reproductive Isolation

Genetic drift, gene flow, nonrandom mating, mutation, and natural selection are mechanisms of evolution. All these mechanisms violate the Hardy-Weinberg principle. Scientists disagree about the extent to which each of these mechanisms contributes to the evolution of new species.

Speciation can be defined as the process by which some members of a sexually reproducing population change so much that they can no longer produce fertile offspring that can mate with the original population. Gene flow can be prevented by two types of reproductive isolating mechanisms. **Prezygotic isolating mechanisms** take place before fertilization occurs. **Postzygotic isolating mechanisms** take place after fertilization has occurred. The organism that results from a postzygotic isolating mechanism is infertile. 

How do prezygotic isolating mechanisms work?

Prezygotic isolating mechanisms prevent genotypes from entering a population's gene pool. The isolation might occur geographically, ecologically, or behaviorally. The eastern meadowlark and western meadowlark exhibit a form of behavioral isolation. They have a similar appearance and live in overlapping areas. However, the two species use different mating songs and do not interbreed.

Time is another factor that can be a reproductive barrier. For example, closely related species of fireflies mate at different times of night. Different species of trout live in the same stream. Because they mate at different times of the year, they do not interbreed.

Does postzygotic isolation occur?

Postzygotic isolating mechanisms prevent offspring from surviving or reproducing. Lions and tigers are considered separate species, but they do sometimes mate. The offspring of such a mating—the liger—is sterile and cannot reproduce.

Speciation

Speciation occurs when a population reproduces in isolation. Most scientists believe that allopatric speciation is the most common form of speciation. In **allopatric speciation**, a physical barrier divides one population into two or more populations. After a long period of time, the two populations will contain organisms that can no longer successfully breed with one another. Physical barriers can include mountain ranges, wide rivers, and lava flows.

Sympatric speciation occurs when a species evolves into a new species without a physical barrier. The ancestor species and the new species live in the same habitat during the speciation process. Scientists think that sympatric speciation happens fairly often in plants. Polyploidy, a mutation that increases the number of chromosomes in an organism, might cause sympatric speciation in plants. A plant that results from polyploidy is no longer able to interbreed with the main population.

Patterns of Evolution

Many details of speciation are not yet known. Speciation is a long process. Observations of speciation are rare. However, evidence of speciation is visible in most patterns of evolution.



Think it Over

- 10. Apply** Two closely related birds live on separate islands and do not interbreed. What type of isolation is occurring?
-



Think it Over

- 11. Explain** Kaibab squirrels live on the north rim of the Grand Canyon, and Albert squirrels live on the south rim. Which form of speciation is more likely taking place? (Circle your answer.)
- allopatric speciation
 - sympatric speciation

 **Reading Check**


12. Define What happens in adaptive radiation?

 **Think it Over**

13. Compare Which statement describes two organisms that emerged by convergent evolution? (Circle your answer.)

- a. They have similar morphology.
- b. They are closely related.

When does adaptive radiation occur?

Adaptive radiation occurs when one species evolves in a short period of time into a number of new species. Adaptive radiation can occur when a species evolves a new, useful trait or when a species arrives in a new habitat. Adaptive radiation, also called divergent evolution, can occur on a large scale. Recall from Chapter 14 that the Cretaceous period ended with a mass extinction. Soon afterward, mammals became more diverse. This example of adaptive radiation on a large scale likely produced the wide variety of mammals on Earth today. 

How do species coevolve?

Two species can evolve together, or coevolve. Coevolution sometimes benefits both species. For example, flowers have markings that guide bees to nectar. While the bees gather nectar, they pollinate the flower. The flowers and bees have coevolved in a way that benefits both species.

What is convergent evolution?

Places far apart on Earth can have similar environments. Deserts in North America are similar to deserts in Africa. Similar environments can cause similar organisms to evolve by natural selection. In convergent evolution, unrelated organisms in different places evolve to resemble one another. Convergent evolution produces organisms with similar morphology, physiology, and behavior, even though the organisms are unrelated.

How quickly do species evolve?

Early in the study of evolution, scientists thought evolution was gradual. **Gradualism** is the idea that evolution occurs in small steps over millions of years. Much evidence favors this theory.

Punctuated equilibrium is the idea that speciation occurs in sudden bursts followed by long periods of stability. Stability does not mean an organism is not changing. The organism's genes might still be changing, but the changes are not reflected in fossils of the organism.

Scientists continue to research the tempo of evolution. Some scientists think the fossil record shows that most change occurs in short bursts. Some scientists think that evolution occurs in a combination of gradual and punctuated changes. Many areas of science will contribute evidence to resolve the question of the pace of evolution.

● Before You Read

Have you ever watched a monkey or an ape in a zoo or on television? On the lines below, list some humanlike behaviors you might have observed. Then read the section to learn some traits you share with your fellow primates.

MAIN Idea

Primate characteristics indicate that primates evolved from a common ancestor.

What You'll Learn

- characteristics of primates
- similarities and differences among major primate groups

● Read to Learn

Characteristics of Primates

Primates are a group of mammals that includes humans, apes, monkeys, and lemurs. Primates have a high level of manual dexterity. Manual dexterity enables primates to grasp objects and move them around in their hands. Primates have well developed eyesight, long mobile arms, and large brains. Primates with the largest brains can reason.

Why is an opposable first digit important?

The hands and feet of all primates have five digits. Most have flat nails and sensitive areas on the ends of their digits. The first digit on the hands of most primates and the first digit on the feet of many primates are opposable. An **opposable first digit**, either a thumb or a toe, is set apart from the other digits. This digit can be brought across the palm or foot to touch or nearly touch the other digits. This action allows primates to grasp objects.



Study Coach

Create a Quiz After you read this section, create a five-question quiz from what you have learned. Then, exchange quizzes with another student. After taking the quizzes, review your answers together.

Picture This

1. **Label** the opposable first digit in the picture.



Organize Information

Use two sheets of notebook paper to make a layered Foldable. As you read about primates, use your Foldable to organize the main ideas and vocabulary.

Primates
Characteristics
Groups
Evolution

How do forward-looking eyes benefit primates?

Most primates rely more on vision than on smell. Their eyes are on the fronts of their faces. This creates overlapping fields of vision called **binocular vision**. Forward-looking eyes provide depth perception and enable primates to judge distance and movement of an object.

Most primates are **diurnal** (di YUR nul) which means they are active during the day. Many diurnal primates also have color vision. **Nocturnal** (nahk TUR nul) primates are active at night. They see only black and white colors.

With smaller snouts, primates have a reduced sense of smell. Their flattened faces aid binocular vision. Their teeth are unspecialized, enabling them to eat a variety of foods.

How do primates move?

Primates rely on hind limbs for movement. Most primates live in trees. Their flexible shoulders enable easy movement from branch to branch. On the ground, all primates except humans walk on four limbs most of the time.

What are characteristics of a primate brain?

Primates have large brains. More areas of their brains are dedicated to vision and fewer to smell. Large areas of their brains are dedicated to memory and to arm and leg movement. Many primates are able to solve problems and engage in social behaviors. Primates have complex ways of communicating with each other, including facial expressions.

What is the reproductive rate of primates?

After a long pregnancy, primates give birth usually to one infant. Newborn infants depend on their mothers for a long time. This allows infants to learn complex social interactions. The low reproductive rate, however, combined with loss of habitat and human predation, has threatened primates.

Primate Groups

Most primates are **arboreal** (ar BOHR ee uhl), or tree-dwelling, and live in tropical and subtropical forests. Scientists classify primates into two subgroups. The strepsirrhines (STREP sihr ines), or “wet-nosed” primates, are the earliest and most basic primates. Most members of this group are lemurs. Haplorhines (HAP lohr ines), or “dry-nosed” primates, include the **anthropoids** (AN thruh poydz), or humanlike primates, as well as a unique primate called the tarsier (TAR see ur).

Reading Check

2. **Identify** the two subgroups of primates.

Strepsirrhines





The table below lists characteristics of some strepsirrhines. Strepsirrhines are the only primates that rely mostly on smell for hunting and social interactions. They have large eyes and ears.

Strepsirrhines live in tropical Africa and Asia. Most are found only in Madagascar and nearby islands. Scientists hypothesize that these animals evolved in isolation when Madagascar drifted away from the African mainland.

Picture This

3. Draw Conclusions

Look at the picture of each animal. What feature suggests that these animals are nocturnal?

Strepsirrhine Group	Lemurs	Aye-Ayes	Lorises	Galagos (ga LAY gohs)
Example				
Active Period	large—diurnal small—nocturnal	nocturnal	nocturnal	mostly nocturnal
Range	Madagascar	Madagascar	Africa and Southeast Asia	Africa
Features	<ul style="list-style-type: none"> vertical leapers use long bushy tail for balance herbivores and omnivores 	<ul style="list-style-type: none"> tap bark, listen, fish out grubs with long third finger 	<ul style="list-style-type: none"> small; slow climbers; solitary lack tail some have toxic secretions 	<ul style="list-style-type: none"> small; fast leapers no opposable digit long tail

Haplorhines

Tarsiers, monkeys, and apes are all members of the large group called haplorhines. Apes include gibbons, orangutans, gorillas, chimpanzees, and humans.

The tarsier lives only in Borneo and the Philippines. This small nocturnal animal has large eyes and lives in trees. It can turn its head halfway around.

Anthropoids are generally larger than strepsirrhines. They have larger brains for their body size. Most are diurnal and have color vision. Anthropoids have complex social interactions. Anthropoids are split into the New World monkeys and the Old World monkeys. New World refers to the Americas. Old World refers to Africa, Asia, and Europe.

Think it Over

4. Apply Howler monkeys live in Central and South American rain forests. Is the howler an Old World monkey or a New World monkey?

Picture This

5. **Explain** how a prehensile tail might benefit a monkey.

What traits do New World monkeys share?

New World monkeys live in the tropical forests of Mexico, Central America, and South America. New World monkeys include marmosets and tamarins. These unique primates do not have fingernails or opposable digits.

Some squirrel monkeys and spider monkeys do have opposable digits. Most of these monkeys are diurnal and live together in social bands. Their **prehensile** (pree HEN sul) tails work like a fifth limb. The tail can grasp tree limbs and support the monkey's weight.



What features distinguish Old World monkeys?

Old World monkeys live in a wide variety of habitats throughout Asia and Africa. Macaques and baboons belong to one subgroup. Colobus and proboscis monkeys belong to another subgroup.

Old World monkeys are diurnal and live in social groups, like New World monkeys. However, Old World monkeys have narrower noses and larger bodies. They spend more time on the ground. Old World monkeys do not have prehensile tails. Some do not have tails. Most have opposable digits.

How do apes differ from monkeys?

Only a few ape species exist today. They have larger brains than monkeys. Their arms are longer than their legs. Apes have barrel-shaped chests, no tails, and flexible wrists. They are highly social and make complex sounds.

Apes are classified into two subgroups: lesser apes and great apes. The lesser apes include gibbons and siamangs. The great apes include orangutans, gorillas, chimpanzees, and humans.

How do lesser apes travel through the trees?

Gibbons and siamangs are gymnasts of the trees. Although they can walk, they often move quickly from branch to branch using a hand-over-hand swinging motion called brachiation.

Reading Check

6. **Name** the ape subgroup to which you belong.

How do great apes walk?

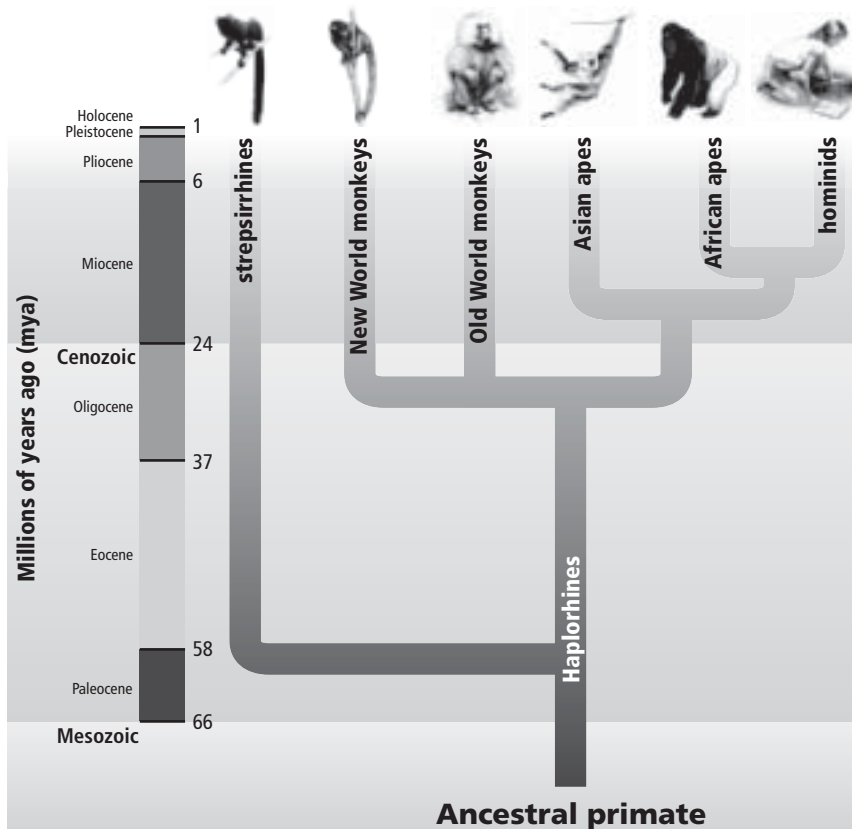
Orangutans are the largest arboreal primates. They spend more time on the ground than in trees. Orangutans are the only great ape species that lives exclusively in Asia.

Gorillas are the largest primates. Like all great apes, they spend most of their time on the ground. They walk on all four limbs, using their front knuckles for support. They use sticks as simple tools. In captivity, they have been taught to recognize characters and numbers.

Chimpanzees and bonobos are also knuckle-walkers. They have well-developed communication and social systems. They are more like humans in their physical structure and behavior than any other primate.

To what category do humans belong?

Humans are part of the great ape family. Humans are classified as hominins. **Hominins** are humanlike primates that appear to be more closely related to present-day humans than they are to present-day chimpanzees and bonobos. Many species of hominins have existed on Earth. However, humans are the only species of hominins that survives today. The figure below illustrates primate evolution.



Reading Check

7. **Identify** the ape that is most closely related to you. (Circle your answer.)
- a. gorilla
 - b. orangutan
 - c. bonobo

Picture This

8. **Study** the evolution of primates, and explain it to another person.

Primate Evolution


Most primates today are arboreal. Prehensile tails, long limbs, binocular vision, brachiation, and opposable toes and thumbs are all traits that help primates live in trees.

How might primates have become arboreal?

Some scientists suggest that primates evolved from ground-living animals that gathered food in top branches of shrubbery. This suggests that the flexible hand and opposable toes and thumbs might have evolved to catch insects rather than to grasp tree branches. Primates then evolved to fill other niches in trees. Other scientists suggest that the rise of flowering plants provided new niches. Arboreal adaptations then enabled primates to gather fruits and flowers of trees.

When did the first primates appear?


The first primates probably lived alongside dinosaurs about 85 mya. One of the earliest fossil primates, called *Altiatlasius* (al tee aht lah SEE us), was a small, nocturnal animal that used its hands and feet for grasping. About 50 mya, anthropoids branched off from tarsiers. By the end of the Eocene, 35 to 30 mya, anthropoids had evolved widely.

About this time, many early strepsirrhines appear to have become extinct. Extinction might have been caused by a cooling climate or competition from the larger, bigger-brained anthropoids. 

When did different lines of monkeys diverge?

Monkeys first appeared at the end of the Eocene between 35 and 25 mya. By this time, Africa and South America had separated into two continents. Some scientists think that New World monkeys evolved from a group of Old World monkeys that drifted to South America on rafts of vegetation. Other scientists think that New World monkeys branched from anthropoids that traveled to South America earlier when sea levels were lower.

What animal might have given rise to apes?

Many anthropoid fossils have been found in the Fayum basin in Egypt. *Aegyptopithecus* (ee gypt oh PIH tuh kus), or the dawn ape, is the largest—about the size of a house cat. Some scientists think this animal might have been part of the anthropoid line that split from Old World monkeys. This line led to orangutans, gorillas, chimpanzees, and humans. 

Reading Check

9. **Name** a key competitive advantage that anthropoids had over early strepsirrhines.

Reading Check

10. **Explain** the importance of *Aegyptopithecus*.

Primate Evolution

section 2 Hominoids to Hominins

● Before You Read

Humans are bipedal—they can walk upright on two legs. On the lines below, list possible advantages of walking upright, instead of walking on four limbs. Then read the section to learn why bipedalism might have evolved.

MAIN Idea

Hominins likely evolved in response to climate changes of the Miocene epoch.

What You'll Learn

- the evolutionary path of hominoids from *Proconsul* to *Homo*
- characteristics of various australopithecine species

● Read to Learn

Hominoids

Hominoids (HAH mih noydz) include all nonmonkey anthropoids—gibbons, orangutans, chimpanzees, gorillas, and humans. By comparing DNA of living hominoid species, researchers conclude that gibbons likely branched from anthropoids first. Next to the branch were orangutans, gorillas, chimpanzees and bonobos, and finally humans. Chimpanzees and bonobos are the closest living relatives to humans. The figure below shows the time line of primate evolution.

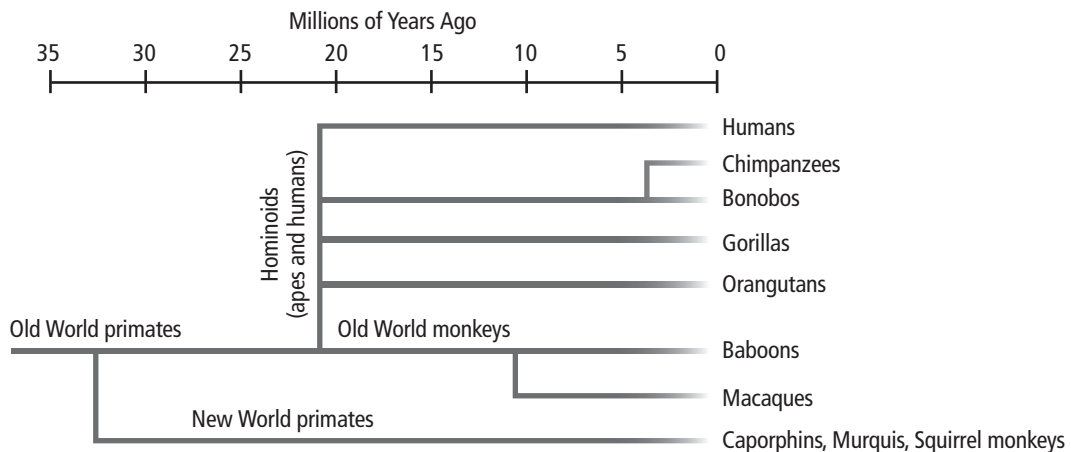
Mark the Text

Highlight Main Ideas

As you read the section, highlight the main ideas in each paragraph.

Picture This

- 1. Identify** Circle the branch containing the human species.



Reading Check

2. Identify a body characteristic of hominins that differs from other hominoids.

Picture This

3. Highlight each important discovery as you read about it in the section.

What characteristics do hominoids share?

Hominoids are the largest primates. They have the largest brains for their body sizes. Typical traits include a broad pelvis, long fingers, no tail, and flexible arm and shoulder joints. They have mostly upright postures. All hominoids, except for hominins, have longer arms than legs. Their teeth are less specialized than other primates. ✓

Earth’s climate changed during the Miocene (25 to 24 mya). It became warmer and drier. Tropical rain forests shrank. Dry forests and savannas appeared. Many new animals evolved, including hominoids, that were able to take advantage of the new environment. Hominoids migrated from Africa to Europe and Asia.

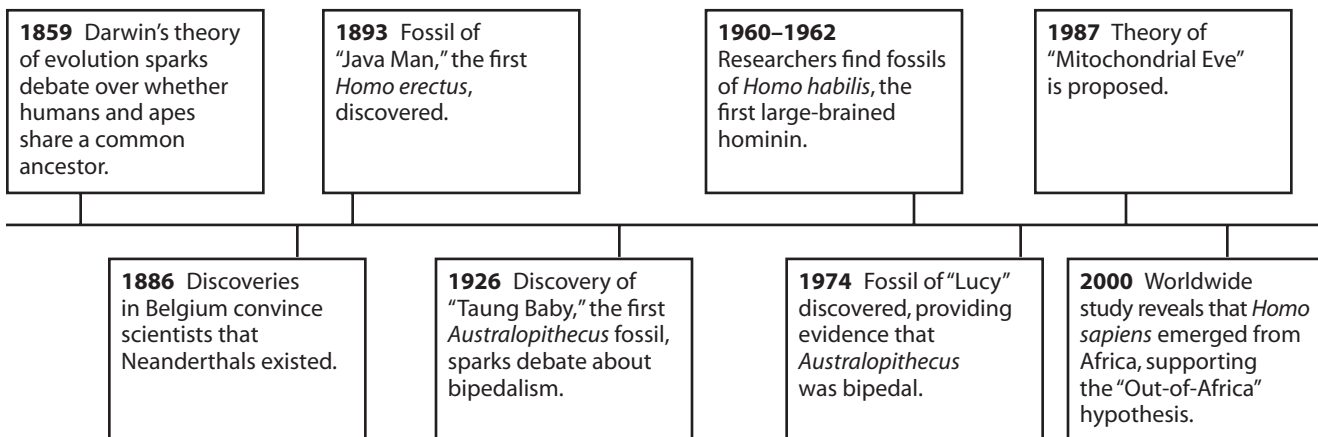
Why is Proconsul important?

Some of the oldest hominoid fossils are from the genus *Proconsul*. *Proconsul* species had small brains. Although they lived mostly in trees, some might have been able to walk upright. Some scientists think that *Proconsul* is a human ancestor. Others suggest that humans rose from a European hominoid that returned to Africa at the end of the Miocene.

Hominins

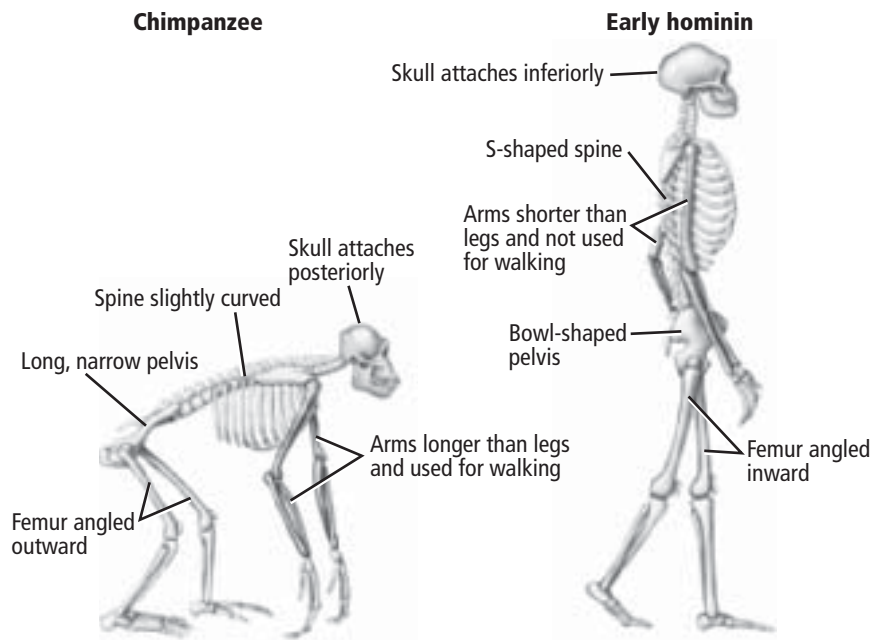
The hominins include humans and all their extinct relatives. Hominins split off from other African apes sometime between 8 and 5 mya. The figure below highlights some important hominin discoveries.

The brains of hominins are larger than those of other hominoids and have more capacity for high-level thought. The hominin face is thinner and flatter. The teeth are smaller. Longer thumbs and more flexible wrists increase manual dexterity.



What structures support upright walking?

Hominins are **bipedal**—they can walk upright on two legs. The figure below shows how the structures of a biped differ from those of a quadruped, an animal that walks on all four limbs. Note how the shapes of the spine, arms, pelvis, and legs are adapted for upright walking. Also note that in quadrupeds, the spine extends from the back of the skull. In bipeds, the spine extends from the base of the skull.



What are some disadvantages of bipedalism?

Walking upright has disadvantages. Bipedal individuals are easier for predators to see. They might not run as fast as their predators. Also, walking upright puts more strain on the hips and back. Because walking upright opposes gravity, it requires more energy than walking on all four limbs.

Why did hominins become bipedal?

At the time hominins evolved, Africa was changing. Many scientists suggest that bipedalism was an adaptation to the new savanna environment. Food sources were sparse and far apart. By walking upright, individuals were able to travel longer distances and to spot food more easily.

Another theory suggests that walking on two legs freed hands for purposes such as carrying objects. Still another theory suggests that an upright posture enabled hominins to reach fruit on low tree branches.

Picture This

4. Color the arms of the chimpanzee and the early hominin.

Reading Check

5. Summarize three possible disadvantages of bipedalism.



Think it Over

6. Draw Conclusions

Based on what you know about bipedal adaptations, where do you think the opening in the skull was in *A. africanus*?

Reading Check

7. Explain

what the paranthropoids were.

What were the first bipedal hominins?

Bipedalism was one of the first hominin traits to evolve. Scientists look for evidence of bipedalism to identify hominin fossils. The **australopithecines** (aw stray loh PIH thuh sees) were the first truly bipedal hominins. They lived in east-central and southern Africa between 4.2 and 1 mya. They were small, only about 1.5 m tall, with apelike brains and jaws. Their teeth and limb joints were humanlike.

What debate did the Taung baby spark?


In 1926, anthropologist Raymond Dart discovered the first australopithecine fossil, the “Taung baby,” in Africa. He called the species *Australopithecus africanus*. The location of the opening in the skull where the spine attached convinced Dart that *A. africanus* was bipedal. Some scientists disagreed. They believed that larger brains evolved before bipedalism.

How did Lucy help to resolve the debate?

The discovery of “Lucy” in Kenya in 1974 by Donald Johanson helped to resolve the debate. Lucy is one of the most complete australopithecine fossils ever found. She was about the size of a chimpanzee. She had a small brain, long arms, and curved finger bones. But her hip and knee joints showed clearly that Lucy walked upright. A few years later, Mary Leakey found fossilized footprints that supported the theory that australopithecines were bipedal.

How can hominin evolution be described?

Hominin fossils show a patchwork of human and apelike traits. Different body parts or behaviors evolved at different rates. This is called mosaic evolution.

Scientists have discovered many more early hominin fossils in the last 30 years. They disagree about how to classify them. For example, *A. bosei* and *A. robustus* were classified as australopithecines. Today, many scientists put these primates in a separate genus called *Paranthropus*. Paranthropoids lived alongside human ancestors but were not human ancestors themselves. 

Many species of hominins lived successfully for years, often overlapping with earlier species. Then they became extinct. No one knows why. By 1 mya, all australopithecines had disappeared from the fossil record. Later hominin fossils were only of humans and their close relatives.

● Before You Read

When you think of “cave men,” what image comes to mind? On the lines below, describe your idea of early humans and their behaviors. Then read the section to learn about your cave-dwelling ancestors.

● Read to Learn

The *Homo* Genus

The genus *Homo* includes living and extinct humans. Members of this genus first appeared in Africa between 3 and 2.5 mya. Scientists think they evolved from an australopithecine ancestor.

Homo species had bigger brains than the australopithecines. They also had lighter skeletons, flatter faces, and smaller teeth. *Homo* species were the first to control fire and to use stone tools. As they evolved, they developed language and culture.

How did *Homo habilis* differ from its ancestors?

The first *Homo* species for which fossils exist is *Homo habilis*. *Homo habilis*, which means “handy man,” used stone tools. The *Homo* traits of *H. habilis* included a larger brain, smaller brow and jaw, flatter face, and more humanlike teeth. Like its australopithecine ancestors, however, *H. habilis* was small, had long arms, and could climb trees. ☑

Another species, *Homo rudolfensis*, might have lived at the same time. However, few fossils of this species exist. Scientists are uncertain about how *H. rudolfensis* relates to the *Homo* line.

MAIN Idea

Tracing the evolution of the *Homo* genus is important for understanding humans.

What You'll Learn

- the Out-of-Africa hypothesis
- similarities and differences between Neanderthals and modern humans

Mark the Text

Read for Understanding

As you read this section, highlight any sentence that you do not understand. When you finish the section, go back and reread the sentences you highlighted.

✓ Reading Check

1. **Describe** two ways in which *H. habilis* was more like apes than like humans.



Think it Over

2. **Explain** why *H. ergaster* might have followed migrating animals.

Reading Check

3. **Describe** the types of fossils that are classified as *Homo heidelbergensis*.

Why is *Homo ergaster* important?

The next species, *Homo ergaster*, appeared only briefly in the fossil record. It had a larger brain than *H. habilis*. It was also taller and lighter with longer legs and shorter arms. Scientists think that *H. ergaster* had the first human nose (with nostrils facing downward).

Tools *H. ergaster* made hand axes and other tools. This species might have been a hunter or a scavenger. The tools might have been used to scrape meat off scavenged bones.

Migration *H. ergaster* appears to be the first African *Homo* species to migrate to Asia and Europe, possibly following migrating animals. Forms of *H. ergaster* in Europe and Asia are called *Homo erectus*. Scientists believe that *H. ergaster* is an ancestor to modern humans.

What skills did *Homo erectus* have?

In Europe and Asia, *Homo erectus* evolved from *H. ergaster*. This species includes “Java Man,” discovered in Indonesia, and “Peking Man,” discovered in China. Unlike earlier species, *H. erectus* adapted to many types of environments.

H. erectus was taller than *H. habilis*. It had a bigger brain and more humanlike teeth. *H. erectus* featured a long skull, low forehead, and a thick brow ridge. This species made advanced tools, used fire, and sometimes lived in caves.

What is the significance of *Homo floresiensis*?

Most scientists believe that *H. erectus* went extinct about 400,000 years ago. Fossils discovered in 2004 on Flores island, Indonesia, suggest otherwise. This species, called *Homo floresiensis* (flor eh see EN sus), descended from *H. erectus* or another hominin. It existed until 12,000 years ago. Nicknamed “The Hobbit,” *H. floresiensis* was only about 1 m tall. Basic stone tools were found with its fossils.

What traits did *Homo heidelbergensis* display?

The transition from *H. ergaster* to modern humans occurred gradually. Many fossils display a mix of traits of *H. ergaster* and modern humans. Some scientists classify these diverse fossils as *Homo heidelbergensis*. Others put them in a broader category called *Homo sapiens*. These humans had larger brains and thinner bones than *H. ergaster*, but they still had thick brow ridges and small chins.

Are Neanderthals our ancestors?

The **Neanderthals**, or *Homo neanderthalensis*, were a human species that evolved only in Europe and Asia. They likely evolved from *H. erectus* or a *Homo* species of the transition period. Neanderthals were larger than humans and had large brains. They had thick skulls and brow ridges, large noses, and heavy muscles attached to their thick bones. ✓

Neanderthals lived near the end of the Pleistocene ice age. They hunted, used fire, and made complex shelters. Evidence suggests that they cared for their sick and buried their dead.

In some areas, Neanderthals overlapped with modern humans. However, DNA tests on fossil bones show that Neanderthals were not part of the human gene pool. They were a different species. Neanderthals went extinct about 30,000 years ago.

Emergence of Modern Humans

The thinner skeletons of *Homo sapiens* give them a more slender appearance than other *Homo* species. They have rounder skulls and smaller faces with an obvious chin. *H. sapiens* first appeared in what is now Ethiopia about 195,000 years ago. Early members of this species chipped stones to make hand axes and other tools. The table below compares *Homo* species.

Species	Time in Fossil Record	Characteristics
<i>Homo habilis</i>	2.4 to 1.4 million years ago	<ul style="list-style-type: none"> • average brain size: 650 cm³ • used tools
<i>Homo ergaster</i>	1.8 to 1.2 million years ago	<ul style="list-style-type: none"> • average brain size: 1000 cm³ • had thinner skull bones • had humanlike nose
<i>Homo erectus</i>	1.8 to 400,000 years ago	<ul style="list-style-type: none"> • average brain size: 1000 cm³ • had thinner skull bones • used fire
<i>Homo neanderthalensis</i>	200,000 to 30,000 years ago	<ul style="list-style-type: none"> • average brain size: 1500 cm³ • buried their dead • possibly had language
<i>Homo sapiens</i>	195,000 years ago to present	<ul style="list-style-type: none"> • average brain size: 1350 cm³ • does not have brow ridge • has a small chin • has language and culture

✓ Reading Check

4. Generalize How did the Neanderthal body differ from the human body?

Picture This

5. Describe the trend in brain size as evolution progressed from earlier species to more recent species.

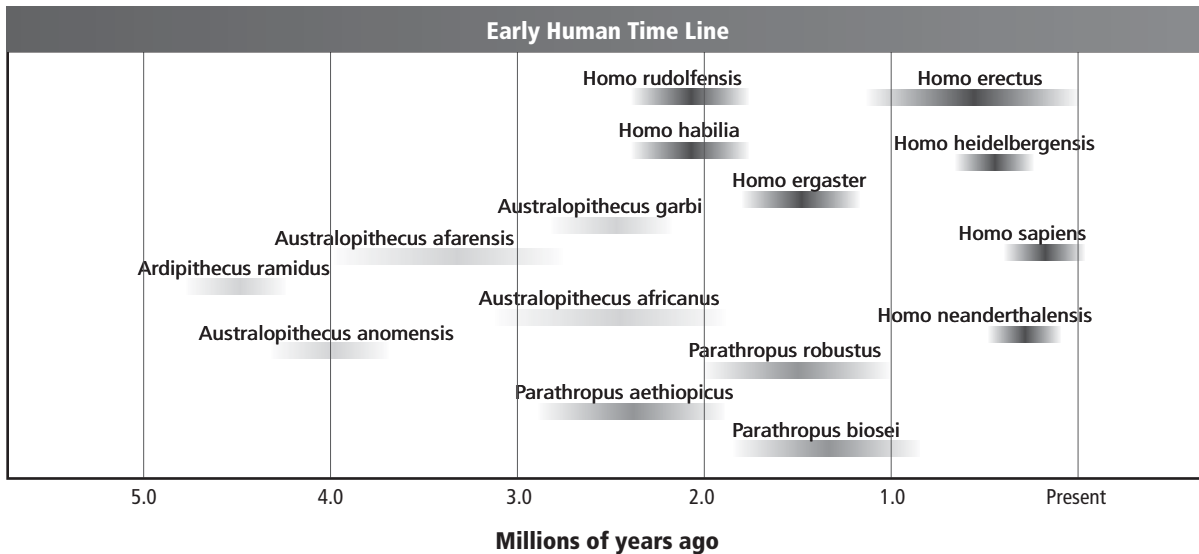
Picture This

6. Highlight Use a marker to highlight the direct ancestor of today's human beings.

What is the “Out of Africa” hypothesis?

As shown in the figure below, many hominin species overlapped until about 30,000 years ago. Then, only modern humans remained.

Some scientists believe that modern humans evolved at the same time in different areas of the world. Most scientists, however, believe the “Out of Africa” hypothesis. This view suggests that humans evolved only once, in Africa, and then migrated to all parts of the world, replacing other hominins.



Think it Over

7. Draw Conclusions

Scientists found the widest variation in mitochondrial DNA in Africans. What conclusion could they draw from this finding?

How did DNA support this hypothesis?

Mitochondrial DNA analysis of today's humans supported this hypothesis. Mitochondrial DNA changes very little over time. As a result, scientists reasoned that populations with the most variation in this DNA must have existed the longest time. They found the widest variation among Africans.

Mitochondrial DNA is inherited only from the mother. Therefore, this analysis suggested that *H. sapiens* emerged in Africa about 200,000 years ago from a hypothetical “Mitochondrial Eve.”

What evidence of human culture appeared?

Unlike Neanderthals, early modern humans expressed themselves using symbols and art. They drew on cave walls and decorated objects, and developed complex tools and weapons. They were the first to fish, make clothing, and raise animals. Cultural expressions such as these marked the first fully modern humans. Some people consider **Cro-Magnons** to be the first hunter-gatherers.

Organizing Life's Diversity

section 1 The History of Classification

● Before You Read

On the lines below, describe how you might organize a personal collection of books or CDs. In this section, you will learn the way biologists organize living things.

MAIN Idea

Biologists use a system of classification to organize information about the diversity of living things.

What You'll Learn

- differences in methods of classifying
- how to write scientific names
- the taxa in biological classification

● Read to Learn

Early Systems of Classification

It is easier for biologists to communicate and keep information about organisms when the organisms are organized into groups. One tool biologists use to organize organisms is classification. **Classification** is the grouping of objects or organisms based on a set of conditions. A regular system of classification helps scientists organize and communicate information about biology.

How did Aristotle classify organisms?

More than two thousand years ago, Aristotle, a Greek philosopher, developed the first commonly accepted system of biological classification. Aristotle classified organisms as either animals or plants. Animals were classified by their habitat and their morphology. Morphology relates to the physical characteristics and structures of organisms. Animals were also classified by the presence of red blood. Aristotle's classification of "bloodless" and "red blood" animals closely matches today's classification of invertebrates and vertebrates. Plants were classified by average size and structure—as trees, shrubs, or herbs. The table on the next page shows how Aristotle might have divided some of his groups. ✓

Mark the Text

Identify Concepts

Highlight each question heading in this section. Then use a different color to highlight the answers to the questions.

Reading Check

1. **Identify** Who developed the first commonly accepted system of classification?

Picture This

2. Classify Using Aristotle's classification system, how would a daisy, a dog, and a whale be classified?

Plants		
Herbs	Shrubs	Trees
violets rosemary onions	blackberry bush honeysuckle flannelbush	apple oak maple
Animals with Red Blood		
Land	Water	Air
wolf cat bear	dolphin eel sea bass	owl bat crow

What were the limitations of Aristotle's system of classification?

Aristotle's system of classification was useful for organizing, but it had many limitations. One limitation was that Aristotle's system was based on his understanding that species are distinct, separate, and unchanging. Because of this understanding, Aristotle's classification did not account for evolutionary history or relationships. Also, many organisms have been discovered that do not fit Aristotle's classification system, such as birds that do not fly and frogs that live on land and in water. Aristotle's system was used for many centuries before it was replaced by a new system. The new system built on the knowledge humans had gained about the natural world.

How did Linnaeus classify organisms?

In the eighteenth century, Swedish botanist Carolus Linnaeus developed a branch of biology called taxonomy. **Taxonomy** (tak SAH nuh mee) is a discipline of biology concerned with identifying, naming, and classifying species based on the morphological and behavioral similarities and differences of organisms. Linnaeus's system built on the foundation of Aristotle's system of classification. Linnaeus used similarities and differences in morphology and behavior to classify birds. The morphological differences can be related to differences in where the birds lived and their behavior.

What is systematics?

Taxonomy is part of a larger branch of biology called systematics. Systematics is the study of biological diversity. Scientists study diversity in the past, as well as present biological diversity.



Think it Over

3. Explain How did Linnaeus's system of classification build on Aristotle's system?



How are scientific names written?

Linnaeus named organisms using binomial nomenclature. **Binomial nomenclature** (bi NOH mee ul • NOH mun klay chur) gives each species a scientific name that has two parts. The first part is the genus (JEE nus) name, and the second part is the specific epithet (EP uh thet), or specific name, that identifies the species. Latin is often used for binomial nomenclature because Latin is a language that is unchanging. Historically, Latin has also been the language of science. The meaning of Latin words can be understood by scientists who speak different languages.

Why do scientists use scientific names?

Biologists use scientific names because common names vary in their use. For example, the bird *Cardinalis cardinalis*, shown above, is commonly called a redbird, a cardinal, and a Northern cardinal. Binomial nomenclature is also used because common names can be misleading. A starfish is neither a star nor a fish, a great horned owl does not have horns, and a sea cucumber is not a plant.

When writing scientific names, scientists follow certain rules. The most important rules are as follows:

- The first letter of the genus name is always capitalized, but the rest of the genus name and all of the specific epithets are lowercase.
- If a scientific name is printed in a book or magazine, it is italicized.
- If a scientific name is written by hand, it is underlined.
- After the complete scientific name has been written once, the genus name will often be abbreviated to the first letter when used again. For example, the scientific name *Cardinalis cardinalis* can be written *C. cardinalis*. ✓

Picture This

- 4. Identify** Which is the scientific name for this bird? (Circle your answer.)
- a. cardinal
 - b. Northern cardinal
 - c. *Cardinalis cardinalis*

✓ Reading Check

- 5. Describe** How should a scientific name be written by hand?

✓ Reading Check

6. Compare How is today's classification system different from Linnaeus's system?

How has the classification system changed?

Linnaeus's classification system made it possible to include evolutionary principles in classification in the 1800s. In the nineteenth century, important scientists, including Jean-Baptiste Lamarck, Charles Darwin, and Ernest Haeckel, introduced classification systems based on evolutionary relationships to organize biological diversity. Categories used in modern classification are based on Linnaeus's system but have been changed to show evolutionary relationships.

Taxonomic Categories

Taxonomists classify organisms by dividing them into smaller groups based on more specific criteria. Taxonomic categories used by scientists are like nesting boxes—each category fits into another. The categories are arranged from broadest to most specific. A named group of organisms is called a **taxon** (plural, taxa).

What are a species and a genus?

Two of the taxa Linnaeus used were genus and species. Today, a **genus** (plural, genera) is defined as a group of species that are closely related and share a common ancestor. A species is a group of organisms that have similar characteristics such as skull shape and size. For example, the species American black bear (*Ursus americanus*) and the species Asiatic black bear (*Ursus thibetanus*), shown below, belong to genus *Ursus*. All species in the genus *Ursus* have massive skulls and similar tooth structure.

Picture This

7. Name characteristics that the American black bear and the Asiatic black bear have in common.



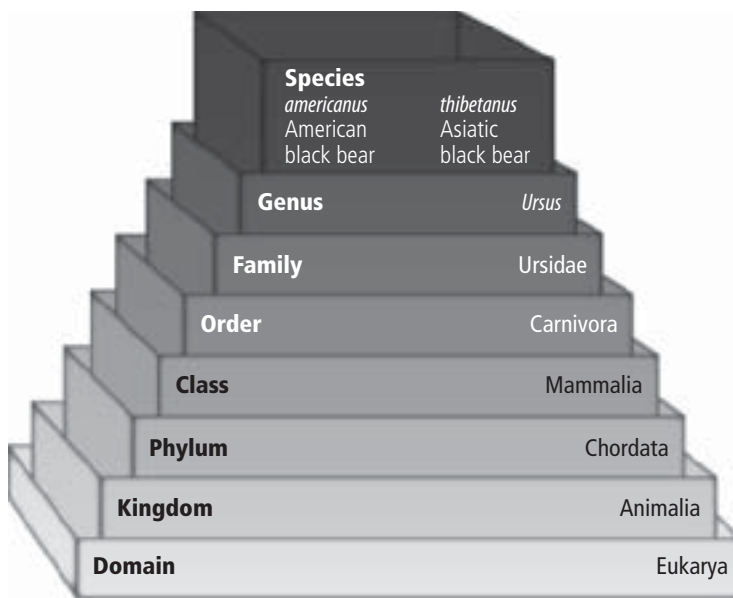
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What is a family?

A **family** is a group of genera that have similar characteristics. All bears, both living and extinct, belong to the family Ursidae. All members of the Ursidae family have similar characteristics. For example, they walk flat-footed and have forearms that can rotate to grasp prey closely.

What are the higher taxa?

An **order** is a group of families that have similar characteristics. A **class** is a group of one or more related orders. A **phylum** (FI lum) (plural, phyla) or a **division** is a group of related classes. The term *division* is used for bacteria and plants. A **kingdom** is a group of related phyla, or domains. The least specific of all taxa is a domain. A **domain** is a group of one or more kingdoms. The pyramid of taxa shown below will help you remember how the taxa are organized.



Systematics Applications

Systematicists are scientists who study classification. They provide detailed guides that enable other people to identify organisms. Many times, field guides have dichotomous (di KAWT uh mus) keys, which are keys based on a series of choices between characteristics. You can tell if a plant or animal is poisonous by using a field guide to identify it. Systematicists also work to identify new species and relationships among known species. If a known species produces a certain chemical, a close relative might produce a similar chemical.

Picture This

8. Determine At what level on the pyramid of taxa is the American black bear distinguished from the Asiatic black bear?

Think it Over

9. Draw Conclusions Why might it be important to know the relationships among species?

Organizing Life's Diversity

section 2 Modern Classification

MAIN Idea

Classification systems have changed over time as information has increased.

What You'll Learn

- species concepts
- methods to reveal phylogeny
- how to construct cladograms

Mark the Text

Identify Main Ideas

As you read, underline or highlight the main ideas in each paragraph.

Reading Check

1. Define What is a type specimen?

Before You Read

On the lines below, describe your system of organizing your class notes and your method of using the information in your notes to study for tests. In this section, you will learn how scientists have used new information to make adjustments to systems and theories.

Read to Learn

Determining Species

Organisms that are different species by one definition might be the same species by a different definition. The definition of species is evolving as scientists learn more information about the organisms they study.


What is the typological species concept?

Aristotle and Linnaeus thought of each species as a group of organisms with similar physical characteristics. This definition of a species is called the typological species concept. It is based on the idea that species are unchanging, distinct, natural "types." A type specimen is an individual of the species that best shows the characteristics of that species. When another specimen was found that was different from the type specimen, it was classified as a different species.

Evolution causes species to change. Because there is a lot of variation among members of some species, the typological species concept has been replaced. Some of its traditions such as type specimens remain.

✓ Reading Check

What is the biological species concept?

In the 1930s and 1940s, the term *species* was redefined as a group of organisms that are able to interbreed and produce fertile offspring in a natural setting. This definition is known as the biological species concept. 

There are limitations to the biological species concept. Wolves and dogs are classified as different species, but they are known to interbreed and produce fertile offspring. Many plant species can also interbreed and produce fertile offspring. The biological species concept also does not consider extinct species or species that reproduce asexually. However, the biological species concept works for most classification, so it is often still used.

What is the phylogenetic species concept?

In the 1940s, the evolutionary species concept was proposed to go along with the biological species concept. The evolutionary species concept defines different species as two or more groups that evolve independently from an ancestral population. This concept has developed into the phylogenetic species concept.

Phylogeny (fi LAH juh nee) is the evolutionary history of a species. The phylogenetic species concept defines a species as a group of organisms that is different from other groups of organisms and that has, within the group, a pattern of ancestry and descent. When a phylogenetic species branches, it becomes two different phylogenetic species. For example, in Chapter 15 you read that when organisms become isolated, they often develop different adaptations. Over time, these isolated organisms become different from the original group.

2. Describe How is species defined as the biological species concept?

Picture This

3. Identify Which species concept classifies according to ancestral history?

Species Concept	Description	Limitation	Benefit
Typological species concept	classification by the comparison of physical characteristics with a type specimen	Alleles produce a wide variety of features within a species.	Descriptions of type specimens provide detailed records of the physical characteristics of many organisms.
Biological species concept	classification by similar characteristics and the ability to interbreed and produce fertile offspring	Some organisms that are different species interbreed occasionally. It does not account for extinct species.	The working definition applies in most cases, so it is still used frequently.
Phylogenetic species concept	classification by evolutionary history	Evolutionary histories are not known for all species.	Accounts for extinct species and considers molecular data.

Reading Check

4. Summarize Why might African elephants be two species, instead of one?

Picture This

5. Compare What physical characteristics do the oviraptor and the sparrow have in common?

Has the classification of a species changed?

For more than one hundred years, Asiatic elephants have been classified as one species and African elephants have been classified as a different species. There are two populations of African elephants. One population lives in the savanna, and one population lives in the forest. Until recently, the two African populations had been classified as the same species. Scientists thought that the two African populations interbred at the borders of their habitats. Recent studies have shown that they interbreed rarely. Scientists also found large differences in the DNA and skull measurements of the two African populations. The two populations might be separate species.

Characters

To determine the species of an organism, scientists put together pieces of evolutionary history, also called phylogenies, using characters. **Characters** are inherited features that vary among species. Characters can be morphological or biochemical.

How are morphological characters used?

Shared morphological characters suggest that species are closely related and that they evolved from a recent common ancestor. Analogous characters do not indicate a close evolutionary relationship. Recall that analogous characters have the same function but different structure. Homologous characters might perform a different function but show similar structure that was inherited from a common ancestor.

Look at the oviraptor and the sparrow shown below. Some dinosaur fossils such as theropods show that they had feathers and large hollow spaces in their bones. Their hip, leg, wrist, and shoulder structures are similar to those of birds. These morphological characters suggest that birds are related more closely to theropod dinosaurs than to other reptiles.



How are biochemical characters used?

Recall from Chapters 9 and 10 that chromosomes are strands of genetic material that become visible during mitosis and meiosis. The number and structure of chromosomes provide information about evolutionary relationships among species. Similarities suggest a common evolutionary history.

DNA and RNA are made up of four nucleotides. The sequence of DNA nucleotides defines the genes that give instructions to RNA for making proteins. Scientists study and understand evolutionary relationships by sequencing DNA of different organisms. They compare the sequences of a variety of organisms. Organisms that are closely related have many similar sequences of nucleotides. Therefore, they have similar proteins. ✓

Broccoli, cabbage, cauliflower, and kale look different, but they have almost the same chromosome structures, which suggest a close evolutionary relationship. Chimpanzees, gorillas, and orangutans also have similar chromosomes.

Different organisms might have many similar sequences in their DNA. However, when all of their DNA sequences are studied, major differences can be found. The more sequences they share, the more likely they are to share a common ancestor.

What are molecular clocks?

Mutations occur randomly in DNA. As time passes, mutations build up in the chromosomes. Some mutations do not affect the function of cells. The rate at which these mutations build up can be viewed as a molecular clock. A **molecular clock** is a model that uses comparisons of DNA sequences to estimate how long species have been evolving.

The rate at which mutations occur does not stay the same. The rate of a mutation is affected by many factors that include the type of mutation, where in the genome the mutation occurs, the type of protein the mutation affects, and the population in which the mutation occurs. In a single organism, genes might mutate at a different rate. This inconsistency makes molecular clocks difficult to read. Scientists are trying to find genes that mutate at a relatively consistent rate throughout a range of organisms.

Even though molecular clocks have limitations, they can be a valuable tool for helping to determine the time when a new species evolved. The molecular clock is often used along with the fossil record to identify the time of divergence.

✓ Reading Check

6. Explain How can DNA sequences be used to determine if organisms are closely related?

Think it Over

7. Discuss Why does the inconsistency in the rate at which genes mutate make molecular clocks difficult to read?

Phylogenetic Reconstruction

Biologists often study evolutionary relationships using cladistics. **Cladistics** (kla DIHS tiks) is a way to study evolutionary relationships that rebuilds phylogenies and hypothesizes evolutionary relationships based on shared characters. The hypothesized relationships formed by cladistics suggest how different groups of organisms might have evolved. To identify possible relationships, the characters of different groups of organisms need to be known.

What are the main character types?

There are two main character types that need to be considered when using cladistics: ancestral characters and derived characters. An ancestral character is found in a variety of groups within the line of descent. A derived character is present in one group within the line of descent, but it is not found in the common ancestor. When comparing two groups of organisms, an ancestral character evolved in a common ancestor of both groups, and a derived character evolved in an ancestor of one group.

For example, when comparing birds and mammals, a backbone is an ancestral character because both birds and mammals have backbones and both have ancestors with backbones. Feathers are derived characters because only birds have an ancestor with feathers. Hair is also a derived character because only mammals have an ancestor with hair.

What is a cladogram?

Scientists use ancestral characters and derived characters to make a cladogram. A **cladogram** (KLAD uh gram) is a branching diagram that shows the proposed phylogeny of a species. A cladogram is similar to a pedigree. Both have branches and show the ancestry of an individual or a group. The groups of a cladogram, called clades, have one or more related species. The branches of a cladogram show hypothesized phylogeny. The hypothesized phylogeny shown in a cladogram depends on information from DNA and RNA sequences, bioinformatics, and morphological studies. Places where branching occurs are called nodes. The common ancestor at the nodes is rarely a known organism, species, or fossil. Scientists hypothesize the ancestor's character types based on the traits of its descendants. Scientists think that the more derived characters groups share, the more recent their common ancestor.

Reading Check

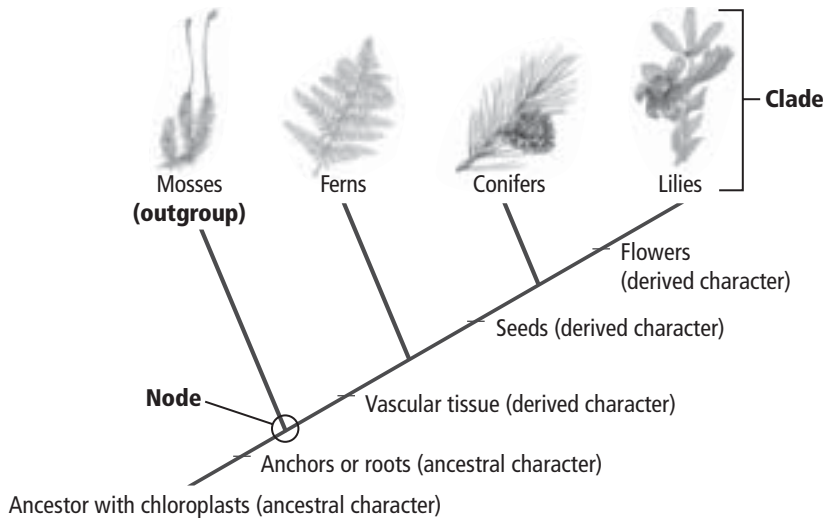
- 8. Compare** What is the difference between ancestral and derived characters?

Reading Check

- 9. Define** What is a cladogram?

How is a cladogram made?

A cladogram of the lily, a flowering plant, is shown below. First the derived characters—vascular tissue, seeds, and flowers—were identified. Then the ancestry of a variety of species was identified based on whether the species had some or all of the derived characters. The groups that are closer to the lily in the cladogram probably share a more recent ancestor than the groups that are farther away. Flowering plants and conifers share three derived characters and are thought to have a common ancestor.



Picture This

10. Identify Which traits do flowering plants and conifers share?

What is a phylogenetic tree?

Phylogenetic trees are used to show the relationships among species and groups of organisms. A phylogenetic tree is a form of cladogram in which each node with descendants represents a common ancestor. The tree of life concept was introduced by scientist Ernest Haeckel. He imagined a tree with a trunk representing ancestral groups. The tree's branches showed species. Similar species were listed on nearby branches. The leaves on the branches represented individual organisms.

A tree that represented all living organisms would be gigantic. Scientists have classified about 1.75 million species. They estimate that millions more have not yet been classified. Although creating a complete tree of life is a large, difficult task, many scientists believe it is important. Scientists representing many disciplines are working together to develop a comprehensive tree of life. Knowing how organisms are related would benefit industry, agriculture, and medicine.

Organizing Life's Diversity

section 17 Domains and Kingdoms

MAIN Idea

The most widely used biological classification system has six kingdoms within three domains.

What You'll Learn

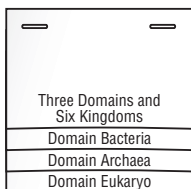
- major characteristics of the three domains
- how to classify organisms at the kingdom level

Study Coach

Make Flash Cards Make a flash card for each kingdom in this section. Write the kingdom on one side of the card. Write the characteristics of the kingdom on the other side. Use the flash cards to review what you have learned.

FOLDABLES™

Take Notes Make a layered Foldable, as shown below. As you read, take notes and organize what you learn about the three domains and six kingdoms of living organisms.



● Before You Read

Kingdom Plantae includes all plants. What kinds of organisms do you think are part of Kingdom Fungi? Write your answer on the lines below. In this section, you will learn characteristics of the domains and the kingdoms.

● Read to Learn

Grouping Species

There are three domains and six kingdoms within those domains. Organisms are classified into domains based on cell type and structure. Organisms are classified into kingdoms based on cell type, structure, and nutrition.

Recall from Chapter 7 that prokaryotes are unicellular organisms that do not have membrane-bound organelles. All bacteria are prokaryotes, and at one time, all bacteria were classified in Kingdom Monera. Even though all bacteria are prokaryotes, are unicellular, and have rigid cell walls, studies have shown that there are two different types of bacteria. Today bacteria are classified in two domains—Bacteria and Archaea.

Domain Bacteria

Members of Domain Bacteria are classified in Kingdom Eubacteria. Because there is no taxonomic difference between the domain and the kingdom, these organisms are called Eubacteria. **Eubacteria** (yoo bak TIHR ee uh) are prokaryotes whose cell walls contain peptidoglycan (pep tih doh GLY kan). Peptidoglycan is a polymer that contains two kinds of sugars. The amino acids on these sugars form a netlike structure that is porous and strong. ✓


What are the characteristics of Kingdom Eubacteria?

Eubacteria are prokaryotes. They are unicellular organisms that do not have a nucleus or other membrane-bound organelles. Eubacteria can survive in many environments. Some eubacteria are aerobic organisms, meaning that they need oxygen to live. Others are anaerobic organisms. They cannot live if atmospheric oxygen is present. Some eubacteria are autotrophic organisms that make their own food. Most are heterotrophic organisms that get their nutrition from other organisms. Eubacteria are found in different shapes. Bacteria are more abundant than any other organism.

Domain Archaea

All of the species in Domain **Archaea** are classified in Kingdom Archaeobacteria. Because there is no taxonomic difference between the domain and the kingdom, these organisms are often called Archaea (ar KEE). Most scientists believe that the species in Kingdom Archaea are more ancient than bacteria. Archaeobacteria (ar kee bak TIHR ee uh) are prokaryotes. They are unicellular organisms that do not have a nucleus or other membrane-bound organelles. Their cell walls do not contain peptidoglycan.

What are the characteristics of Kingdom Archaeobacteria?

Archaeobacteria are found in many shapes. They obtain nutrients in several ways. Some archaeobacteria are autotrophic organisms. Most are heterotrophic organisms. Sometimes archaeobacteria are called extremophiles because they live in the most extreme environments on Earth. Extreme environments include hot springs, salty lakes, thermal vents on the ocean floor, and the mud of marshes. No oxygen is found in the atmosphere in these environments. One extremophile lives near thermal vents in deep ocean waters. The water temperatures can reach 98°C, almost boiling. 

Domain Eukarya

All organisms with membrane-bound organelles are classified in Domain Eukarya and are called eukaryotes. Domain Eukarya contains Kingdom Protista, Kingdom Fungi, Kingdom Plantae, and Kingdom Animalia.



Think it Over

- 1. Apply** What is a good definition of the term anaerobic?

Reading Check

- 2. Explain** Why are archaeobacteria sometimes called extremophiles?

Think it Over

3. Compare How are plantlike protists and animal-like protists different?

What are the characteristics of Kingdom Protista?

Members of Kingdom Protista are called protists. **Protists** are eukaryotes and have membrane-bound organelles. They can be unicellular, a colony of cells, or multicellular. Protists are not similar to one another. However, they do not fit into any other kingdoms either. Protists are classified in three groups: plantlike protists, animal-like protists, and funguslike protists.


What are the characteristics of the three groups of protists?

Plantlike protists are called algae. Algae, such as kelp, are autotrophic organisms. They make their own food by performing photosynthesis.

Animal-like protists are called protozoans. Protozoans, such as amoebas, are heterotrophs. Plantlike protists and animal-like protists do not form organs like species in the plant and animal kingdoms.

Funguslike protists are slime molds and mildews. Euglenoids (yoo GLEE noyds) are protists that have both plantlike and animal-like characteristics. Euglenoids are usually grouped with plantlike protists because they perform photosynthesis.

What are the characteristics of Kingdom Fungi?

A member of Kingdom Fungi is called a fungus. A **fungus** is a eukaryote that absorbs nutrients from organic materials in its environment. Fungi are unable to move. Their cell walls contain chitin, which is a rigid polymer that gives cells structural support. Fungi also have hyphae (HI fee). Hyphae are threadlike strands that enable the fungi to grow, feed, and reproduce. More than 70,000 species of fungi have been identified. 

Most fungi, such as mushrooms, are multicellular. A few fungi, such as yeasts, are unicellular. Fungi are heterotrophs. Unlike other heterotrophic organisms that digest food internally, fungi secrete digestive enzymes into their food source and then absorb the nutrients directly into their cells.


Parasitic fungi include saprobes and symbionts. They grow and feed on other organisms. Saprobes get their nourishment from dead or decaying organic matter. Symbionts that live in a mutualistic relationship with algae are lichens. Lichens get their food from algae that live among the fungi's hyphae.

Reading Check

4. Define What are hyphae?

What are the characteristics of Kingdom Plantae?

Members of Kingdom Plantae (PLAN tuh) are called plants. There are more than 250,000 species of plants in Kingdom Plantae. Plants form the base of all land habitats.

All plants are multicellular. The cell walls of all plants contain cellulose. Most plants are autotrophs. Plants trap and convert energy from the Sun in photosynthesis. A few plants are heterotrophs. For example, the dodder is a parasitic plant. It obtains food through suckers connected to the host plant. 

All plants have cells that are organized into tissues. Most vascular plants have organs such as roots, stems, and leaves. Plants cannot move. However, some plants have reproductive cells that have flagella. The flagella can move the reproductive cells through water.


What are the characteristics of Kingdom Animalia?

Members of Kingdom Animalia are called animals. All animals are heterotrophs and are multicellular. Animals are eukaryotic organisms and have membrane-bound organelles.

Animals do not have cell walls. They have cells that are organized into tissues. Most animals have tissues that are organized into organs such as skin, a stomach, and a brain. Animal organs are often organized into complex organ systems, such as digestive, circulatory, and nervous systems.

Animals range in size from a few millimeters to many meters. Animals live in water, on land, and in the air. Most animals are able to move. A few animals such as coral cannot move in their adult form.

Is there an exception to the classification system?

If you have ever had a cold or the flu, you have had a virus. A virus is a nucleic acid that is surrounded by a protein coat. Viruses do not have cells, and they are not cells. Viruses are not considered to be living. Because they are not living, they are not usually placed in the biological classification system. 

Virologists, scientists who study viruses, have created a special classification system to group viruses. Viral classification is based on a variety of factors that you will read more about in Chapter 18.

Reading Check

5. State How many species are in Kingdom Plantae?

Reading Check

6. Explain Why are viruses an exception to the classification system?

Picture This

7. Name What is an example of an animal that cannot move as an adult?

What characteristics define differences in the six kingdoms?

The characteristics of living things are summarized in the table below. The table shows the similarities and differences in cell type and structure, nutrition, habitat, and mobility. As you review the table, think of organisms that fit into each kingdom.

Kingdom Characteristics				
Kingdom	Cell Type and Structure	Nutrition	Habitat	Mobility
Eubacteria	prokaryotes with cell walls made of peptidoglycan	most are heterotrophic; some are autotrophic	live in many environments	can move
Archaeobacteria	prokaryotes with cell walls that are not made of peptidoglycan	most are heterotrophic; some are autotrophic	live in many environments	can move
Protista	unicellular and multicellular eukaryotes	autotrophic and heterotrophic	live in moist environments	can move
Fungi	unicellular and multicellular eukaryotes with cell walls made of chitin	heterotrophic	live in many environments	cannot move
Plantae	multicellular eukaryotes with cell walls made of cellulose	most are autotrophic that perform photosynthesis; some are heterotrophic	live in water and on land	cannot move
Animalia	multicellular eukaryotes without cell walls	heterotrophic	live in water, on land, and in air	most can move; some cannot move, such as adult coral

● Before You Read

When you hear the word *bacteria*, what comes to mind? On the lines below, describe places you think bacteria might live. Then read the section to learn about some surprising places where bacteria thrive.

● Read to Learn

Diversity of Prokaryotes

The first organisms on Earth were small, unicellular organisms called prokaryotes (proh KE ree ohts), or **bacteria**. Today, prokaryotes are the most numerous organisms on Earth. Prokaryotic cells do not have organelles or a nucleus. Instead, their DNA is found in a region of the cell. Prokaryotes are grouped into two domains—Bacteria (eubacteria) and Archae (archaeobacteria).

Where are eubacteria found?

Eubacteria live almost everywhere except in the most extreme environments. They have strong cell walls.

Where do archaeobacteria live?

Archaeobacteria live in extreme environments. One type lives in hot, acidic environments such as sulfur hot springs, thermal vents on the ocean floor, and around volcanoes. A second type lives in salty environments such as the Dead Sea. This type photosynthesizes using a substance other than chlorophyll. A third type cannot live in an environment that has oxygen. They use carbon dioxide during respiration and give off methane gas as waste. They live in swamps and in human intestines. They make the gases that are released from the lower digestive tract.

MAIN Idea

Bacteria are prokaryotic cells.

What You'll Learn

- how archaeobacteria differ from eubacteria
- how bacteria can survive environmental challenges
- ways that bacteria benefit humans

Study Coach

Make an Outline Make an outline of the information you learn in this section. Start with the headings. Include the boldface terms.

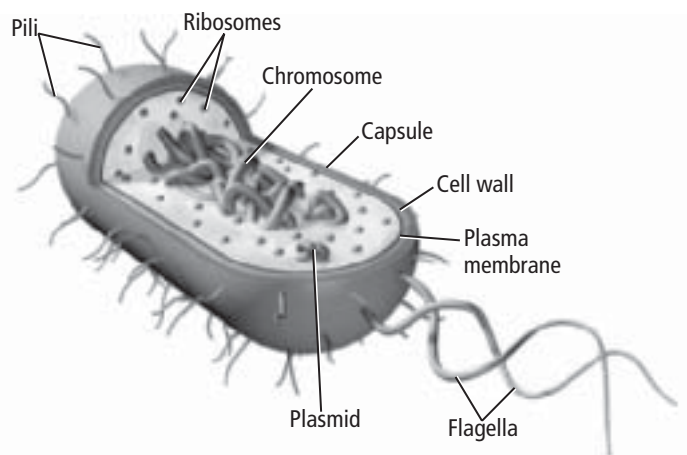


Think it Over

1. **Apply** Prokaryotes that live in the Great Salt Lake belong to which domain? (Circle your answer.)
 - a. Bacteria
 - b. Archae

Picture This

2. **Highlight** each structure in the figure as you read about it.



How are the chromosomes arranged?

The genes of a prokaryotic cell are on a circular chromosome in an area of the cell called the **nucleoid**. Many prokaryotes also have at least one smaller, circular piece of DNA. It is called a plasmid.

What are the functions of the capsule?

Some prokaryotic cells form a **capsule** by secreting a layer of polysaccharides around the cell wall. The capsule keeps the cell from drying out and helps it attach to surfaces. It also protects the cell from white blood cells and antibiotics.

How do pili help a bacterial cell?

Some bacteria have pili on their outer surface. **Pili** (singular, pilus) are hairlike structures that are made of protein. Pili help a bacterial cell attach to a surface. Pili can also serve as a bridge between bacteria. Copies of plasmids can cross the bridge, providing new genetic characteristics. Resistance to antibiotics can be transferred this way. ✓

Reading Check

3. **Explain** how pili are helpful during reproduction.

How do bacteria benefit from their size?

Prokaryotes are small, even when viewed with a microscope. Small cells have a larger surface-area-to-volume ratio than larger cells. As a result, nutrients and other important substances can diffuse to all parts of the cell easily.

Identifying Prokaryotes

Scientists can identify bacteria by their shape, cell walls, and movement.

What shapes do prokaryotes display?

There are three main shapes of prokaryotes. Those shaped like spheres are called cocci (KAHK ki) (singular, coccus). Bacilli (buh SIH li) (singular, bacillus) are rod shaped. Spiral-shaped spirilli (spi RIH li) (singular, spirillum) are called spirochetes (SPI ruh keets).

Why is the Gram stain test important?

All eubacteria have peptidoglycan in their cell walls. Biologists add dyes to the bacteria cells to identify the two major types of bacteria—those with and those without an outer layer of lipid. The dye technique is called a Gram stain. Bacteria without a lipid layer have a lot of peptidoglycan and appear dark purple. They are called gram positive. Bacteria with a lipid layer have less peptidoglycan and appear light pink. They are called gram negative. Some antibiotics attack the cell walls of bacteria. The Gram stain identifies the type of cell wall so doctors can prescribe the right antibiotic.

How do prokaryotes move?

Some bacteria do not move. Others use a flagellum (plural, flagella) to move toward light, oxygen, or sources of nutrients. Others glide over a layer of secreted slime.

Reproduction of Prokaryotes

Prokaryotes reproduce either by binary fission or by conjugation. The figure on the next page shows both.

What is binary fission?

Binary fission is the division of a cell into two cells with identical genes. The prokaryote's chromosome replicates. The cell gets longer as the chromosome and the new copy separate. A new plasma membrane and cell wall form and separate the cell into two identical cells.

Reading Check

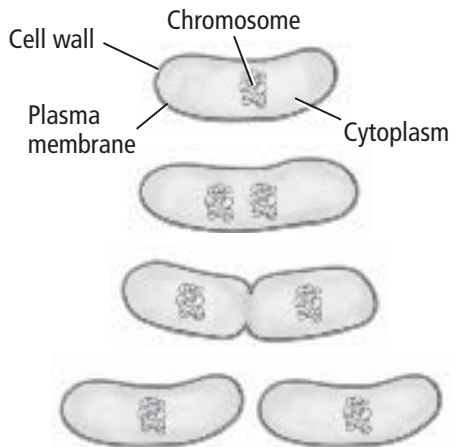
4. Describe the three shapes of prokaryotes.

Reading Check

5. Apply Why do doctors use Gram stains?

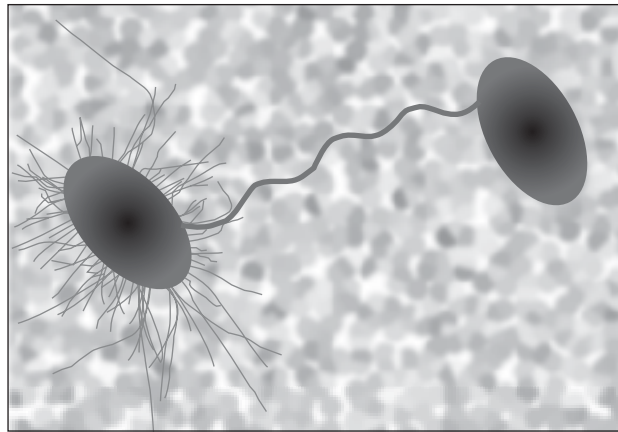
Picture This

6. Label Write the labels *genetic information exchanged* and *identical cells formed* next to the appropriate reproduction diagram in the figure.



How do prokaryotes reproduce by conjugation?

In **conjugation**, two prokaryotes attach to each other and exchange genetic material. As shown in the figure below, the two cells attach using their pili. The transfer of genetic material from one cell to the other creates new gene combinations. This increases the diversity of prokaryotes.



Metabolism of Prokaryotes

Bacteria can be grouped based on how they obtain energy. Some are heterotrophs and others are autotrophs.

How do heterotrophs obtain energy?

Heterotrophs cannot make their own food. They need to take in nutrients. As shown in the figure on the next page, many heterotrophic bacteria are saprotrophs. They obtain nutrients by decomposing organic materials associated with dead organisms or organic waste.

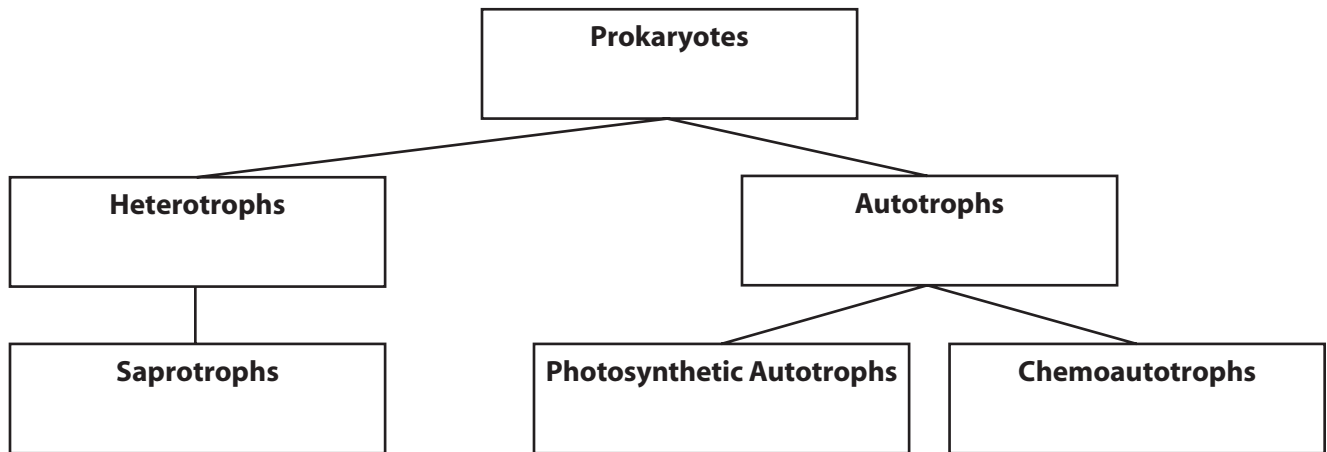
In what ways are photoautotrophs like plants?

Autotrophs (AW tuh trohfs) can make their own food. Photoautotrophs, or cyanobacteria, carry out photosynthesis. Like plants, these bacteria live in areas where there is light, such as shallow ponds and streams, in order to make organic molecules to use as food. Also like plants, they are at the base of some food chains and they release oxygen into the environment.

Scientists once thought that these organisms were eukaryotes and called them blue-green algae. Later discoveries showed that they were prokaryotes. Scientists call these organisms cyanobacteria. Cyanobacteria might have been the first organisms to release oxygen into Earth's early atmosphere.

Reading Check

7. Compare What is the main difference between heterotrophs and autotrophs?



What do chemoautotrophs use to make food?

Chemoautotrophs do not need light. They use the process of chemosynthesis to break down and release inorganic materials that contain nitrogen or sulfur. They help cycle nitrogen and other inorganic materials through ecosystems.

How do some bacteria grow without oxygen?

Obligate aerobes are bacteria that need oxygen to grow. Obligate anaerobes do not need oxygen. They obtain energy by fermentation. Facultative anaerobes can use oxygen or fermentation.

Survival of Bacteria

Bacteria have several ways that they can survive if their environment becomes unfavorable.

When environmental conditions are harsh, some types of bacteria produce a structure called an **endospore**. A spore coat surrounds a copy of the bacterial cell's chromosome and a small part of the cytoplasm. The bacterial cell dies, but the endospore can survive for long periods. An endospore might be able to survive conditions that would kill a bacterium such as extreme heat, cold, or dehydration. When conditions improve, the endospore grows into a new bacterial cell.

How do mutations benefit bacteria?

Mutations are changes or random errors in a DNA sequence. They lead to new genes, new gene combinations, new characteristics, and genetic diversity. Because bacteria reproduce quickly, gene mutations occur quickly. If the environment changes, some bacteria might have the right combination of genes that will enable them to survive and repopulate.

Picture This

8. Label each type of heterotroph and autotroph in the figure with the way it obtains nutrients.

Think it Over

9. Draw Conclusions

What might happen if bacteria did not mutate and the environment changed?

Reading Check

10. Describe how nitrogen fixation benefits plants.


Picture This

11. Explain Suppose a friend showed you this table and said, "See, bacteria are bad." How would you respond?

Ecology of Bacteria

Bacteria are decomposers. They get energy from dead organisms and return nutrients to the environment. Most bacteria do not cause disease. In fact, many benefit humans.

How do bacteria benefit plants?

All organisms use nitrogen to make proteins, DNA, and RNA. Most of Earth's nitrogen is gas in the atmosphere. Some bacteria can use nitrogen gas directly. In a process called **nitrogen fixation**, these bacteria convert nitrogen gas into nitrogen compounds that plants can use. Some of these bacteria live in soil. Others live in root nodules of plants. Nitrogen is passed on to organisms that eat the plants. 

Why are bacteria important to humans?

Your body is covered with harmless bacteria called normal flora. Normal flora help prevent harmful bacteria from infecting your body and causing disease.

Some *Escherichia coli* (*E. coli*) bacteria can cause food poisoning. Other *E. coli* bacteria live symbiotically in the digestive tracts of humans and other mammals. These *E. coli* make vitamin K, which humans use for blood clotting. In exchange, the *E. coli* get a warm place with food to live.

Bacteria are used to make many foods such as cheese, yogurt, and pickles. Bacteria break down the covering of cocoa beans during the production of chocolate. Some vitamin pills are made with the help of bacteria. Several common antibiotics were originally made by bacteria.

How do bacteria cause disease?

The small percentage of bacteria that cause disease do so in two ways. Some bacteria multiply at an infection site and can spread to other parts of the body. Other bacteria secrete a toxin or other substances such as the acid that causes tooth decay. The table below lists some diseases caused by bacteria.

Category	Human Diseases
Sexually transmitted diseases	syphilis, gonorrhea, chlamydia
Respiratory diseases	strep throat, pneumonia, whooping cough, anthrax
Skin diseases	acne, boils, infections of wounds or burns
Digestive tract diseases	gastroenteritis, many types of food poisoning, cholera
Nervous system diseases	botulism, tetanus, bacterial meningitis

● Before You Read

Have you ever heard of mad cow disease? On the lines below, write what you know about mad cow disease. In this section, you will read about what causes mad cow disease.

MAIN Idea

Viruses and prions invade cells and can alter cellular functions.

What You'll Learn

- the general structure of viruses
- how viruses and retroviruses replicate
- how prions cause disease

● Read to Learn

Viruses

A **virus** is a non-living strand of genetic material within a protein coat. Some are harmless, while others cause disease in living things. The table below lists some diseases in humans caused by viruses. Viral diseases such as HIV and genital herpes transmitted through sexual contact have no cure or vaccine.

The origin of viruses is not known. One theory, however, is that viruses came from parts of cells. Scientists found that viruses are similar to genes in cells. These genes somehow became able to exist outside the cell.

Human Diseases Caused by Viruses	
Category	Disease
Sexually transmitted diseases	AIDS (HIV), genital herpes
Childhood diseases	measles, mumps, chicken pox
Respiratory diseases	common cold, influenza
Skin diseases	warts, shingles
Digestive tract diseases	gastroenteritis
Nervous system diseases	polio, viral meningitis, rabies
Other diseases	smallpox, hepatitis

Mark the Text

Restate the Main Point

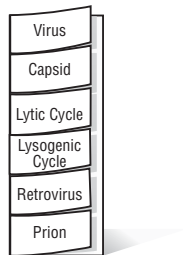
As you read the section, highlight the main point in each paragraph. Then restate each main point in your own words.

Picture This

- 1. Contrast** How is a cold different from strep throat?

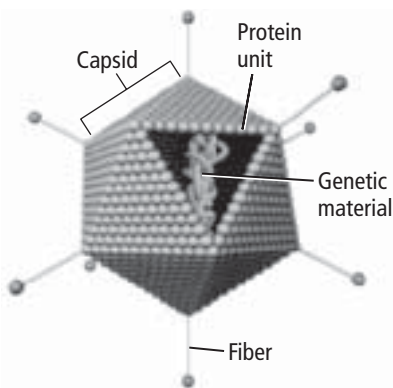
FOLDABLES™

Take Notes Make a vocabulary Foldable to take notes and organize information about viruses and prions.



Picture This

2. Highlight the names of the basic structures that all three viruses in the figure have in common.



How are viruses structured?

The figure below shows the structure of three viruses. Adenovirus causes a cold. Influenza virus causes the flu. A bacteriophage (bak TIHR ee uh fayj) is a virus that infects bacteria. Notice that all three viruses have the same basic structure. Viruses have an outer layer called a **capsid** that is made of protein. Inside the capsid is genetic material, which could be DNA or RNA but not both. Viruses are classified as either DNA or RNA based on the type of genetic material they contain.

Smallpox, caused by a DNA virus, infected humans for thousands of years. A successful worldwide vaccination program eliminated the disease.

Viral Infection

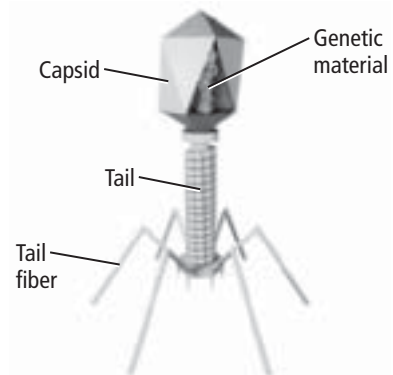
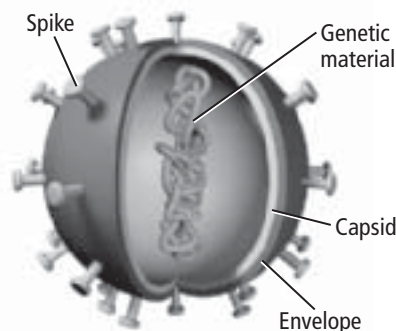
A virus attaches to the host cell using receptors on the plasma membrane of the host. Different species have receptors for different types of viruses. As a result, many viruses cannot pass from one species to another.

Once attached, the genetic material enters the cytoplasm of the host cell. The virus then replicates by either the lytic cycle or the lysogenic cycle.

How do viruses replicate in the lytic cycle?

In the **lytic cycle**, the host cell makes many copies of the viral RNA or DNA. The viral genes instruct the host cell to make a protein coat around the copies of genetic material, forming capsids. These new viruses leave the cell by exocytosis or by cell lysis—bursting of the cells. The new viruses are then free to infect other cells.

Viruses that replicate by the lytic cycle cause active infections. This means that symptoms start in one to four days. Colds and flu are examples of active infections.

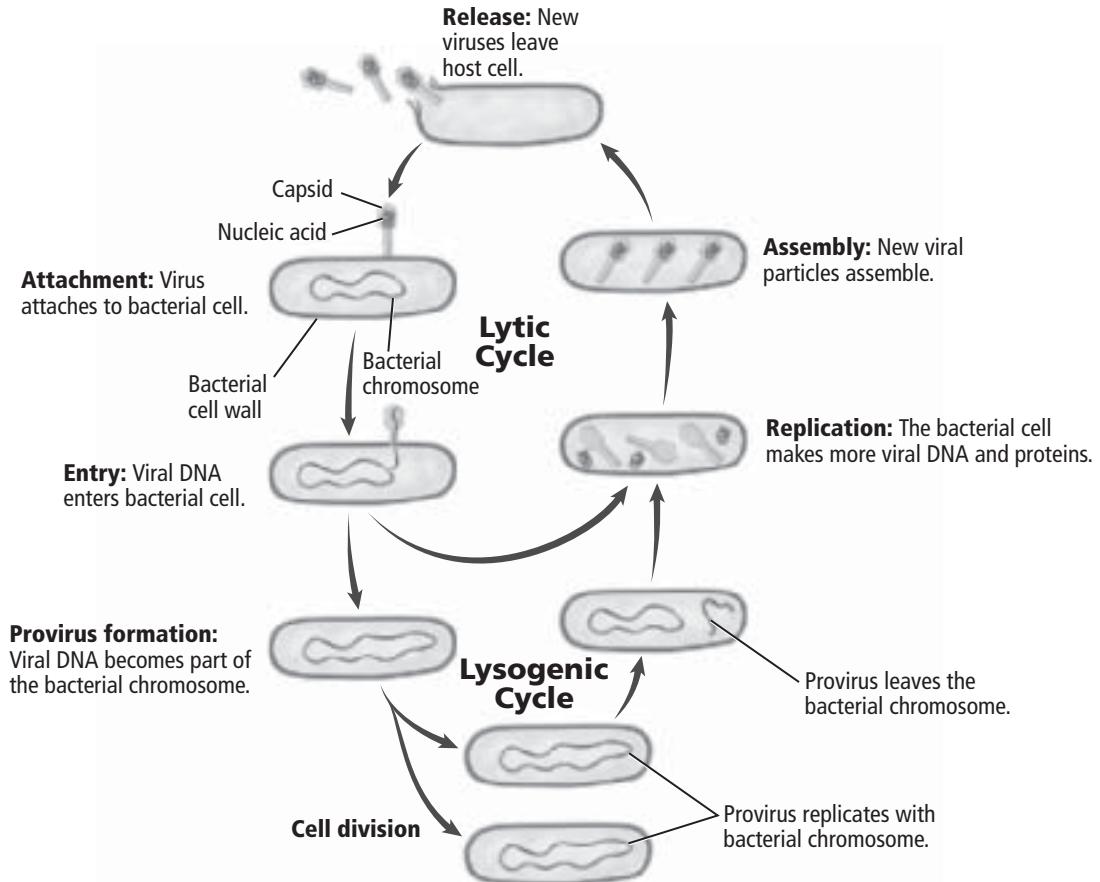


How does the lysogenic cycle differ?

In the **lysogenic cycle**, shown in the figure below, the viral DNA enters the nucleus of the host cell. The viral genes become a permanent part of the host chromosome. The genes might stay inactive for months or years until something activates them. When activated, the viral genes replicate by the lytic cycle and cause active infection.

Picture This

3. **Label** the active period and the dormant period in the virus's cycle.



Retroviruses

Some viruses are made of RNA instead of DNA. A **retrovirus** is a type of RNA virus with a replication cycle that has many parts. Human immunodeficiency virus (HIV) is a retrovirus.

What is the structure of HIV?

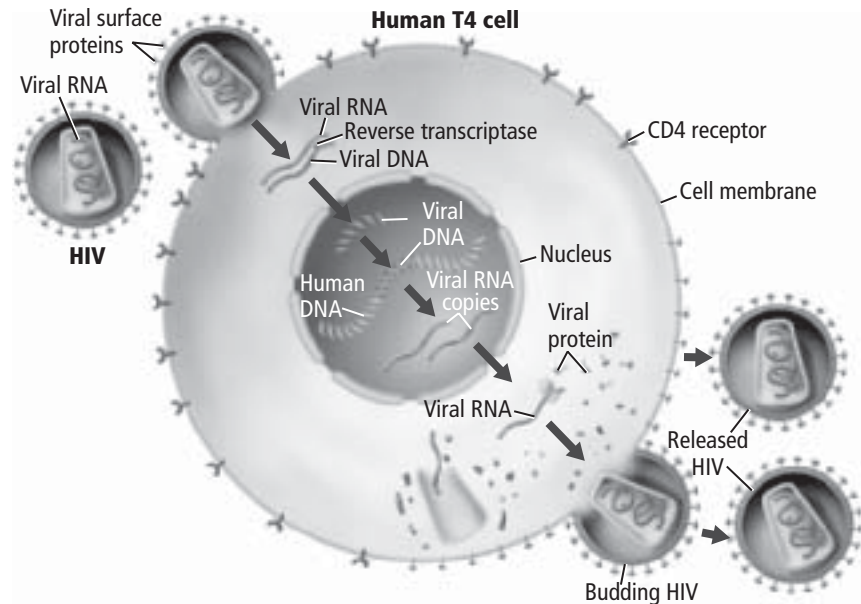
The structure of HIV is similar to other viruses. It has a protein capsid. Around the capsid is a lipid envelope that it got from the plasma membrane of the host cell. In the core of a retrovirus is RNA and an enzyme called reverse transcriptase. This enzyme makes DNA from the viral RNA.

Reading Check

4. **Identify** What does reverse transcriptase make?

Picture This

5. Explain Use the figure to explain to a partner how HIV replicates.



Prions

A **prion** (PREE ahn) is a protein that can cause infection or disease. Prions normally exist in cells. Normal prions are shaped like a coil. Mutations in the genes that code for these proteins occur, causing the proteins to be misfolded. Mutated prions are shaped like a piece of paper folded many times. Mutated prions can cause normal proteins to mutate. Abnormal prions infect and burst nerve cells in the brain, leaving spaces that make the brain look like a sponge.

What is a disease caused by prions?

Prions cause diseases such as “mad cow.” Abnormal prions are found in the brains and spinal cords of cattle. Scientists think that spinal cords might be cut during butchering, infecting the meat, and then infecting humans that eat the meat. Other examples caused by prions include Creutzfeldt-Jakob disease (CJD) in humans, scrapie (SKRAY pee) in sheep, and chronic wasting disease in deer and elk.

Reading Check

6. Explain how normal prions become harmful.

section 1 Introduction to Protists

● Before You Read

Suppose you want to determine if an organism is more like a plant or more like an animal. On the lines below, write two questions you would ask about the organism to help you decide. Read the section to learn about the animal-like, plantlike, and funguslike characteristics of protists.

● Read to Learn

Protists

Protists are more easily classified by what they are not than by what they are. Protists are not animals, plants, or fungi. Members of the Kingdom Protista are a diverse group of more than 200,000 members. All protists share one important trait—all are eukaryotes. This means that their cells contain membrane-bound organelles.

How are protists classified?

Some scientists classify protists by the way they obtain nutrition. Using this method, protists are divided into three groups: animal-like protists, plantlike protists, and funguslike protists. The table on the next page summarizes these groups.

What are animal-like protists?

A **protozoan** (proh tuh ZOH un) (plural, protozoa or protozoans) is a one-celled, animal-like protist. It is classified as animal-like because it is a heterotroph. This means that it must eat other organisms. Protozoans usually eat bacteria, algae, or other protozoans. An amoeba is one example of a protozoan.

MAIN Idea

Protists are subdivided based on their method of obtaining nutrition.

What You'll Learn

- how protists might have evolved into organisms with organelles
- why the organization of Kingdom Protista might change

Mark the Text

Identify Class

Characteristics Highlight each protist class as you read about it. In another color, highlight the characteristics of that class.



Think it Over

1. **Explain** why a protist with chloroplasts would not be classified as an animal-like protist.

Picture This

- 2. Synthesize** You can determine the group to which a protist belongs by its method of
- moving.
 - obtaining nutrients.
 - reproducing.

Why are algae considered plantlike?

Plantlike protists are known as algae (AL jee) (singular, alga). They are plantlike because they make their own food through photosynthesis. Algae can have one or many cells.

How do funguslike protists differ from fungi?

Both funguslike protists and fungi absorb nutrients from other organisms. These protists are not true fungi because they have centrioles, and fungi do not. Centrioles are small, cylindrical organelles used in mitosis. Also, the cell walls of fungi and funguslike protists contain different materials.

Protist Group	Examples	Characteristics
Animal-like protists (protozoans)	amoebas, ciliates	animal-like because they eat other organisms; some are parasites
Plantlike protists (algae)	giant kelp, algae	plantlike because they make their own food through photosynthesis
Funguslike protists	slime mold, water mold	funguslike because they feed on decaying organic matter and absorb nutrients through cell walls

Where do protists live?

Protists usually live in damp or water environments, such as ponds, streams, oceans, decaying leaves, and damp soil. Some live in symbiotic or parasitic relationships with other organisms. **Microsporidia** (MI kroh spo rih dee uh) are microscopic protozoans. They live in the guts of termites and produce enzymes that help termites digest wood.

Origin of Protists

Chapter 14 discussed the theory of endosymbiosis. This theory suggests that eukaryotes, including protists, formed when a large prokaryote engulfed a smaller one. The two lived symbiotically. Eventually, the two organisms evolved into a single, more highly developed organism. Some scientists suggest that the mitochondria and chloroplasts in some eukaryotes were once individual organisms. Protists might have been the first eukaryotes billions of years ago.

As scientists learn more about protists' evolutionary history, the organization of the Kingdom Protista will likely change. Scientists think that protists evolved from a common ancestor. Mitochondria became part of protist cells early in evolution. Chloroplasts entered later. Algae are the only protists with chloroplasts. Thus, algae are the only protists that perform photosynthesis.

Reading Check

- 3. Identify** two structures within protists that might have been individual organisms at one time.

section 2 Protozoans—Animal-like Protists

● Before You Read

Have you ever tried to grab an object that was sinking to the bottom of a swimming pool? On the lines below, describe how you captured the object. Read the section to learn how tiny amoebas surround food particles in their watery home.

MAIN Idea

Protozoans are animal-like, heterotrophic protists.

What You'll Learn

- the structures and organelles of protozoans
- the life cycles of protozoans


● Read to Learn

Ciliophora

Protozoans are grouped into many phyla. One way that scientists group protozoans is by the way they move. Members of the phylum Ciliophora (sih lee AH fuh ruh) are known as ciliates (SIH lee ayts). They are animal-like protists with short, hairlike projections called cilia (singular, cilium). Cilia can cover their whole bodies, or only part of the membrane. Ciliates use their cilia to propel themselves through water. Some also use cilia to pull in food. Ciliates are common in oceans, lakes, and rivers. Many are also found in mud.

What are paramecia?

Members of the genus *Paramecium* (per uh MEE see um) (plural, paramecia) are one-celled protozoans. As you read about the structures of a paramecium, identify them in the figure on the next page.

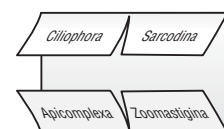
A membrane called a **pellicle** encloses a paramecium. Beneath the pellicle is a layer of cytoplasm called ectoplasm. Within the ectoplasm are the **trichocysts** (TRIH kuh sihsts). These long, cylinder-shaped bodies discharge spinelike structures. Scientists are not sure of the purpose of trichocysts. A paramecium might use them for defense, as a reaction to injury, to anchor itself, or to capture prey. 

Study Coach

Create a Quiz As you read this section, write quiz questions based on what you have learned. After you write the questions, answer them.

FOLDABLES™

Take Notes Make a four-door Foldable, as shown below. As you read, take notes and organize what you learn about the classification of protists, based upon the way they move.



How does a paramecium feed and digest food?

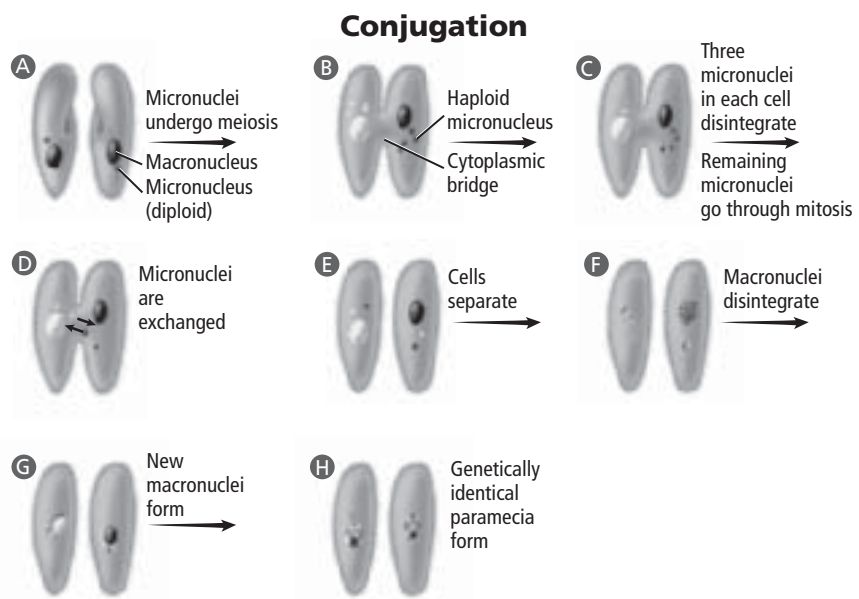
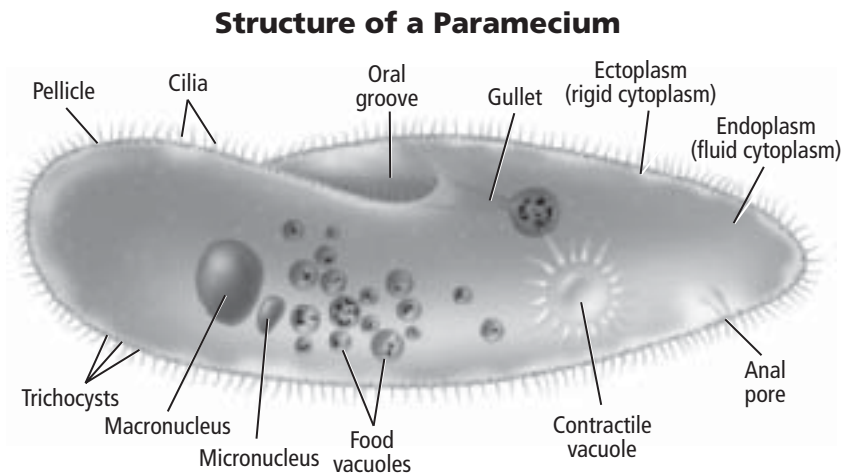
Cilia completely cover the paramecium. A paramecium uses its cilia to feed and move. Cilia along the oral groove guide food into the gullet. At the end of the gullet, food is enclosed in a food vacuole. Enzymes within the food vacuole break down food into nutrients. The nutrients then diffuse into the cytoplasm. Wastes exit through the anal pore.

What is the function of contractile vacuoles?

Water constantly enters the paramecium by osmosis. The **contractile vacuoles** (kun TRAK tul • VAK yuh wohlz) collect the extra water and expel it, along with wastes, from the cell. This helps maintain homeostasis in the cell.

Picture This

- Highlight** the structures of the paramecium that are involved in feeding and digestion.



How do ciliates reproduce?

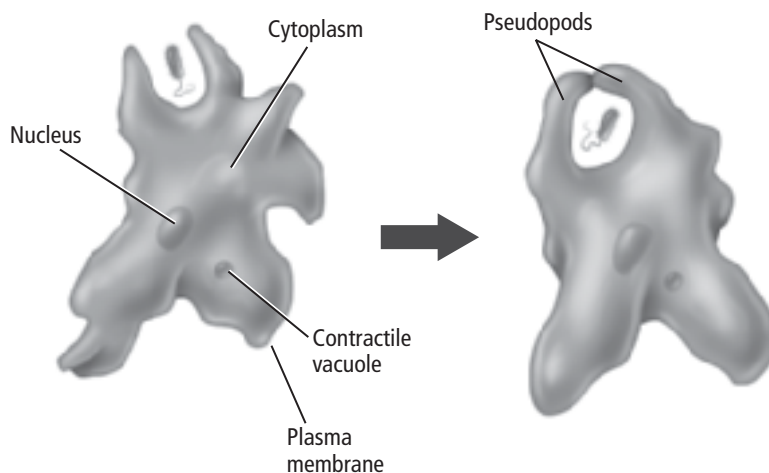
All known ciliates have two types of nuclei—the macronucleus and the micronucleus. A cell can have more than one of each type. Both nuclei contain the genetic information for the cell. The macronuclei control the everyday life functions such as feeding and maintaining water balance. The micronuclei are used for reproduction.

Ciliates reproduce asexually by binary fission. They do not divide by mitosis. Instead, the macronucleus grows longer and splits. Most ciliates exchange genetic information in a sexual process called conjugation. Conjugation is not sexual reproduction because new individuals do not result from it.

During conjugation, two paramecia form a bridge of cytoplasm. Their diploid micronuclei undergo meiosis. After three of the new micronuclei dissolve, the remaining micronucleus undergoes mitosis. One micronucleus from each connected cell is exchanged. The two paramecia then separate. The macronucleus dissolves in each paramecium. The micronuclei then combine to form a new diploid macronucleus with a new combination of genetic information.

Sarcodina

Sarcodines (SAR kuh dineez) are members of the phylum Sarcodina (sar kuh DI nuh). They are animal-like protists that use pseudopods for feeding and movement. A **pseudopod** (SEW duh POD) is a temporary extension of cytoplasm. The figure below shows how an amoeba forms pseudopodia to take in food. Most amoebas live in salt water, but some live in streams, the muddy bottoms of ponds, and in damp moss and leaves. Other amoebas are parasites that live inside a host animal.



Think it Over

- 2. Compare** How is conjugation different from binary fission?

Picture This

- 3. Explain** What happens to the pseudopods from the left figure to the right figure?

Reading Check


4. Explain how an amoeba excretes wastes without an anal pore.

Think it Over

5. Draw Conclusions

How does a tsetse fly become infected with zooflagellates?

What are the structures of an amoeba?

Amoebas have an outer plasma membrane and an inner stiff membrane called ectoplasm. Inside the outer membrane is cytoplasm. The cytoplasm contains a nucleus, food vacuoles, and sometimes contractile vacuoles. Amoebas do not have an anal pore. Amoebas excrete wastes and take in oxygen through their outer membranes by diffusion. Some species have a **test**—a hard, porous covering similar to a shell that surrounds the plasma membrane. 

How does an amoeba reproduce?

An amoeba reproduces asexually. It divides into two identical offspring. In harsh living conditions, some amoebas form cysts that can survive until conditions improve.

Apicomplexa

Members of phylum Apicomplexa (ay puh KOM pleks uh) are called sporozoans (spo ruh ZOH unz) because they can reproduce through spores. Spores are reproductive cells that form without fertilization and produce a new organism. Sporozoans lack contractile vacuoles and structures for movement. Like in amoebas, respiration and excretion occur by diffusion.

All sporozoans are parasites. Organelles at one end can penetrate the host tissues. The sporozoan then obtains its nutrition from the host.

A sporozoan has both sexual and asexual stages in its life cycle. It often needs two or more hosts to complete its life cycle. Members of the genus *Plasmodium* can cause malaria in humans. Malaria is a serious disease passed to humans by mosquitoes.

Zoomastigina

Zooflagellates (zoh oh FLA juh layts) are animal-like protozoans that belong to the phylum Zoomastigina (zoh oh mast tuh JI nuh). Zooflagellates use flagella for movement. Recall that flagella are long whiplike projections from the cell.

Can zooflagellates infect humans?

Some zooflagellates are parasites. Some species can cause sleeping sickness in humans. Their life cycles includes two hosts. In Africa, tsetse flies spread the disease when they feed on the blood of humans or other mammals.

● Before You Read

You probably come into contact with algae every day. Algae are used in foods, household cleaners, and other products. Some algae are used to make liquid foods thicker. On the lines below, list some foods that might contain algae. Read the section to learn about algae and their many uses.

MAIN Idea

Algae are plantlike, autotrophic protists.

What You'll Learn

- the characteristics of several phyla of algae
- the secondary photosynthetic pigments of some algae
- the differences between diatoms and most other algae


● Read to Learn

Characteristics of Algae

Algae (singular, alga) are plantlike protists. Like plants, they have photosynthetic pigments. These pigments enable the algae to make their own food using energy from the Sun. This process is called photosynthesis. Algae are not plants because they lack roots, leaves, and other plant structures.

The pigments are found in the algae's chloroplasts. In many algae, the primary pigment is chlorophyll. This is the same pigment that gives plants their green color. Many algae also have secondary pigments. These pigments allow algae to absorb light energy in deeper water. Because of these secondary pigments, algae occur in a variety of colors.

Diversity of Algae

Scientists use three characteristics to classify algae. They group algae by pigment types, method of food storage, and composition of the cell wall. Algae can have one cell or many cells. Some one-celled algae are called phytoplanktons—meaning “plant planktons.” Phytoplanktons provide the base of the food web in their aquatic ecosystem. They also produce much of the oxygen in Earth's atmosphere. 

Study Coach

Restate the Main Point

As you read this section, stop after each paragraph, and put the main ideas into your own words.

Reading Check

1. **List** two reasons why phytoplankton are important.

Reading Check

2. Describe How do the halves of a diatom fit together?

What triggers sexual reproduction in diatoms?

Diatoms are one-celled algae of the phylum Bacillariophyta (BAH sih LAYR ee oh FI tuh). Diatoms have two halves. One half fits inside the other, forming a box. ✓

Diatoms produce food using chlorophyll and secondary pigments called carotenoids. Carotenoids make diatoms appear golden yellow. Diatoms store their food as oil. The oil makes them a nutritious food for other marine life. The oil also helps diatoms float close to the surface, where they can absorb energy from the Sun.

How do diatoms reproduce?

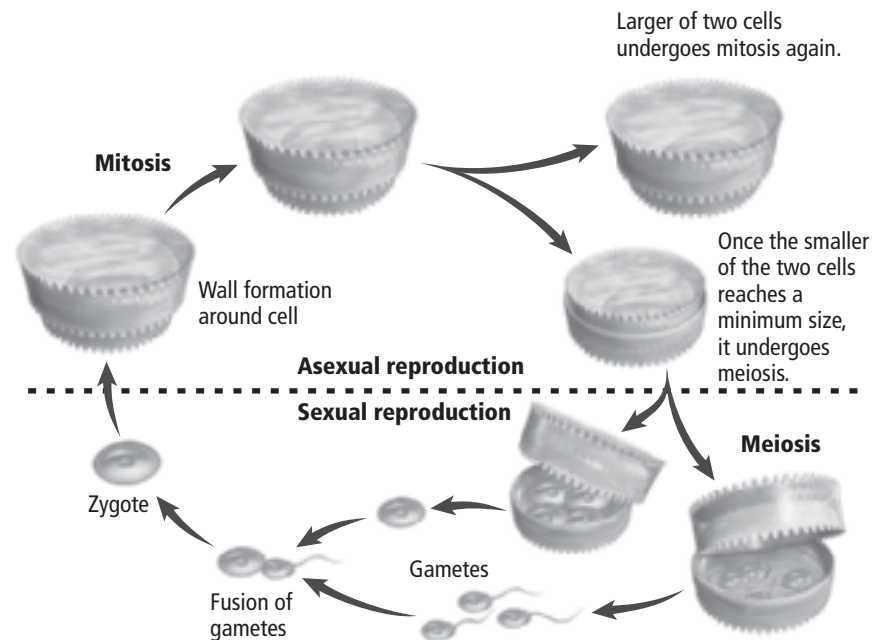
The figure below shows how diatoms reproduce both sexually and asexually. In asexual reproduction, the two halves separate. They create a new half that can fit inside the old one. This process produces smaller diatoms. When a diatom is about one-quarter of the original size, sexual reproduction begins. The diatom produces gametes that fuse to form a zygote. The zygote develops into a full-sized diatom, and the reproduction cycle repeats.

How do humans use the remains of diatoms?

The hard silicon walls last a long time after the diatom has died. These silicon walls form sediment on the ocean floor. This sediment can be collected and used as an abrasive and a filtering agent. It gives toothpaste its gritty texture.

Picture This


3. Identify Diatom asexual reproduction begins with
a. meiosis.
b. mitosis.



How do dinoflagellates move?

Dinoflagellates (DI nuh fla juh layts) are plantlike protists of the phylum Pyrrophyta (puh RAH fuh tuh). Most are one cell and have two flagella at right angles to one another. The beating flagella cause dinoflagellates to spin as they move through the water.

Bioluminescent (BI oh lew muh NE sunt) dinoflagellates emit light. Most dinoflagellates live in salt water as part of the phytoplankton. Some dinoflagellates are photosynthetic autotrophs. Others are heterotrophs. They can be carnivorous (meat eating), parasitic, or symbiotic.

Algal blooms When dinoflagellates have plenty of food and favorable conditions, they reproduce in great numbers. These population explosions are called blooms. Blooms deplete the nutrients in the water. When food supplies decrease, dinoflagellates die. As they decompose, they deplete oxygen in the water, killing other sea life. 

Red tides Some dinoflagellates have red pigments. Their blooms are called red tides because they make the ocean look red. Some species produce a poisonous substance. People can die from eating shellfish that have eaten these species.

How do euglenoids differ from plants?

Euglenoids (yoo GLEE noydz) are members of the phylum Euglenophyta (yoo gluh NAH fuh tuh). They are plantlike protists with only one cell. Most live in shallow freshwater. Like plants, most euglenoids carry out photosynthesis. Like animals, some euglenoids consume other organisms.

Unlike plants, euglenoids do not have a cell wall. Instead, they are covered by a flexible, tough outer pellicle, similar to a paramecium. They have an eyespot to detect light and flagella to move toward food or light. The contractile vacuole expels water to maintain homeostasis.

What pigments color the chrysophytes?

Members of the phylum Chrysophyta (KRIS oh fyt uh) are called chrysophytes (KRIS oh fytz). They get their yellow or golden brown color from carotenoids. Most chrysophytes are one-celled, but some form a group of cells that join together in close association called a **colony**. Chrysophytes have two flagella attached at one end. All perform photosynthesis. They usually reproduce asexually, and they live in both freshwater and salt water.

Reading Check

4. Explain what triggers dinoflagellates to bloom.

Think it Over

5. Draw Conclusions A euglenoid has an eyespot that detects light. Why is the ability to detect light important to the euglenoid?

✓ Reading Check

6. Summarize What are three characteristics of both green algae and plants?

Picture This

7. Draw Conclusions
How do you think sea lettuce got its nickname?

What phylum includes brown algae?

Brown algae belong to the phylum Phaeophyta (FAY oh FI tuh). Brown algae have many cells and a pigment called fucoxanthin (fyew ko ZAN thun) that gives them their brown color. A common example of this phylum is kelp. Most species of brown algae live along rocky coasts in cool areas. The kelp has a bulblike structure called a bladder. The bladder is filled with air, helping the kelp float near the surface where it can use sunlight for photosynthesis.

How are green algae like plants?

Green algae, of phylum Chlorophyta (kloh RAH fy tuh), share some traits with plants. Both contain chlorophyll, have cell walls, and store their food as carbohydrates. ✓

Most green algae live in freshwater. Some live on damp ground, in snow, and even in the fur of some animals.

Green algae can have one cell or many cells. The one-celled species Volvox forms colonies that look like a hollow ball. Gelatinlike strands of cytoplasm hold the colony together. The flagella of all cells beat at the same time to move the colony. Smaller daughter colonies form balls inside the larger colony. When the daughter cells have matured, they digest the parental cell and become free-swimming.

What pigment gives red algae their color?

Red algae, of phylum Rhodophyta (roh dah FI duh), get their red color from the pigment phycobilins. This pigment enables red algae to absorb the light that can penetrate deep water. As a result, red algae can live in deeper water than other algae. Some red algae help form coral reefs.

Uses for Algae

The high protein content of algae makes them a nutritious food for animals and people. As shown in the table below, algae are used in many foods and in other products.

Type of Algae	Uses
Red algae	soups, sauces, sushi, and pie fillings; scientific gels; preservatives in canned meat and fish; thickening agent for puddings and shampoos
Brown algae	stabilizers for syrups, ice cream, and paints; eaten with meat or fish and in soups
Green algae	sea lettuce eaten in salads, soups, relishes, and with meat or fish
Diatoms	used for filtering beverages, oils, water supplies; used as abrasives

Life Cycle of Algae

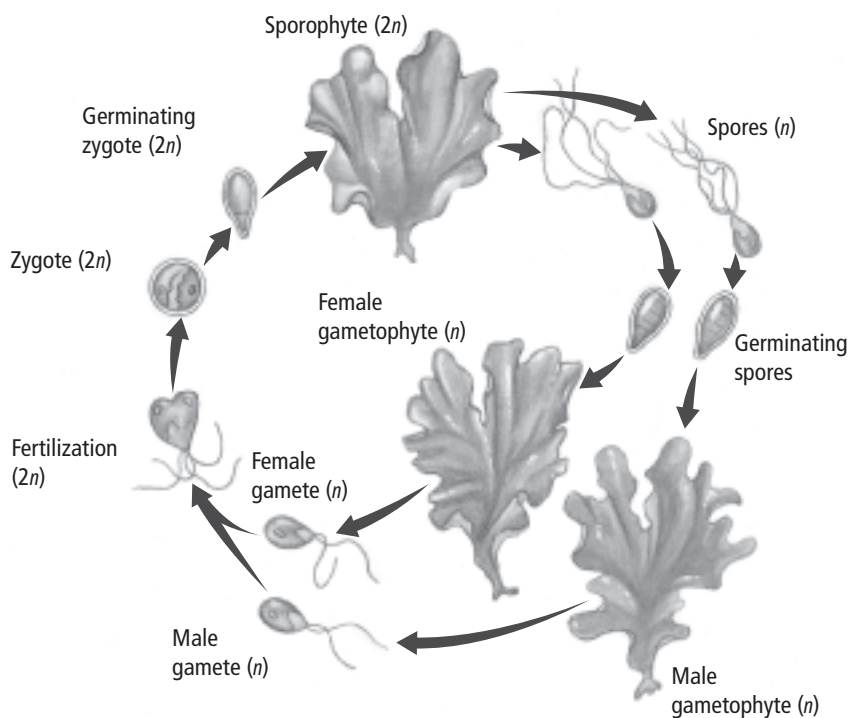
Algae can alternate between forms that produce spores and forms that produce gametes. They can reproduce sexually or asexually. Green algae can also reproduce through fragmentation. In fragmentation, the green alga breaks into pieces, and each piece grows into a new individual.

What is the life-cycle pattern of algae?

The life cycles of many algae show a pattern called alternation of generations. The figure below illustrates this pattern for sea lettuce. **Alternation of generations** is a life cycle of algae that takes two generations to complete. One generation reproduces sexually. The other generation reproduces asexually. Algae alternate between a diploid ($2n$) form and a haploid (n) form. Each form is a generation.

How does alternation of generations work?

Follow the arrows in the figure below to review how the two generations alternate. The haploid form is called the gametophyte generation because it produces gametes. Gametes from two individuals join to form a zygote with two complete sets of chromosomes. The zygote develops into the sporophyte ($2n$). Some cells in the sporophyte divide by meiosis and become haploid spores (n). Spores develop into gametophytes that continue the cycle.



Reading Check

8. Compare How do the two generations differ in the way they reproduce?

Picture This

9. Label both the haploid and diploid forms of the sea lettuce.

section 4 Funguslike Protists

MAIN Idea

Funguslike protists obtain their nutrition by absorbing nutrients from dead or decaying organisms.

What You'll Learn

- the characteristics of cellular and acellular slime molds
- the life cycle of cellular and acellular slime molds

Study Coach

Make an Outline Make an outline of the information you learn in this section. Start with the headings. Include the boldface terms.



Think it Over

1. Draw Conclusions

From what you know about acellular slime molds, what do you think the prefix “a” means? (Circle your answer.)

- a. with
- b. without

Before You Read

Have you seen commercials about household cleaners that get rid of molds and mildews? From what you have observed, where are molds and mildews most often found? On the lines below, list the conditions that might make a good environment for molds and mildews. Read the section to learn how these funguslike protists thrive and reproduce.

Read to Learn

Slime Molds

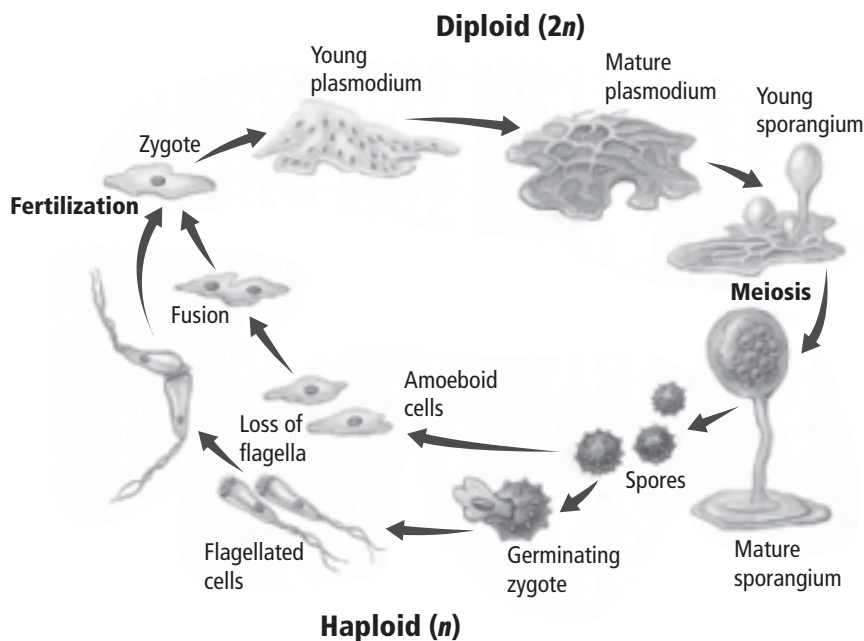
Slime molds are funguslike protists. They share some characteristics with fungi. Both fungi and slime molds reproduce through spores, and both feed on decaying organic matter. Both absorb nutrients through their cell walls, but the composition of their cell walls is different. The cell walls of fungi are made of chitin (KI tun), a complex carbohydrate. The cell walls of funguslike protists contain cellulose or similar compounds, instead of chitin.

Slime molds are found in many colors. They usually grow in damp, shady places among decaying matter such as decaying leaves or wood. Slime molds are classified as either acellular or cellular.

Why are some slime molds called acellular?

The phylum Myxomycota (mihk soh mi COH tuh) includes acellular slime molds. They are called acellular because they go through a phase in their life cycle in which the nucleus divides, but no internal cell walls form. The result is a mass of cytoplasm with many nuclei. To see how this happens, look at the life cycle of an acellular slime mold in the figure on the next page.

Life Cycle of Acellular Slime Molds



How do acellular slime molds reproduce?

As you can see in the figure above, acellular slime molds begin as spores, usually in harsh conditions. Spores form without fertilization and can produce a new organism. When water is present, the spore produces cytoplasm and flagella. The flagella propel the cell until it contacts a surface, then draw into the cell. The cell forms pseudopods that allow it to move like an amoeba. Both the flagellated cell and the amoeba-like cell are haploid (n) gametes.

When two gametes join, the next phase begins. The nuclei of the fertilized cells divide repeatedly, forming a plasmodium. A **plasmodium** (plaz MOH dee um) is a mass of cytoplasm with many diploid nuclei but no separate cells. This is the feeding stage. The organism creeps through decaying leaves or wood to feed. When food or moisture becomes limited, the slime mold produces spores that are spread by the wind. When the spores are in water, the cycle repeats.

How do cellular slime molds differ?

The phylum Acrasiomycota (uh kray see oh my COH tuh) contains cellular slime molds. These funguslike protists spread over moist soil, feeding on bacteria. Unlike acellular slime molds, they spend most of their life cycle as single amoeba-like cells. They also have no flagella.

Picture This

- Label** Place a 1 beside the structure that forms without fertilization. Place a 2 beside the structure that forms when the fertilized cell divides repeatedly.

Reading Check

- Explain** how spores produce a new organism.

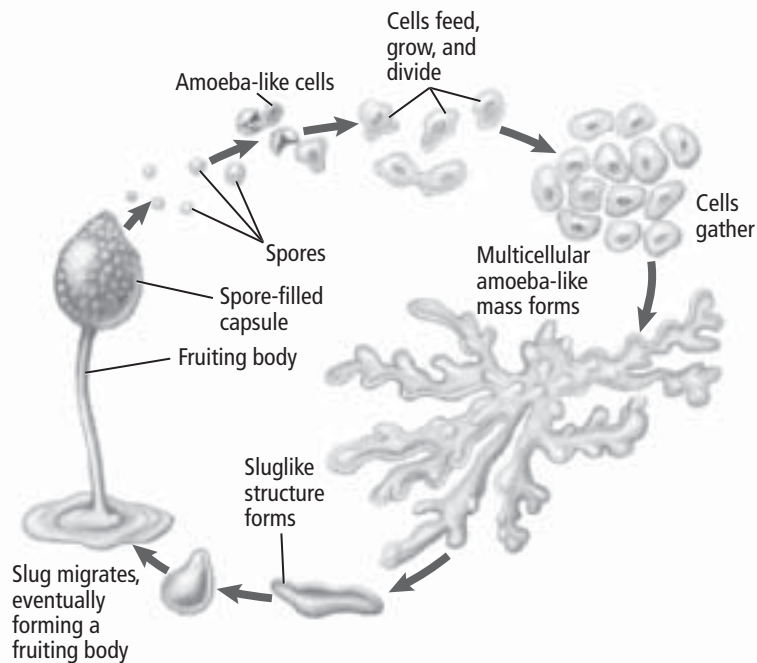
What is the life cycle of cellular slime molds?

The life cycle of cellular slime molds is shown in the figure below. When plenty of food is available, the single amoeba-like cells reproduce sexually. Two haploid amoebas join, forming a zygote. The zygote develops into a giant cell. After the giant cell divides repeatedly, it breaks open, releasing new haploid amoebas.

When food is limited, the single amoeba-like cells reproduce asexually. The starving cells give off a chemical called **acrasin** (uh KRA sun). This chemical signals the amoebas to gather, forming a sluglike colony. The colony moves and functions like a single organism. Eventually, the colony forms a fruiting body that produces spores. After the spores are released, they germinate, forming amoeba-like cells, and the cycle repeats.

Picture This

4. Explain Use the figure to explain the life cycle of cellular slime molds to a partner.



Water Molds and Downy Mildew

Water molds and downy mildews are members of phylum Oomycota (oo oh my COH tuh). Most live in water or damp places. Some absorb nutrients from the water or soil around them. Others obtain nutrients from other organisms.

Like fungi, water molds enclose their food with a mass of threads and absorb nutrients through their cell walls. Water molds differ from fungi in two main ways. Their cell walls are made of different materials, and the reproductive cells of water molds have flagella.

Reading Check

5. State how water molds obtain nutrients.

section 1 Characteristics of Fungi

● Before You Read

On the lines below, describe places where you have seen mushrooms growing. In this section you will learn how mushrooms and other fungi live.

● Read to Learn

Characteristics of Fungi

Members of the kingdom Fungi (FUN ji) (singular, fungus) are some of the oldest organisms on Earth. More than 10,000 species of fungi have been identified. Mushrooms on your pizza and mold growing on an old loaf of bread belong to this kingdom. All fungi are eukaryotic—their cells have a true nucleus and they have membrane-bound organelles. Also, all fungi are heterotrophs, which means that they cannot make their own food. Instead, they get nutrients from organic matter.

Are multicellular fungi really plants?

Most fungi, such as mushrooms, have many cells. Multicellular fungi can look like plants. Scientists have determined, however, that fungi are different enough to belong in their own kingdom.

What are unicellular fungi?

A fungus composed of one cell is called a yeast. Yeasts grow in soils, on plant surfaces, in sugary substances, and in the human body. Yeasts are used to make bread and beer.

Major Features in Fungi

Scientists have compared the features of plants and fungi. The features that distinguish fungi from plants include their cell walls, their body filaments, and their cross-walls.

MAIN Idea

Fungi have unique characteristics.

What You'll Learn

- how decomposers and other fungi obtain nutrients
- three types of asexual reproduction in fungi

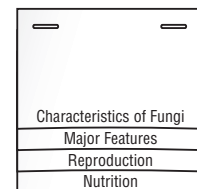
Mark the Text

Read for Understanding

As you read this section, highlight any sentence that you do not understand. Reread the highlighted sentences to make certain that you understand their content. Ask your teacher to help you with anything that you still do not understand.

FOLDABLES™

Take Notes Make a layered Foldable, as shown below. As you read, take notes and organize what you learn about the characteristics of fungi.



Think it Over

- 1. Apply** When you see a mushroom growing in the woods, what part of the fungus are you seeing? (Circle your answer.)
 - a. mycelium
 - b. fruiting body

Picture This

- 2. Label** two septa in the diagram.

How do cell walls differ in plants and fungi?

The cell walls of plants are made up of cellulose. The cell walls of fungi are made up of **chitin** (KI tun)—a polysaccharide. Recall that polysaccharides are complex carbohydrates composed of many simple sugars.

Of what are the bodies of fungi made?

Fungi are made up of **hyphae** (HI fee) (singular, hypha), which are tubelike filaments. Hyphae grow from their tips and branches to form a netlike mass called a **mycelium** (mi SEE lee um) (plural, mycelia). The mycelium grows underground. It provides the fungus with nutrients. The part of the fungus above ground is the **fruiting body**. The fruiting body's function is reproduction. It is also composed of hyphae.

How do materials move through the septa?

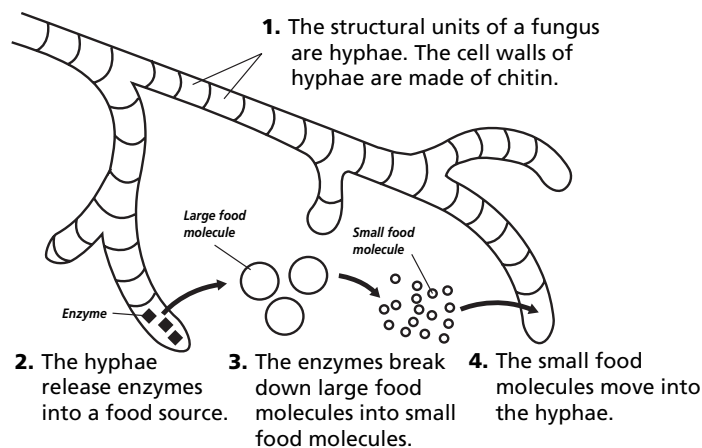
In many fungi, cross-walls called **septa** (singular, septum) divide hyphae into cells. Pores in the septa allow materials, such as nutrients and cytoplasm, to flow between cells. Some fungi are aseptate—they have no septa. In these fungi, materials flow freely through the hyphae.

Nutrition in Fungi

Unlike humans, fungi digest their food before they consume it. As shown below, the digestive enzymes of fungi break down food into smaller molecules outside their bodies. The fungi then absorb the nutrients through their cell walls. All fungi feed on organic matter, but they obtain nutrients in different ways.

Which fungi are decomposers?

Saprophytic fungi are decomposers. They recycle nutrients from dead organisms or organic wastes back into food webs.



How do parasitic fungi get nutrients from hosts?

A parasitic fungus absorbs nutrients from a living host. Special hyphae called **haustoria** (haws toh REE ah) grow into the host's tissues and absorb nutrients.

What fungi live in cooperative relationships?

Fungi that live in cooperative relationships with other organisms are mutualists. For example, a fungus that covers the root of a plant takes sugar from the plant while helping the plant absorb minerals.

Reproduction in Fungi

Fungi can reproduce sexually or asexually. Budding and fragmentation are forms of asexual reproduction.

How do yeasts reproduce?

Yeasts reproduce asexually by budding. New cells develop while attached to the parent cells. The plasma membrane of a new cell pinches off to partially separate the bud from the parent cell.


How does fragmentation occur?

Reproduction by fragmentation occurs when a piece of the mycelium of a fungus is broken off. If the piece lands in good growing conditions, the hyphae will grow into new mycelia.

How do fungi reproduce by spores?

Spores are part of both asexual and sexual reproduction. A **spore** is a reproductive cell with a hard outer coat. Spores develop into new organisms without the fusion of eggs and sperm. In sexual reproduction, fungi produce spores by meiosis.

How are spores adapted for survival?

Fungi produce trillions of spores, increasing the chance that some will find favorable growing conditions. Spores weigh so little that they can be spread by the wind and small animals. Their hard outer coats protect them from weather extremes. 

What is one way that fungi are classified?

Fungi are classified by the type of fruiting body, or sporophore, they produce. For example, some fungi produce spores in a sac or case called a **sporangium** (spuh RAN jee uhm) (plural, sporangia). The sporangium protects the spores and keeps them from drying out before they are released.



Think it Over

- 3. Contrast** How are mutualists different from other parasitic fungi?

Reading Check

- 4. List** three features of spores that help them survive.

section 2 Diversity of Fungi

MAIN Idea

Fungi are grouped into four major phyla.

What You'll Learn

- the traits that make each fungi phylum different from the others
- how members of each fungi phylum reproduce

Mark the Text

Identify Phyla Circle each phylum name as you come to it. Then highlight the characteristics of the phylum as you read about each one.

Reading Check

1. **Contrast** How are chytrids different from all other fungi?

Before You Read

Do you group similar clothes together in drawers? On the lines below, explain what you do with a unique piece of clothing, such as a bathing suit, that doesn't fit your pattern of organization. In this section, you will learn what scientists do with fungi that don't seem to fit into a major phylum.


Read to Learn

Classification of Fungi

Biologists group fungi into phyla based on their structures and methods of reproduction. The four major phyla are Chytridiomycota, Zygomycota, Ascomycota, and Basidiomycota.

Fungi probably appeared on land the same time as plants. However, scientists found molecular evidence that fungi are more closely related to animals than to plants. Fungi and animals might share a common ancestor.

Chytrids

The phylum Chytridiomycota (ki TRIHD ee oh mi koh tuh) are often called chytrids (KI trihdz). Some chytrids are saprophytes, or decomposers. Others are parasites. Most are aquatic chytrids and have a unique feature—their spores have flagella. For this reason, scientists first thought that chytrids were a type of protist. 

Studies of chytrid molecules, however, suggest a closer relationship to fungi than to protists. Also, like other fungi, chytrids have chitin in their cell walls. Scientists think that chytrids might have been the first fungi. Chytrids could be the evolutionary link between protists and fungi.

Common Molds

Molds found on bread and other foods belong to the phylum Zygomycota (zi goh mi KOH tuh). Most molds live on land. Many are mutualists—they live in cooperative relationships with plants.

How do molds obtain nutrients?

Molds form special types of hyphae called stolons and rhizoids. **Stolons** (STOH lunz) are hyphae that spread across the surface of food. **Rhizoids** (RIH zoydz) drill into food and absorb the nutrients. Rhizoids also anchor the mycelium and produce digestive enzymes. Zygomycetes can also be found on decaying plants and animal remains.

How do molds reproduce asexually?

Zygomycetes reproduce both asexually and sexually, as shown in the figure below. Asexual reproduction begins when upright hyphae, called sporangiophores, form sporangia at their tips. Each sporangium releases thousands of spores. As the wind spreads the spores, some fall into favorable growing conditions and produce new hyphae.

What causes molds to reproduce sexually?

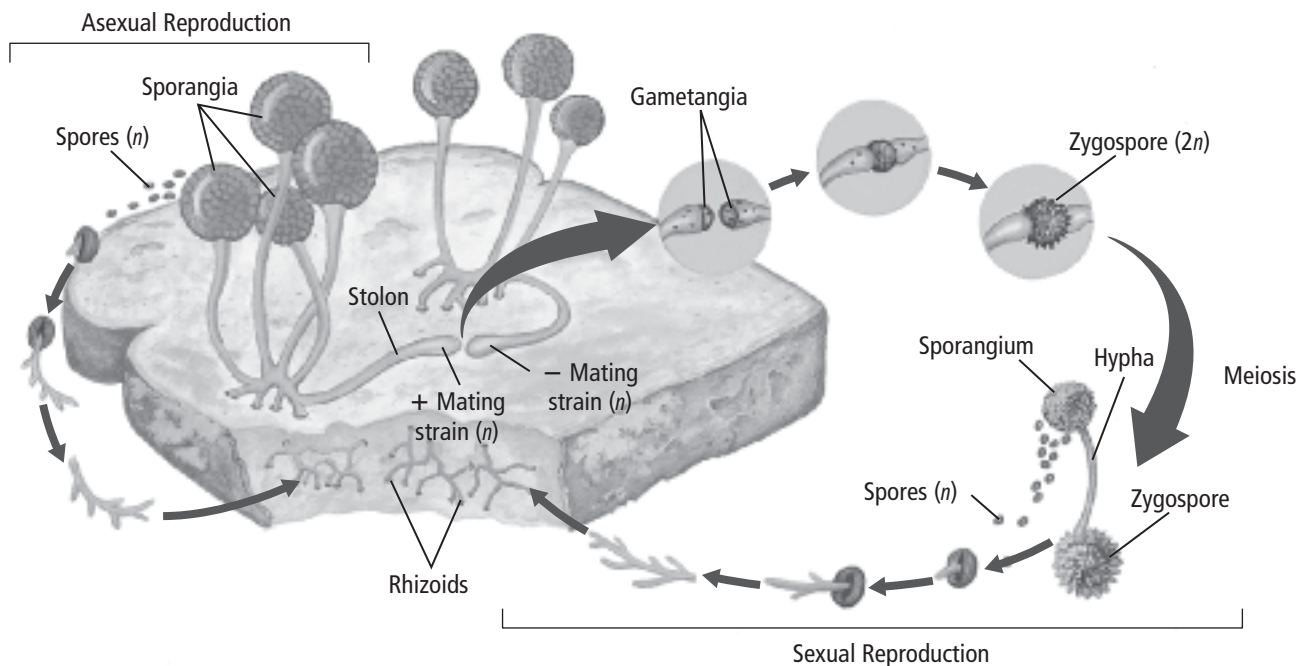
Sometimes growing conditions in the environment become unfavorable. For example, food can become scarce. Unfavorable growing conditions can cause molds to reproduce sexually.

Reading Check

2. **Describe** three main functions of rhizoids.

Picture This

3. **Identify** the structure that produces spores in both sexual and asexual reproduction. (Circle your answer.)
- zygospore
 - sporangium
 - gametangium



 **Think it Over**

4. Infer What adaptive advantages are evident in zygospores?

Picture This

5. Identify Add an appropriate title to this figure.

How does sexual reproduction take place?

Fungi are not divided into males and females. Instead, they have plus (+) and minus (-) mating strains. The hyphae of a plus mating strain and a minus mating strain grow together. Each hypha produces a reproductive structure called a **gametangium** (ga muh TAN jee um) (plural, gametangia). The haploid nuclei of the gametangia fuse to form a diploid zygote. The zygote develops a tough outer coat and becomes a dormant zygospore.

How long can a zygospore remain dormant?

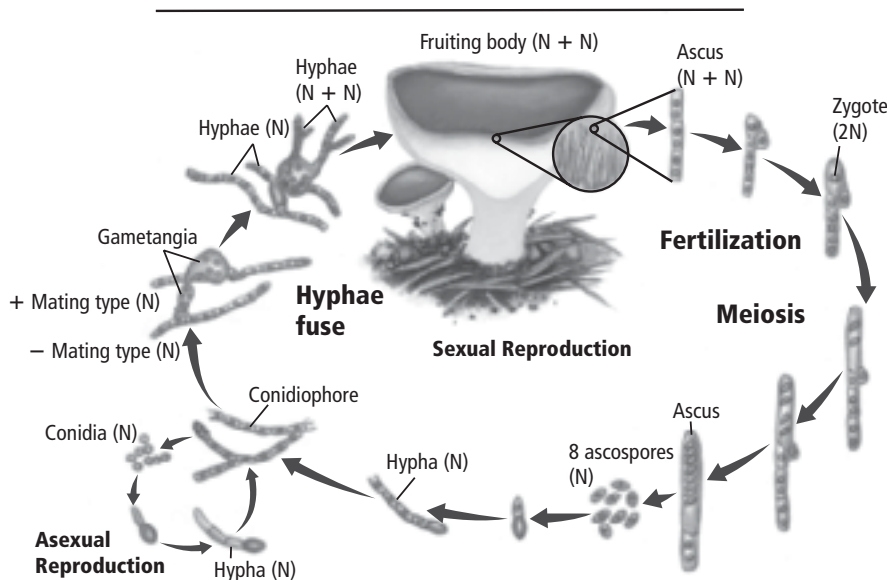
A zygospore can remain dormant for months. When conditions in the environment improve, the zygospore germinates. It undergoes meiosis to produce hyphae with sporangia. Each haploid spore in the sporangia can grow into a new mycelium.

Can molds cause disease?

Molds can cause infection called zygomycosis in humans and animals. The molds can infect respiratory passages, lungs, intestines, and skin. Cases of zygomycosis are rare.

Sac Fungi

The phylum Ascomycota (AS koh mi koh tuh) is the largest phylum of fungi containing over 60,000 species. Its members are often called sac fungi or ascomycetes. Unicellular yeasts belong to this phylum, as do many multicellular species. Sac fungi can reproduce sexually or asexually, as shown in the figure below.



How do sac fungi reproduce asexually?

In asexual reproduction, they form special hyphae called conidiophores. **Conidiophores** (koh NIH dee uh forz) produce chains or clusters of spores called conidia at their tips. Wind, water, and animals spread the spores.

How do sac fungi reproduce sexually?

In sexual reproduction, the hyphae from plus and minus mating strains fuse. One nucleus from each strain pairs off in a separate cell. The cell contains two haploid nuclei.

As the hyphae continue to grow, they develop reproductive structures called **ascocarps**. Within an ascocarp, the haploid nuclei fuse to form a zygote. The zygote divides by meiosis and then by mitosis. The result is eight haploid nuclei. These nuclei develop into spores in a saclike **ascus**. The spores produced in the ascus are called **ascospores**. When growing conditions are favorable, the ascospores develop a mycelium.

Club Fungi

The members of the phylum Basidiomycota are mushrooms, or club fungi. They are called basidiomycetes (buh SIH dee oh mi see teez). Basidiomycetes can be saprophytic, parasitic, or mutualistic. Saprophytic species are major decomposers of wood.

How do club fungi reproduce?

Club fungi rarely reproduce asexually. They reproduce sexually by forming **basidiocarps** (buh SIH dee oh karpz), or fruiting bodies. The mushrooms you see in a grocery store or growing in the woods are the basidiocarps.

Basidiocarps grow quickly because their cells enlarge rather than divide. The underside of a mushroom's cap is made up of club-shaped hyphae called **basidia** (buh SIH dee uh). Basidia produce haploid spores called **basidiospores** by meiosis. Wind, water, and animals spread the basidiospores. Mushrooms can produce up to a billion basidiospores. ✓

Other Fungi

Members of the phylum Deuteromycota are a diverse group. They share only one unique trait—they appear to lack a sexual stage in their life cycle. As a result, they are referred to as imperfect fungi. Recent studies, however, continue to lead scientists to reclassify these fungi into other phyla.



Think it Over

6. Draw Conclusions

Why do you think ascomycetes are called sac fungi?

✓ Reading Check

7. **Explain** why mushrooms tend to grow quickly.

section 1 Ecology of Fungi

MAIN Idea

Lichens have distinct characteristics.

What You'll Learn

- the features of mycorrhizal relationships
- the positive and negative effects of fungi on humans

Study Coach

Make Flash Cards Make a flash card for each question heading in this section. On the back of the flash card, write the answer to the question. Use the flash cards to review what you have learned.



Think it Over

1. **Recall** What is photosynthesis?

Before You Read

Think about a recent or historical natural disaster. On the lines below, describe how you think the event affected the environment. In this section, you will learn how fungi can help the environment recover from a natural disaster.

Read to Learn

Fungi and Photosynthesizers

Lichens and mycorrhizae are mutualists. They are a combination of fungi and other organisms. Both organisms benefit from the symbiotic relationship.

What is a lichen?

A **lichen** (LI ken) is a symbiotic relationship between a fungus and an organism capable of photosynthesis. The fungus is usually an ascomycete. The photosynthetic organism is either a green alga or a cyanobacterium. The figure on the next page summarizes the benefits of this relationship to both organisms and to the ecosystem.

The photosynthetic organism provides food for both organisms. The fungus provides a dense web of hyphae in which the algae or cyanobacterium can grow.

How do lichens get what they need to live?

Lichens need only light, air, and minerals to grow. They can be found in the harshest environments. The fungus absorbs moisture and minerals from the air and from rainwater. Some fungi produce chemicals that keep animals from eating the lichen.

Where do lichens live?

Most lichens live in temperate or arctic areas. On the tundra, grazing animals feed on lichens that cover the ground.

Lichens can survive droughts. When there is little water, lichens dry out and stop photosynthesizing. Dry pieces can break off, blow away, and form new colonies where they land. When the rain returns, lichens absorb the moisture and start photosynthesizing again.

Recall from Chapter 3 that pioneer species can grow on rocks and in little soil. Lichens are often a pioneer species after lava flows or other natural disasters clear the land. Lichens help plants return to the cleared area. The fungi produce acids that break down rocks into soil. The lichens trap soil and nitrogen that plants need.

How do lichens serve as bioindicators?

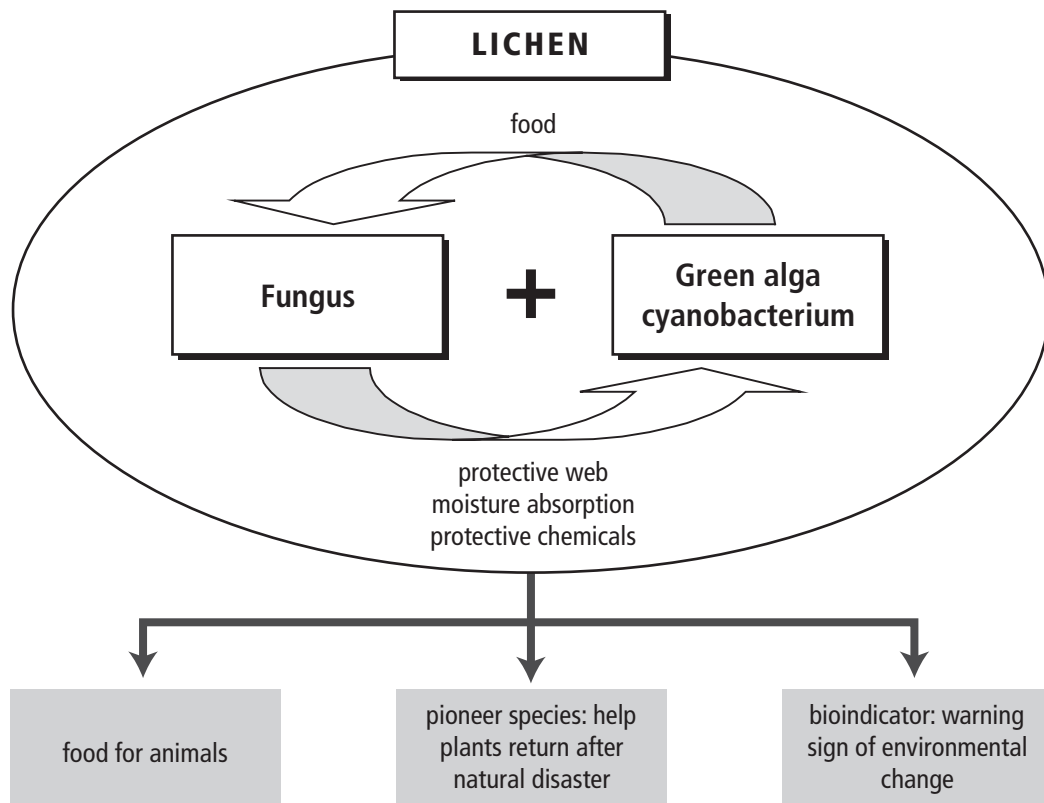
A **bioindicator** is a living organism that is one of the first organisms to respond to changes in environmental conditions. Lichens absorb water and minerals directly from the air and rain. As a result, they are very sensitive to air pollution. When lichens begin to die, it is a sign that pollution is rising in the area.

Think it Over

2. **Explain** how lichens can reproduce in drought conditions.

Picture This

3. **Explain** why it is important for fungi to partner with an organism that can photosynthesize.





Think it Over

4. Predict how Earth's surface could be different without decomposers.

Reading Check

5. Describe how fungi clean the environment of pollutants.

What are mycorrhizae?

A **mycorrhiza** (my kuh RHY zuh) (plural, mycorrhizae) is a symbiotic relationship between a fungus and the root of a plant. The fungus absorbs minerals for the plant roots. The fungus also creates a larger surface area for the plant roots, which helps the plant absorb more water and minerals. In return, the plant provides food for the fungus.

Why are mycorrhizae important?

Between 80 and 90 percent of plants have mycorrhizae. Many crops, including corn and potatoes, depend on mycorrhizae to help them stay healthy. Some plants, like the orchid, cannot survive without mycorrhizae.

Fungi and Humans

Fungi are mostly beneficial to humans. Their role as decomposers is especially important. Fungi recycle nutrients from dead organisms back into food webs.

How are fungi used in medicine?

Fungi have many medical uses. A type of fungi is the source of penicillin, a life-saving antibiotic. Chemicals found in some fungi can reduce bleeding and lower high blood pressure.

How are fungi used in foods?

Fungi contribute to human diets in many ways. People eat a variety of mushrooms. Yeast causes the fermentation of sugars. Bread rises when carbon dioxide is released during fermentation. Fermentation of fruits and grains creates the alcohol in wine and beer. Fungi are also used as flavoring in some colas.

What is the role of fungi in bioremediation?

Fungi can be used to clean the environment of pollutants. When mixed with water or soil, fungi decompose harmful materials in the pollutants. Using microorganisms to remove environmental pollutants is called **bioremediation**. ✓

In what ways can fungi harm other organisms?

Some types of fungi have killed many trees in North America. A parasitic fungus causes leaf blotch in alfalfa plants, killing most of the crop. Parasitic fungi also attack grapes.

Fungal parasites can infect animals, including humans. Athlete's foot, ringworm, and yeast infections are all fungal infections in humans.

Introduction to Plants

section 1 Plant Evolution and Adaptations

● Before You Read

In your mind, picture different plants that you have seen. Scientists classify living things by their characteristics. On the lines below, write at least four characteristics of plants.

● Read to Learn

Plant Evolution

Plants are necessary for human survival. Much of the oxygen in the atmosphere comes from plants. Humans use plants for food. Many of the things that make our lives comfortable, such as clothing and furniture, come from plants. When you think of a plant, you might picture a tree, a shrub, or a houseplant.

Biologists describe plants as multicellular eukaryotes with tissues and organs. The tissues and organs have specialized structures that perform various functions. For example, most plants have tissues where photosynthesis occurs. Organs such as roots that anchor plants to the soil or to another object also have specific functions.

Primitive land plants first appeared about 400 million years ago. Biochemical and fossil evidence suggests that freshwater green algae are the ancestors of land plants. Some of these ancient green algae might have been able to survive periods of drought. Through natural selection, these drought-resistant green algae might have passed adaptations to future generations that helped them survive drought.

MAIN Idea

Adaptations allow plants to live on land.

What You'll Learn

- how plants and green algae are alike
- the importance of vascular tissue to plant life on land
- the alternation of generations in plants
- the divisions of the plant kingdom

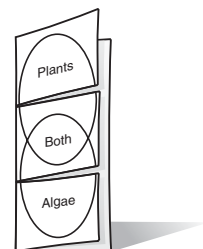
Study Coach

Make Flash Cards Write a question about each paragraph on one side of a flash card. Then write the answer on the other side. Quiz yourself until you know the answers.

FOLDABLES™

Organize and Learn

Make a three-tab Venn diagram Foldable, as shown below. Note what you learn about plants and algae, then determine what they have in common.



What do plants and algae have in common?

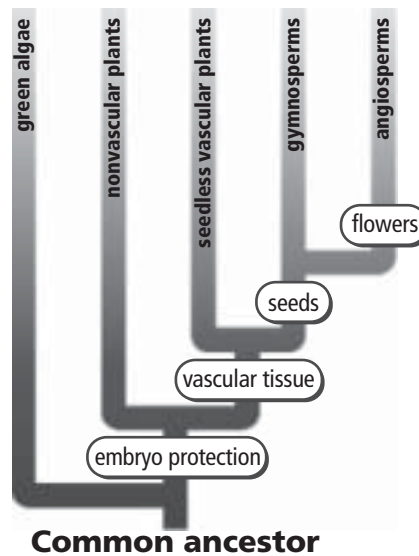
Scientists have compared present-day plants and algae. They have found the following common characteristics:

- cellulose cell walls
- the formation of a cell plate during cell division
- similar genes for ribosomal RNA
- food stored as starch
- the same types of enzymes in cellular vesicles.

The evolutionary tree below shows the relationship between ancient freshwater green algae and present-day plants.

Picture This

1. **Circle** the name of the ancestor of present-day land plants.



Plant Adaptations to Land Environments

Land organisms face many challenges that aquatic organisms do not face. Land organisms must survive with limited water resources. Over time, land plants developed adaptations that helped them survive when water was scarce. Land plants also developed adaptations to other environmental factors.

What purpose does cuticle serve in land plants?

Most plant parts that grow above ground have a coating called a cuticle on the outer surface of their cells. The cuticle is formed by wax and fats, which are lipids that do not dissolve in water. It is the wax in the cuticle that gives some plant leaves their gray appearance. The cuticle helps keep water from evaporating from the plant tissues. The cuticle also stops microorganisms from invading the plant.

Think it Over

2. **Conclude** Why do land plants need to conserve water?

What structure enables gas exchange?

Most plants carry on photosynthesis. Photosynthesis produces glucose and oxygen from carbon dioxide and water. For photosynthesis to occur, gases need to move between the plant and the environment. If the cuticle reduces water loss, it might prevent the movement of gases.

Stomata (STOH muh tuh) (singular, stoma) are adaptations that enable gas exchange. Stomata are openings in the outer cell layer of leaves and some stems. Most stomata are found in plant leaves, which are the site of most plant photosynthesis.

What are the functions of vascular tissues?

Vascular (VAS kyuh lur) **tissue** is a specialized transport tissue that is another plant adaptation to life on land. Plants with vascular tissues are called **vascular plants**. Plants that lack specialized transport structures are **nonvascular plants**. Water travels from cell to cell in nonvascular plants by osmosis and diffusion.

Vascular tissues provide support and structure to vascular plants. They help substances move faster than in nonvascular plants. Vascular tissues with thickened cell walls allow vascular plants to grow larger than nonvascular plants.

What are the features of a seed?

The evolution of the seed was another adaptation that helped vascular plants succeed on land. A **seed** is a plant structure that contains an embryo and nutrients for the embryo. The embryo and nutrients are protected by a seed coat. Seeds are adapted to survive in harsh environmental conditions and then sprout when favorable conditions exist.

Alternation of Generations

The life cycle of plants includes two stages, or alternating generations. One generation is the gametophyte generation. The other is the sporophyte generation.

The gametophyte generation produces gametes—sperm and eggs. Sperm and eggs are both haploid cells. Some plants produce both sperm and eggs on one gametophyte. Other plants produce sperm and eggs on separate gametophytes. When the sperm fertilizes the egg, a diploid zygote forms. The zygote goes through mitosis repeatedly to form a multicellular sporophyte.

The sporophyte generation produces spores. The spores can grow to form the next gametophyte generation.



Think it Over

3. **Explain** how the cuticle and stomata function together.

Reading Check

4. **Name** the two plant generations.

 **Think it Over**

- 5. Predict** Which generation is dominant in most nonvascular plants? (Circle your answer.)
- a. gametophyte
 - b. sporophyte

Picture This

- 6. Label** on the lines in the chart the ways in which water and other substances are transported in nonvascular and vascular plants.

How is the dominant generation identified?

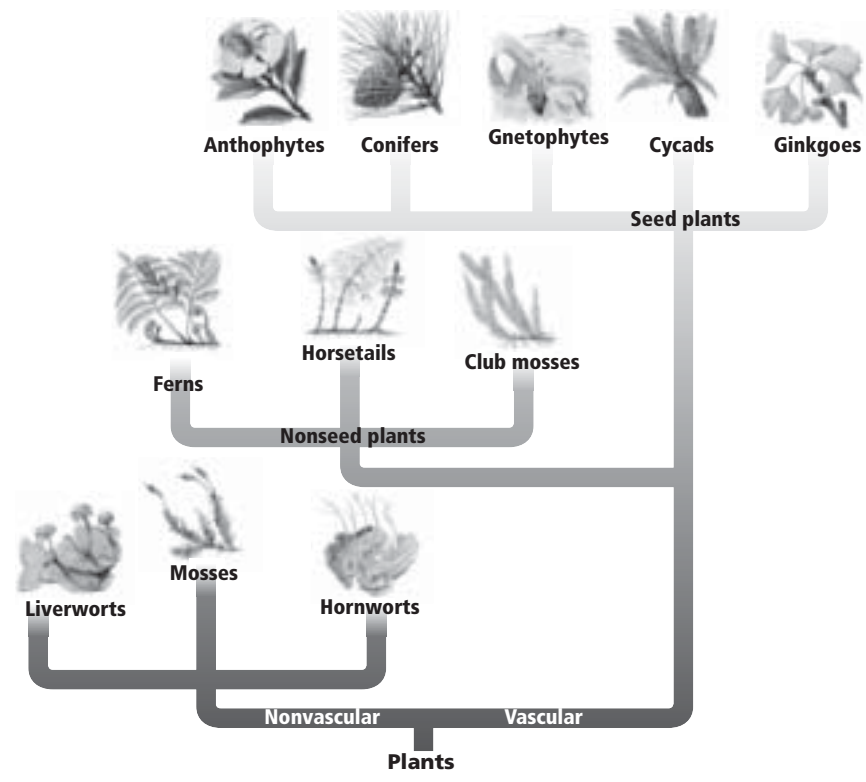
Depending on the type of plant, one generation is dominant over the other. The dominant generation is larger and more easily seen. For example, the grass growing in a park is the sporophyte generation of the plant. Most plants you see are the sporophyte generation for those plants. The trend in plant evolution was from dominant gametophytes to dominant sporophytes that contain vascular tissue.

Plant Classification

All plants belong to the plant kingdom. Over time, plant adaptations led to a diversity of plant characteristics. Botanists use these characteristics to classify plants into divisions. You will learn more about the characteristics of these divisions in the next three sections.

Division names end in an *a*. Botanists commonly drop the *a* from the division name and add *es*. Therefore, members of division Bryophyta are called bryophytes (BRI uh fites).

The 12 plant divisions are organized into two groups—nonvascular plants and vascular plants. Vascular plants are organized further into plants that produce seeds and plants that do not produce seeds. The basic organization of the plant kingdom is shown below.



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● Before You Read

One nonvascular plant often lives in a mutualistic relationship with another. You learned about mutualism in Chapter 2. On the lines below, explain this type of relationship.

MAIN Idea

Nonvascular plants are small and only grow in damp environments.

What You'll Learn

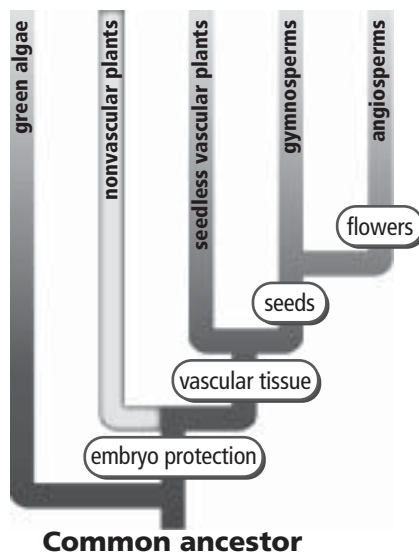
- the structures of nonvascular plants
- the differences among the nonvascular-plant divisions

● Read to Learn

Diversity of Nonvascular Plants

Evidence suggests that four major groups of plants evolved along with green algae from a common ancestor. The figure below shows characteristics that separate each group.

Nonvascular plants are usually small, which enables materials such as water and nutrients to move easily within them. These plants are often found in damp, shady areas that provide the water needed for reproduction and the movement of nutrients.



Mark the Text

Identify Plant Divisions

Underline or highlight the name of each nonvascular plant division. Say the name aloud. Then circle the words or phrases that describe that plant division.

Picture This

1. **Highlight** the characteristic on the chart that separates nonvascular plants from all other plants.


 **Reading Check**

2. Describe where photosynthesis occurs in mosses.

 **Think it Over**

3. Compare Name one characteristic that bryophytes and hepaticophytes share. Name one characteristic that differs.

What plants are bryophytes?

The most familiar bryophytes are mosses. These small, nonvascular plants often grow on a damp log or along the sides of a stream. They have structures that are similar to leaves. Photosynthesis occurs in these leaflike structures, which are usually only one cell thick. 

Mosses are anchored to the soil or another surface by multicellular rhizoids. Water and dissolved minerals can diffuse into a moss's multicellular rhizoids. Water and other substances move throughout a moss by osmosis or diffusion.

Some mosses have stems that grow upward from the plant. Others have stems that trail like a vine. Some mosses form mats that help hold soil in place on rocky slopes.

About 1 percent of Earth's surface might be covered with bryophytes. Mosses can survive climate changes. Many mosses freeze and thaw without damage. Some mosses can survive drought and begin growing again when water returns.

What is the smallest division of nonvascular plants?

Anthocerophytes (an tho SAIR uh fites) are the smallest division of nonvascular plants. Members of division Anthocerophyta are commonly called hornworts because of their hornlike sporophytes.

These plants have one large chloroplast in each cell of the gametophyte and sporophyte. The sporophyte produces much of the food used by both generations of hornworts.

You can see the large chloroplast by looking at a hornwort under a microscope. You might also observe that the spaces around cells are filled with slime. Cyanobacteria often grow in this slime. The hornwort and the cyanobacteria exhibit mutualism. In other words, both benefit from the relationship.

What are hepaticophytes?

Hepaticophytes (hih PA tih koh fites) are commonly called liverworts. They are found in habitats ranging from the tropics to the arctic. Liverworts usually grow near the ground and in areas with plenty of moisture. Like other nonvascular plants, water and other substances are transported by osmosis and diffusion.

Liverworts are classified as either thallose (THAL lohs) or leafy. A **thallose** liverwort has a fleshy, lobed body. A leafy liverwort has a stem with flat, thin, leaflike structures arranged in three rows. Liverworts have unicellular rhizoids.

● Before You Read

The vascular tissues of plants serve as a type of plumbing for the plants. On the lines below, write what you think are the main purposes of plumbing.

● Read to Learn

Diversity of Seedless Vascular Plants

Three plant groups have vascular tissues. The most diverse group in form and size is the seedless vascular plant group. Seedless vascular plants consist of club mosses and ferns. Club mosses are small plants. They are usually less than 30 cm tall. Tropical tree ferns can grow to a height of 25 m.

An adaptation seen in the sporophytes of many seedless vascular plants is the strobilus (STROH bih lus). A **strobilus** is a cluster of structures that produce spores.

What is the dominant generation of lycophytes?

Fossil evidence suggests that lycophytes (LI kuh fites) were once the size of trees and were part of the early forest community. Modern members of division Lycophta are much smaller and are called club mosses.

Unlike true mosses, the sporophyte generation is dominant in lycophytes. The gametophyte generation is small and grows from spores. Lycophytes have roots, stems, and small, scaly, leaflike structures. Their vascular tissue is found in a vein that runs down the middle of each leaflike structure.

Many tropical lycophyte species are known as epiphytes (EH puh fites). An **epiphyte** is a plant that lives anchored to another plant. In tropical forests, these lycophytes create a habitat in the forest canopy. ✓

MAIN Idea

Seedless vascular plants are adapted to drier environments.

What You'll Learn

- the characteristics of seedless vascular plants
- the differences between club mosses and ferns

Mark the Text

Highlight Main Ideas

Read the paragraphs under each question heading. Underline the part of the text that answers the question.

Reading Check

1. **Define** What is an epiphyte?

✓ Reading Check

2. Identify the kind of environment in which most ferns grow.

Picture This

3. Highlight the name of the food storage structure. Color the structure where photosynthesis occurs green.

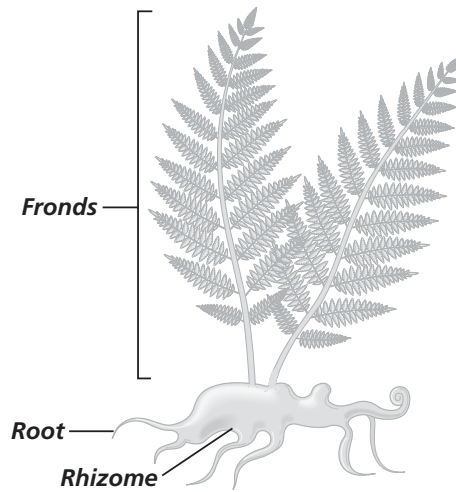
Where do ferns grow best?

Division Pterophyta includes ferns and horsetails. Approximately 350 million years ago, ferns were the most abundant land plants. They grow best in moist environments. However, some can survive in dry environments. ✓

How is the fern sporophyte produced?

The fern gametophyte is a tiny, thin structure. It grows from a spore and has male and female reproductive structures. After fertilization, the sporophyte grows from the gametophyte. Ferns that live in dry areas have an adaptation that allows them to produce sporophytes without fertilization.

The sporophyte produces roots and a thick underground stem called a **rhizome**. Food is stored in the rhizome. Photosynthesis occurs in the leafy structures known as fronds. The fronds shown below have branched vascular tissues and are part of the sporophyte generation.



Where do fern spores form?

Fern spores form in a structure called a **sporangium** (plural, sporangia). Groups of sporangia form a **sorus** (plural, sori). Sori can be found on the underside of fronds.

What are the structures of horsetails?

Horsetails have hollow stems with circles of scalelike leaves. Spores are produced in strobili at the tips of reproductive stems. Horsetail spores develop into gametophytes when environmental conditions are right.

Present-day horsetails and ferns are much smaller than their ancestors. Like ferns, horsetails grow best in places where water is abundant. Horsetails are found most often in marshes, swamps, and stream banks.

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