CHAPTER 1

The Nature of Science and Scientific Inquiry

KEY IDEAS

- The scientific method is an organized way of learning about the natural world.
- The nature of a scientific question determines the method that a scientist uses to investigate it.
- Science and technology are very different, but related, fields and often advance together.

Chapter Preview

You have been studying science in school for a number of years. You may have even participated in a science fair. Based on your experiences and your knowledge of science up to now, how would you explain what science is and how it operates to someone who is unfamiliar with it? Do all cultures think of science the way we do? How important is science in our everyday life?

What are the characteristics of a scientist? If you walk into a room full of people or along a busy street, could you identify a scientist? Do scientists look different from non-scientists? Do they act differently? What do scientists do anyway? Could you be a scientist? Are you a scientist now?

In this chapter, you will investigate the nature of science and what scientists do.

TRY THIS: The Qualities of a Scientist

Skills Focus: recording

When you hear or read the word "scientist," what images come to mind? Do you think scientists have special qualities and abilities? In a small group discussion, share what you believe scientists do and what qualities you associate with scientists. In your discussion, consider these questions:

- What do scientists do that people in other occupations do not do?
- How do you view scientists? On what do you base your views?
- Do scientists work alone or in groups?
- Do scientists have interests other than science?
- Are scientists usually young or old? Are they mostly male or female?

1. Record your ideas in a table like the one below.

Qualities of scientists	What scientists do

2. Have a spokesperson share your group's ideas with the class. Based on the ideas of the whole class, answer the questions below.

A. What are the qualities we most commonly associate with scientists?

B. What are the tasks we most commonly associate with scientists?

C. Do you think the common perceptions of scientists are accurate or are they stereotypes? Explain.

D. Find the word "science" or "scientist" in a newspaper. Decide whether the sentence refers to science or a scientist in a positive, neutral, or negative way. Share your findings with the class.

1.1

The Nature of Science

What Is Science?

Science is often thought of as facts, laws, and theories. While this is partially true, science is much more. Science or more specifically, scientific inquiry, is a way of learning about the natural world by observing things, asking questions, proposing answers, and testing those answers. The main goal of science is to understand the natural world, and the main product of science is knowledge in the form of facts, laws, and theories. For example, we know that Earth revolves around the Sun. This is accepted as a scientific fact. It came from repeated observations and analysis of the Sun and the night sky.

Science is also the processes that are used to gather knowledge about the natural world and organize it. Science, then, is both our present understanding of the natural world and the processes that led to this understanding.

Scientists make the following basic assumptions about science and the natural world:

LEARNING TIP

When you are reading bulleted text, ask yourself, "How does each point add to what I am learning?"

- We live in a natural world, not a mental construction (Figure 1).
- The natural world is mostly structured and understandable. There is, however, some randomness in the natural world. Therefore, the natural world is not always entirely predictable.
- Human intelligence enables us to understand the natural world, and scientific research is one of the best ways to advance this understanding.
- Our knowledge is constructed, tentative, and incomplete. It will likely change or be modified, and grow through continued research.

Figure 1 The world around us is a natural world. This group of campers is hiking near Squamish, British Columbia.

The Characteristics of Science

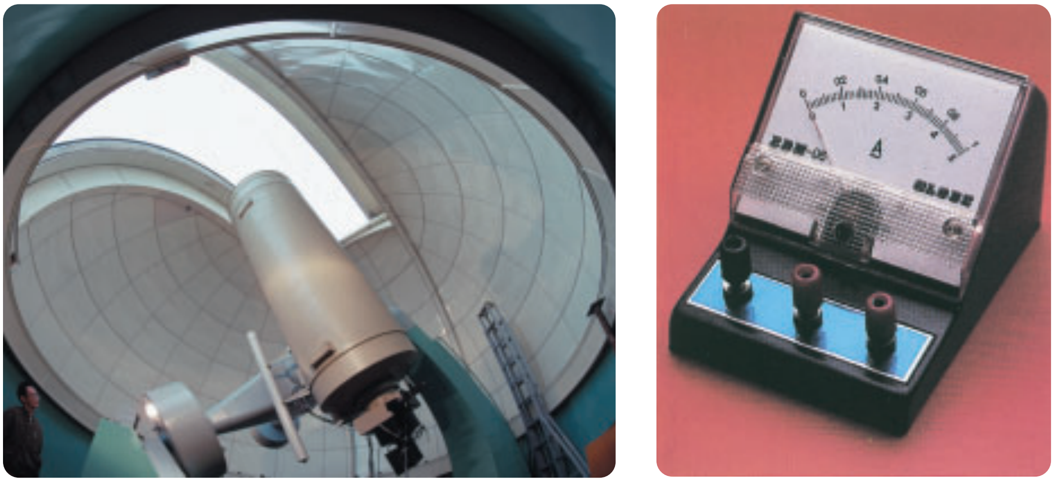
Science has some characteristics and methods that make it similar to other areas of study. Science is also unique in some ways.

Science starts from observations that lead to questions.

Scientific investigations always start from observations that lead to an appropriate question. The question may arise from curiosity or from a serious problem that faces society. For example, you may ask the question "What kind of seeds do the birds at my bird feeder prefer?" A scientist may ask, "What causes cancer?" Scientists gather many observations or set up experiments to provide evidence that may help them answer their question.

Scientists describe the natural world using their observations. **Observations** are evidence gained by the five senses—touch, smell, taste, vision, and hearing. Scientists often use special tools and equipment (such as microscopes, telescopes, meters, radar, and sensors) to expand or extend the capabilities of their senses and to quantify their observations (Figure 2).

Scientists cannot always directly observe the subject of their investigation. Instead they make indirect observations. Scientists pride themselves on being able to devise clever ways of figuring out the characteristics of things that cannot be directly observed. For example, scientists cannot see the particles of an atom, yet scientists have inferred the existence and characteristics of protons, neutrons, and electrons through indirect evidence. An **inference** is a tentative conclusion based on logic or reasoning.



(a) (b)

Figure 2 Telescopes (a) and ammeters (b) are examples of technology that scientists use to make observations.

Scientific knowledge comes from observation.

Scientific knowledge is acquired by careful observation and experimentation. Knowledge that is obtained in this way is generally referred to as **empirical knowledge**. Thus, empirical knowledge is knowledge gained through experiences.

People often think that empirical knowledge is produced only by science done in laboratories. There are other very important sources of empirical knowledge, however. Traditional or **Indigenous Knowledge (IK)** has been around much longer than modern science and provides a wealth of empirical knowledge that could not possibly be obtained through laboratory studies. Indigenous Knowledge can help us learn better ways to live in harmony with our world.

LEARNING TIP

Check your understanding. Explain to a partner how Indigenous Knowledge can help us learn ways to work with the natural world.

Aboriginal peoples lived in their traditional territories long before the first explorers and immigrants arrived in North America. Indigenous peoples, and later the Métis people, lived very closely with nature. From their experiences, they developed very detailed empirical knowledge about their environment, including knowledge about plants, animals, weather, and landforms. For this reason, Indigenous Knowledge is also known as **Traditional Ecological Knowledge and Wisdom** (TEKW).

Indigenous peoples have an oral tradition: their empirical knowledge has been carefully told by one generation to the next so that it will not be lost (Figure 3). The Elders are the people in each community who have this important knowledge. They teach it to the young people so that future generations can live carefully and successfully in the environment.

Figure 3 Indigenous Knowledge is passed on from generation to generation. This totem pole is being carved near Duncan on Vancouver Island.

Did You KNOW?

Coca-Cola

Coca-Cola, invented in 1866, contained an extract of the coca plant. It still does, but the chemicals that produce the anesthetic properties are removed.

There are numerous examples of how Indigenous Knowledge has benefited humanity. For example, many modern drugs have been developed based on the knowledge of Indigenous peoples. Lidocaine, one of the most common local anesthetics (pain relievers) used by doctors and dentists, is derived from the coca shrub. This shrub is native to the Andes Mountains in South America, and Indigenous peoples were well aware of its anesthetic properties. There is evidence that the leaves of this shrub were chewed for pain relief as early as 300 BCE. Quinine, made from the bark of the cinchona tree, is used to treat malaria. Curare, a powerful muscle relaxer derived from the bark of the Strychnos plant, was used as arrow poison by indigenous South American tribes. Today, curare is used during surgery. The discovery of many of these very prominent drugs, however, has been claimed by modern western science. Today, these chemicals are synthesized in laboratories with little recognition of the Indigenous Knowledge that led to the technological achievement.

As they have done for centuries, Indigenous peoples around the world continue to observe, describe, explain, predict, and work with the natural world. Indigenous knowledge is becoming increasingly valued as people around the world are becoming aware of, and concerned about, environmental issues.

In British Columbia, as in other places around the world, more and more scientists are working with Aboriginal communities and tapping into Indigenous Knowledge. Indigenous Knowledge has made many contributions to modern society and continues to provide scientists with important biological and ecological insights.

Scientific knowledge is tentative but reliable.

Scientists analyze their observations by looking for patterns or regularities. If a pattern is discovered, a law may be formulated. A **law** is a general statement, based on extensive empirical data, about *what* has happened: it does not explain *why* this happened. Scientists can use a law to make predictions. The law of gravity is a good example. Through extensive and repeated observations, Sir Isaac Newton (Figure 4) concluded that all objects in the universe exert a gravitational force on each other, and that the strength of the force depends on two factors: the masses of the objects and the distance between the objects. According to Newton's law, called the universal law of gravitation, the attractive force between two objects increases as the masses increase and decreases as the distance between them increases. The universal law of gravity does not explain gravity, but it describes the effects of gravity. It can also be expressed mathematically.

Figure 4 Sir Isaac Newton (1642–1727)

A law cannot be proven true because testing every possible situation in which the law might apply is impossible. A law can be proven false, however, if evidence is provided that contradicts (disagrees with) it. For example, suppose that a location is found in a remote part of our solar system where objects "fall" upward. This contradicts the law of gravity as we know it, and the law may have to be rejected or modified to account for the new observations. Even though scientific laws cannot be proven true, you should be confident in their validity because of the vast number of observations that support them.

Unlike a law, which is determined by careful analysis of observations, a theory is a product of a scientist's creativity and inventiveness. A **theory** is an explanation of observations (or of a law). In attempting to develop a theory, a scientist first suggests a tentative answer or an untested explanation called a **hypothesis**. The most important characteristic of a hypothesis is its testability, or the ability to obtain evidence that will test the explanation. Such a test can never prove a hypothesis to be true. A test can either support a hypothesis or refute it—that is, prove it to be unacceptable.

For an explanation (hypothesis) to become a theory, it must be widely accepted in the scientific community as the best possible explanation after being tested extensively by repeated observations. In some cases, theories can be tested by experimentation under controlled conditions. In other cases, scientists must rely on observations of natural phenomena rather than experiments (Figure 5).

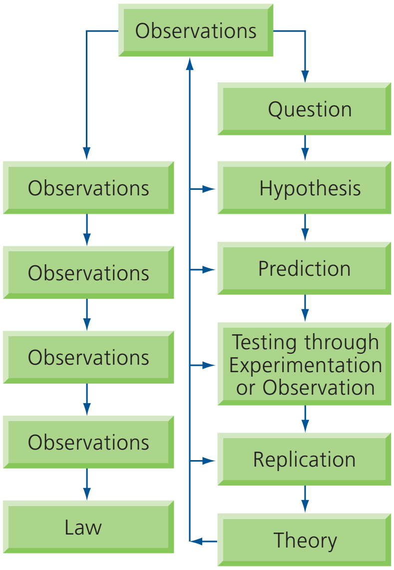


Figure 5 A scientific law is a description. A scientific theory is an explanation.

For example, when formulating the theory of plate tectonics, scientists could not control conditions. The movements of the plates take place very slowly, over long periods of time, and are impossible to control. Scientists therefore relied on direct observations and indirect evidence rather than observations through experimentation to support their hypotheses. This is frequently the case in geology and astronomy.

Science is progressive.

As already mentioned, a scientific theory is a current but tentative explanation—it is not a fact. Theories are never final and are always being examined and questioned. This means that a theory can change. Even though scientific knowledge is very reliable, it is also tentative, meaning that it can change with new evidence. A theory is valid only as long as every new piece of evidence supports it. This is one of the characteristics that distinguish scientific knowledge from other types of knowledge. A theory is accepted by the scientific community when all available empirical evidence supports it. A theory, however, can change when new scientific evidence suggests that a change is justified. This does not make the original theory any less valuable. Just because a theory is not 100 % correct does not automatically make it 100 % wrong. Even a theory that is not quite right provides a basis for further scientific investigations, which often results in an improved theory. For example, in the early 1600s, Galileo believed that the force of gravity depended only on the mass of an object. His theory did not properly explain the arrangement and movements of the planets in the solar system. So Newton and other scientists used Galileo's work as the basis for further investigations, which eventually led to modification of Galileo's theory to account for new observations. Even today, scientists continue to investigate gravity in an attempt to improve their current understanding. Science is progressive and can advance because scientists build on existing knowledge and are willing to change their thinking when new knowledge is available.

Misunderstandings about Science

Scientists attempt to base their conclusions on evidence and logic. But science does not always provide evidence, and it is not always logical. Scientists' interpretations of their observations can be influenced by personal, social, and cultural biases, and by assumptions. Science cannot provide an answer to every possible question. Some questions are unanswerable, and other questions, even though they may be unanswerable, are outside the realm of science.

Many people misunderstand what science is and what it can do. Some of the most common misunderstandings are briefly described here.

LEARNING TIP

Look for, and make use of, organizational patterns such as the headings. In your notebook, make a two-column table. As you read the section called "Misunderstandings about Science," write the name of the heading in the first column and the important information, in point form, in the second column.

Misunderstanding 1: All scientists follow the "scientific method."

Many people think there is one "scientific method" that all scientists follow while conducting their research. This method is usually described as a series of steps:

1. A scientist first asks a testable question and develops a hypothesis or possible answer.
2. Then the scientist designs and carries out an experiment, makes observations, and analyzes them.
3. Finally, the scientist draws a conclusion based on the evidence, and compares the conclusion with the hypothesis to determine whether the evidence supports the hypothesis.

Variations of this method are common in science, because different scientists approach problems differently. Furthermore, different scientific fields require different approaches, and scientists use different skills and technologies. If you asked 10 scientists to describe their method, you would likely get 10 different descriptions. There would be similarities, however. There is no doubt that science is methodical. It follows procedures that generally lead to a logical conclusion, which addresses the goal of the investigation. Nevertheless, there is no single scientific method that all scientists follow, step by step. The term **scientific method** refers to the general types of mental and physical activities that scientists use to create, refine, extend, and apply knowledge.

Misunderstanding 2: Science always involves experimentation.

It is commonly believed that experimentation is the process that leads to the creation of scientific knowledge. Experimentation, however, is not the only approach to conducting scientific investigations (Figure 6). Many scientific investigations are not experiments. Some sciences, such as astronomy and environmental science, do not lend themselves to experimentation because the conditions are impossible to control. Other types of scientific investigations are equally valid for producing valuable scientific knowledge. For example, most of the basic discoveries in astronomy have been based on extensive observations of naturally occurring phenomena.

Figure 6 Only some scientists conduct experiments in labs.

Misunderstanding 3: Scientific investigations provide proof.

While scientific investigations can result in scientific knowledge, they cannot provide proof. Empirical evidence can support or validate a law or theory, but can never prove a law or theory to be true. The only real proof that can be provided by science occurs when an idea is proven false or disproven. Consider the earlier example of the law of gravity. All the evidence collected worldwide, to date, leads scientists to conclude that objects always fall downward, or toward Earth. The discovery of a situation in which objects fall upward would prove that the law of gravity, as we know it, is not true.

Nevertheless, scientific laws are reliable. Because they are based on vast numbers of observations, it is very unlikely that evidence will be found to prove them false. In fact, scientific laws are seldom proven false. The law of gravity and other scientific laws are probably as close to the scientific "truth" as we may ever come.

Misunderstanding 4: Science is not very successful.

Science is often criticized because of what it has not done—for example, it has not found a cure for cancer or the common cold, or been able to predict the weather accurately. However, we consider the outstanding achievements of science in a relatively short period of time, science has been very successful in helping us understand the structure of the natural world and how it functions. For example, we know that matter is made of invisible atoms, that living things are made of cells that pass on information in the genetic material DNA, and that the continents are slowly moving across the surface of Earth. Scientific and technical knowledge has allowed us to land on the Moon, communicate at the speed of light, and perform open-heart surgery. Recent advances in the diagnosis and treatment of cancer are possible because scientists are learning more and more about what causes cancer and how different types of cancers behave. A cure for all cancers has not yet been found, but the knowledge that is being gathered may one day provide this cure. Science is not perfect, but it is one of the best ways we have to explore and find out about the natural world.

Misunderstanding 5: Science can provide the answer to all questions.

While science is one of the best ways to learn about the structures and functions of the natural world, it cannot answer moral, ethical, and social questions. Is abortion appropriate? Should euthanasia be used? Should we allow mining in environmentally sensitive areas? Which of 10 patients should receive a donor kidney? Questions such as these cannot be answered by science. Scientific knowledge can, however, provide information to help individuals and groups make important decisions on such issues.

LEARNING TIP

Skim the headings to get a general sense of the text. As you read each part, say in your own words what you have learned. This helps you understand and remember what you read.

What Isn't Science?

It is important to understand what science is all about. It is also important to be able to recognize what is not science. There are several forms of information that are presented intentionally or unintentionally as science. You have probably seen examples on television, in magazines, and especially on the Internet.

Non-Science

There are some areas of study that are presented as scientific when, in fact, they represent disciplines such as religion or history. For example, what is commonly referred to as "creation science," or creationism is really a belief system that uses scientific language to create the impression that it is valid, credible science. A belief system does not rely on evidence, falsification, and replication of experiments; it relies on belief and faith. Creationism is not science and cannot be studied using scientific methods.

History, also, is not science. History is a description or interpretation of past social events. While some of the investigative methods of history are similar to the methods used in science, history does not rely on empirical evidence and experimentation to explain the natural world.

Pseudoscience

Pseudoscience (*pseudo* means "false") is the practice of presenting claims so that they appear scientific, even though they have not been tested by scientific methods and are not supported by sound scientific evidence. For example, the alternative medical practice of magnetic healing (Figure 7) relies on the scientific concept of magnetic fields to give it credibility. Those who promote magnetic healing claim that magnetic fields promote the healing of bones and help blood circulation. The very little scientific testing of magnetic healing that has been done to date, however, has found no evidence that magnetic therapy has a healing effect. Most of the statements supporting magnetic therapy have been personal testimonials from people, including credible scientists, who claim that it helped them.

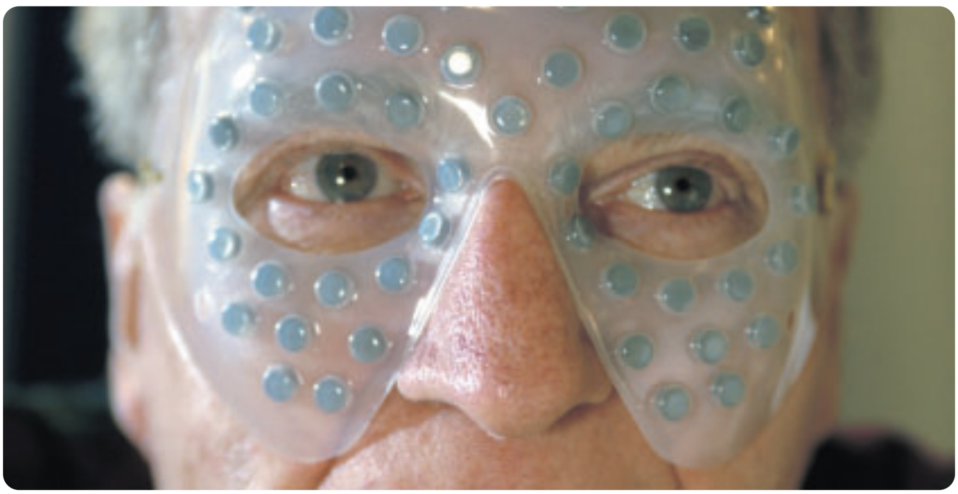


Figure 7 The magnetic field in most magnetic therapy pads isn't strong enough to penetrate the skin.

Faulty Science

Faulty science results when scientists do not follow the established standards and practices that science requires. Faulty science often results when scientific methods are affected by bias. **Bias** occurs when a scientist allows emotions or personal values to affect the scientific method and the analysis of data. Ideally, scientists should be totally objective or unbiased, but, because they are human, they often believe something to be true before they have a body of evidence to support it. Because of their beliefs and maybe a desire to be accepted by other scientists, they may design and conduct experiments that are guaranteed to obtain results that support their position.

Hoaxes and Frauds

Hoaxes and frauds are intentional attempts to mislead people with false claims or with information that is misrepresented. Scientific hoaxes and frauds prey upon people's lack of scientific knowledge.

Hoaxes may be carried out as a joke, but they may also be motivated by greed, desire for fame, or pressure to announce a significant scientific discovery. Most hoaxes are pranks, and the only harm done is the embarrassment of falling for the trick. Figure 8 is supposedly a picture of an iceberg floating in an ocean.

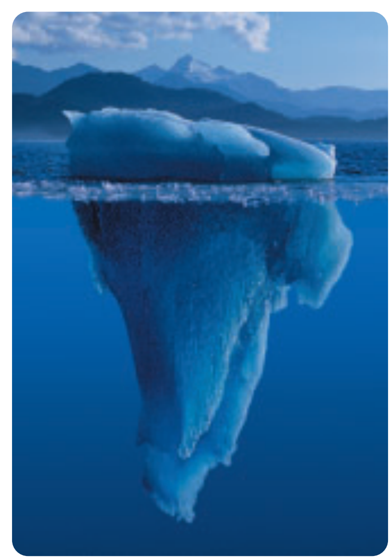


Figure 8 The World Wide Web is a constant source of touched-up photographs that are presented as real. Near the coast, light can penetrate through the ocean to a maximum depth of about 50 m and most of the visible light is absorbed in the first 10 m. Based on this information, how can you tell that the photograph is a fake?

A well-known case of scientific fraud (misrepresentation) used scientific terminology to trick the public. As an April Fool's joke, a newspaper correspondent wrote an article about dihydrogen monoxide, describing it as a chemical that is found in many toxic materials and is often used as a solvent. The article included a list of true statements about the chemical, but in a very misleading way. Many people who read the article did not recognize that dihydrogen monoxide is simply a scientific name for water, or H_2O. A city council introduced a resolution to ban the use of Styrofoam cups because dihydrogen monoxide was used in their production. The resolution was withdrawn and the council was spared further embarrassment when one of its members recalled from her high-school chemistry that dihydrogen monoxide is simply water.

Urban Legends

There are many interesting stories or claims that have been circulated so widely, and for so long, that they are generally accepted as true. Such stories, referred to as urban legends, are often presented as being scientific, and many people never question their truth. They have become a part of folklore, and no one knows where or why they began. GO

To learn more about what isn't science, go to
www.science.nelson.com GO

TRY THIS: *Urban Legend or Science?*

Skills Focus: recording, analyzing, communicating

There are literally thousands of urban legends, many of which have a connection to science. The problem with urban legends is that they are generally accepted as true, so it is important to question all claims until a satisfactory "scientific" explanation is available. The ultimate test, of course, is verification through replication. However, some of the claims are not easily verified, so we have to depend on reliable experts to help us make our judgement.

1. In a small group, discuss each of the following urban legends. Using your science knowledge, decide if it is totally false (F), totally true (T), partially true (PT), or if its truth is undetermined (U). Explain your answer.
   - A special chemical added to the water in a swimming pool will reveal the presence of urine.
   - Water that is boiled in a microwave oven can suddenly explode.
   - Credit cards that are placed in an eelskin wallet will become demagnetized, because of the leftover charges from the skin of the electric eels.
   - If you tap the side of a shaken can of pop you will prevent the contents from foaming over when you open the can.
   - The only human-made object on Earth that is visible from the Moon is the Great Wall of China.
   - More people are killed annually in bicycle accidents than in commercial airline crashes.
   - The average person swallows eight spiders per year.
   - Hair and fingernails continue to grow for a period of time after a person dies.
   - Your loved one's cremated remains can be turned into diamonds.
   - A penny placed on train tracks will derail a train.
   - A person who weighs 750 N at the equator would weigh about 5 N more at the North Pole.
   - Lemmings commit suicide by jumping off cliffs.
   - Spontaneous human combustion is real. People can suddenly burst into flames.
   - Fire walking is an example of the power of the mind over matter.
   - Turtles never die of old age.
   - A cockroach can survive for up to a month with its head cut off.
   - Sharks do not get cancer, so eating shark cartilage can prevent cancer in humans.

2. Use the Internet and other resources to determine the "scientific" explanation of these claims.

www.science.nelson.com GO

Science and Technology

Science and technology are very different activities, but we often hear about them together. This is because they are highly interrelated and often go hand in hand. Science is the study of the natural world. The main product of science is knowledge or understanding of natural phenomena. Observations of the natural world that lead to new knowledge are referred to as **discoveries**. Technology refers to the tools, instruments, devices, and processes developed through the application of scientific concepts. Technology responds to society's needs and wants. For example, different technologies help people travel; communicate; grow, process, and store foods; and find, extract, and process important chemicals, such as metals and fuels. Those who develop technologies through invention and innovation include technologists, technicians, and engineers. An **invention** is a new device or process that was developed to help people meet their needs or satisfy their desires. For example, radios, televisions, telephones, and computers were invented to improve communication (Figure 9). GO

Did You KNOW?

Canadian inventors have pioneered the development of communication technologies. Starting with Alexander Graham Bell's invention of the telephone in 1876, other Canadian communication inventions include radio voice transmission, the Walkie-Talkie, and the Blackberry.

If you want to learn more about Canadian inventions and discoveries, go to **www.science.nelson.com** GO

(a)

(b)

Figure 9 In the past, people used rotary phones (a) to communicate with each other. Now many people use wireless handheld devices (b) to communicate. What devices do you use to help you communicate?

Science and technology are closely related. Scientists use technologies in their research. Engineers and technologists use scientific principles when designing and developing new technologies. However, scientific discoveries often follow technological inventions. For example, the invention of glass lenses led to the development of light microscopes (Figure 10), which allowed scientists to see microscopic organisms and understand that certain micro-organisms (commonly called germs) cause diseases. The invention of glass lenses also led to the development of telescopes, which allowed astronomers to observe and learn more about our solar system and the universe. Sometimes, technological inventions follow scientific discoveries. For example, the television was invented after scientists had created theories to explain the structure of the atom and understood electrons, current electricity, and electromagnetism. The relationship between science and technology is mutually beneficial; scientific discoveries lead to technological advances, which lead to further scientific discoveries, and so on.

Figure 10 Glass lenses focus and magnify the image in a compound light microscope.

A good example of the relationship between science and technology is the development of the heart pacemaker. When the heart is working properly, a small nerve centre in the heart sends electrical signals that regulate the beating of the heart, and blood is pumped, delivering oxygen to every cell in the body. Some people have a defect in the heart which can result in irregular heartbeats, decreased blood flow, and a decrease in the amount of oxygen that reaches the cells. Knowing how a normal heart functions allowed technologists to develop the cardiac pacemaker (Figure 11), a device that corrects the irregular heartbeat by sending tiny electric shocks to the heart. The heart beats regularly and blood flow returns to normal.

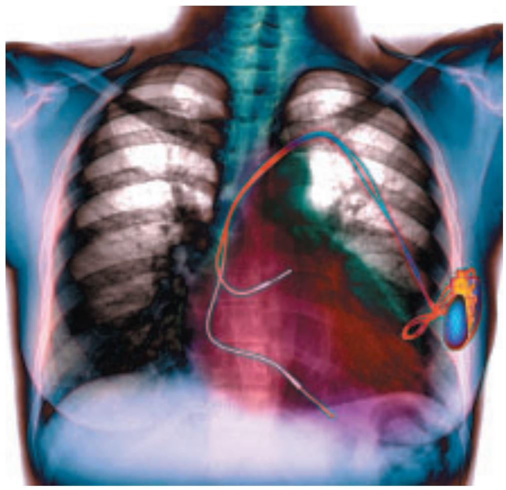


Figure 11 A coloured chest X-ray that shows a surgically-implanted heart pacemaker (blue/orange)

Ethical Behaviour in Science

Ethics is the study of what is right and wrong, and how this affects the way we behave as individuals or in a group. From early childhood, we have been taught right from wrong. Some of these teachings have been clearly defined as rules and laws that we all must obey. Other teachings aren't as clearly defined, but are just as significant in determining how we behave in all areas of life. For example, most cultures and all the major religions of the world promote a version of what is commonly known as the "golden rule"—Do unto others as you would have them do unto you. Between written and unwritten rules, most of us have a good sense of right and wrong.

As in other areas of everyday life, there are acceptable and unacceptable behaviours in science. Some of them have been alluded to earlier. For example, a scientist should act in an unbiased manner. We know, however, that because scientists are human, they are sometimes affected by their emotions and their values.

There is a set of general rules, or guiding principles, that all scientists should follow when conducting scientific research.

- *The principle of scientific honesty*: Do not commit scientific fraud. In other words, do not fabricate (make up), trim (cut or take out), destroy, or misrepresent data. Report all results accurately.

- *The principle of carefulness*: Make every effort to avoid careless errors or sloppiness in all aspects of scientific work. Think about the potential consequences of careless errors.
- *The principle of intellectual freedom*: Do not be afraid to pursue new ideas and criticize old ideas. Feel free to conduct research in an area that interests you.
- *The principle of openness*: Share data, results, methods, theories, equipment, and so on. Allow others to see your work, and welcome criticism.
- *The principle of credit*: Do not copy the work of other scientists. Give credit where credit is due, but do not give credit where it is not due.
- *The principle of public responsibility*: Report the results of scientific research to the public if it has important implications for the good of society, but after it has been validated and verified by other scientists.

TRY THIS: *Unethical Science*

Skills Focus: identifying, recording, communicating

Read each of the following scientific research scenarios:

1. A religious cult created a company whose main goal was to give life to the first human clone. On December 26, 2002, they announced that the first cloned human baby had been born. In May 2004, they announced that there were 23 pregnancies involving human clones, as well as 13 cloned babies already living. To date, the company has chosen not to provide the identities of these babies or any proof or independent confirmation of their births.
2. ABC Pharmaceuticals provided annual funding to a team of medical researchers to test a new drug developed for the treatment of arthritis. After a three-year study, the researchers submitted the results to the company, accurately reporting how the patients responded to the treatment. According to the terms of the contract, the researchers were required to report only on the effectiveness of the drug. Therefore, observations of potential side effects were not reported.
3. Two physicists were awarded the Nobel Prize in Physics for their work in space exploration. A third person, a graduate student who assisted in the work, was not identified or recognized in the report that was the basis for awarding the Nobel Prize.
4. Two scientists conducted research on nuclear fusion and believed that they had solved the world's energy crisis. Because of pressure from the university where they worked to publish their results, as well as the potential fame from making an important discovery, the scientists made a public announcement. Other scientists later tried unsuccessfully to duplicate the experiments.
5. A young biochemistry graduate was hired by a government-funded medical research company and was invited to present her proposal for research. After review of her proposal, the company directed her to discontinue her proposal and reassigned her to an existing research project. A senior researcher then assumed the research project that was proposed by the new employee.

A. For each scenario, identify the guiding principle(s) that have been or may have been violated. Briefly explain your answer.

B. Do you think that there may be circumstances when any of the guiding principles for scientists should not be followed? Give an example.

1.2 The Nature of Scientific Inquiry

Scientific inquiry is a general term that refers to the different processes and methods that scientists use to investigate the natural world. The word *inquiry* (from the root word "inquire") means "question" or "investigation." This is a very appropriate word since all scientific investigations explore a question.

Types of Scientific Inquiry

LEARNING TIP
Before you read Table 1, read the title. What is the purpose of the table? Pay attention to the headings because they tell you what is important in the different parts of the table.

All scientific investigations use similar processes to find answers to questions. In most cases, these processes attempt to identify relationships between variables. A **variable** is any condition that could change in an investigation. In some cases, the investigator can change or control the variables; in other cases the variables cannot be changed or controlled. The methods used in scientific inquiry depend, to a large degree, on the purpose of the inquiry and on the nature of the variables (Table 1).

Table 1 Examples of Different Types of Scientific Inquiry

Type of inquiry	Question	Design
Controlled experiment	What is the effect of acid rain on the growth of plants?	Three vinegar solutions, with different pH values, will be used to simulate acid rain. Distilled water (pH = 7) will be used as a standard for comparison. Four plants will be watered with these solutions from the time the seeds are placed in the soil. The independent variable will be the pH of the solutions. The dependent variable will be the growth of the plants. All other variables (light, nutrients, temperature, and time) will be controlled. The growth will be determined by measuring the height of the plants, as well as the total surface area of the leaves. The general appearance of the plant (e.g., colour) will also be considered.
Correlational study	Is there a statistical relationship between smoking and heart disease?	The most recent statistics from Statistics Canada will be used to determine the percentage of the general public who smoke. This information can be broken down by gender and age group. Anonymous medical records of an appropriate sample of individuals experiencing some form of heart disease will be used to determine the percentage of heart disease patients who smoke. This will be controlled for gender, age group, and life-style factors so that fair comparisons can be made. An analysis of the data will show any correlation between the two variables, smoking and heart disease.
Observational study	Do a greater percentage of the male population or the female population smoke?	The sample or survey method will be used to determine which gender of the population has the higher percentage of smokers. A representative sample of equal numbers of males and females will be interviewed and asked whether they smoke. The individuals will be randomly selected from the population to ensure that all ages, socioeconomic backgrounds, ethnic origins, and other characteristics are represented. The inquiry can be modified by asking the age range of the individuals to determine the percent of smokers in the different age groups.

If the purpose of an investigation is to determine the relationship between two variables—for example, the voltage and the current in an electric circuit—then you can carry out a **controlled experiment**. This means that you can control the variables. If the purpose of an investigation is to test a suspected relationship between two variables—for example, automobile speed and the number of highway deaths—a controlled experiment is not possible. (It is not appropriate to create crashes on the highway to see if higher speeds cause more deaths.) Instead, you can conduct a **correlational study**. If the purpose of an investigation is to describe and understand a natural phenomenon—for example, the rotation of the Moon around Earth or the rings of Saturn—neither a controlled experiment nor a correlational study is appropriate. The investigator must rely on extensive observations in order to describe the phenomenon. An **observational study** is used when the investigator is unable to, or does not wish to, control the variables. In both correlational and observational studies, it is difficult, if not impossible, to determine cause and effect.

Controlled Experiments

A controlled experiment is a test in which one variable is systematically changed to determine its effect (if any) on a second variable. An attempt is made to control all the other variables—that is, to hold them constant. This allows researchers to be reasonably confident that any outcomes were caused by the variable that was changed. The ability to control variables makes a controlled experiment different from other types of scientific inquiry. For example, you may observe that the maple trees in your area do not look very healthy: it is mid-summer, but the leaves are faded and small, and they have yellow spots on them. You ask yourself what is causing this problem with the leaves. You may suggest a number of possible answers to explain your observations. For example, you may think that insects are attacking the trees or a disease has been introduced. Since all the leaves on the trees are affected, you think that maybe acid rain is causing the problem. This is your hypothesis. A hypothesis is a possible explanation for your initial observations. From your hypothesis, you can make a prediction that can be tested in a controlled experiment. For example, if acid rain is causing the problem with the leaves of maple trees, then you predict that maple seedlings in a greenhouse will experience the same problem if they are sprayed with water of the same acidity as the acid rain (Figure 1).

Figure 1 A controlled experiment can help us understand the effects of acid rain on maple seedlings.

LEARNING TIP

Different methods can be used to help you understand new vocabulary. As you read the words in bold, focus on the examples. How do the examples help you understand the meanings of new terms?

In a controlled experiment, you attempt to identify all the different conditions (variables) that could affect the experiment. The variable that you, the investigator, change is called the **independent variable**. In a controlled experiment, you change only one variable. The variable that changes in response to the change in the independent variable is called the **dependent variable** because its value "depends" on the change in the independent variable. All the other possible causes of the result are kept constant and are known as **controlled variables**. By controlling all the other variables, you can be reasonably certain that the change in the independent variable caused any observed change in the dependent variable. In the maple tree example, the controlled variables (light, nutrients, and temperature) are kept constant, so you can be reasonably certain that the acid rain (the independent variable) caused a change in the health of the maple leaves (the dependent variable).

In a controlled experiment, it is important to include a control. A **control** is a setup that acts as a standard or reference with which the results from the experiment can be compared. A control group is necessary to enable the investigator to determine that the changes in the independent variable caused the changes in the dependent variable. In the maple tree example, trees that are sprayed with pure, non-acidic water act as the control because you suspect (assume) that pure water will not have a damaging effect on the leaves. If all the other variables are kept constant, then you can be reasonably certain that the acid rain damaged the leaves. 1A Investigation

1A Investigation

Get in the Swing: Controlling Variables

To perform this investigation, turn to page 30.

In this investigation, you will control variables to see what effect they have on a swinging pendulum.

Correlational Studies

In a correlational study, a scientist tries to determine whether one variable is affecting another without purposefully changing or controlling any of the variables. Instead, the variables are allowed to change naturally.

Correlation coefficients indicate the degree of similarity between two sets of data. Correlation coefficients range from −1 to +1. A **positive correlation** indicates a direct relationship—that is, an increase in one variable corresponds to an increase in the other variable (Figure 2). A **negative correlation** indicates an inverse relationship—an increase in one variable corresponds to a decrease in the other variable (Figure 3). A correlation of 0 indicates no relationship between two variables (Figure 4). Notice that the points are randomly distributed on the graph.

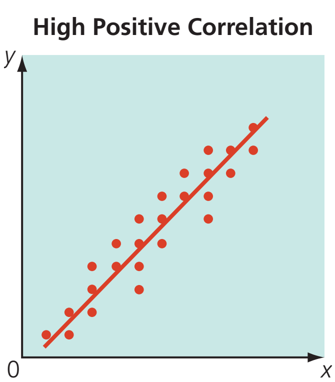


Figure 2 In a positive correlation, variable *y* increases as variable *x* increases.

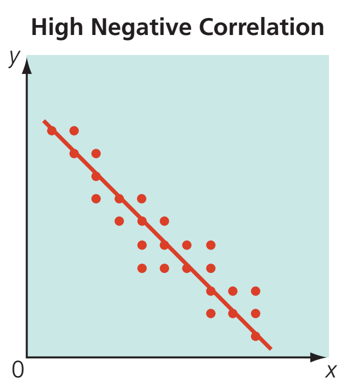


Figure 3 In a negative correlation, variable *y* decreases as variable *x* increases.

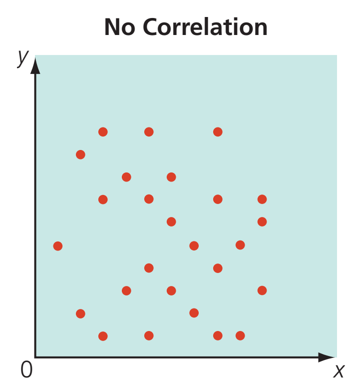


Figure 4 If there is no correlation, there is no pattern in the data.

As an example, consider the relationship between hours of study and exam grades (Table 2 and Figure 5). As you might expect, the correlation between hours of study and exam grades is positive and fairly high. In other words, as the amount of study time increases, so does the grade received. If the correlation between these two variables were +1, this relationship would be true in practically every case. A perfect correlation is unlikely, however, because not everyone who studies hard gets good grades. Two people could spend the same amount of time studying and get different grades. So the correlation between these two variables is somewhere between 0 and +1.

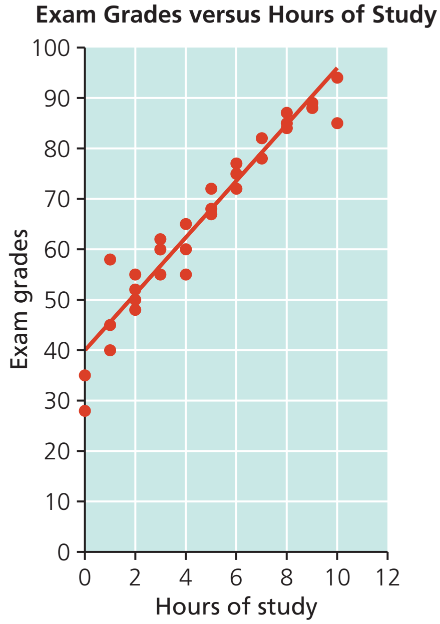


Figure 5 When the data in Table 2 are plotted on a graph, the graph shows a high positive correlation between hours of study and exam grades.

Table 2 Hours of study and exam grades for a class of 30 students.

Student	Hours of study	Exam grades
1	3	55
2	0	28
3	1	45
4	9	88
5	5	68
6	2	50
7	6	77
8	2	48
9	8	85
10	4	55
11	7	82
12	3	60
13	5	67
14	4	65
15	1	58
16	5	72
17	8	87
18	2	55
19	6	75
20	3	62
21	6	72
22	7	78
23	2	52
24	1	40
25	10	94
26	8	84
27	0	35
28	9	89
29	10	85
30	4	60

When you know that two variables are correlated (either positively or negatively) you can predict one variable based on your knowledge of the other. Generally, the higher the correlation (either positive or negative) the more probable it is that your prediction will be correct. In the example above, you could predict with some certainty that a person who spends a lot of time studying will get good grades.

Correlational studies require very large sample numbers and many replications to increase the validity of the results. Even then, it is often difficult to establish cause and effect. A correlation between two variables does not indicate that one variable causes an effect on the other. While any two variables can be compared, it is important for a scientist to determine whether a reasonable, plausible link is possible or whether a correlation would be simply a coincidence. As an extreme example, you could graph the annual earthquake tremors in British Columbia against the frequency of car accidents in Vancouver, and possibly discover that the years with the greatest number of earthquake tremors correspond to the years with the greatest number of car accidents. There is no apparent reason for these two variables to correlate, and it is highly unlikely that a reasonable link could be established

LEARNING TIP

When you are reading dense text, ask yourself, "Am I on track?" If you find yourself reading without understanding, stop and ask why. Is it because the ideas are difficult, because there are many difficult terms and phrases, or because there are simply too many ideas?

between the two. Any positive or negative correlation is likely due to coincidence. An example of a more reasonable pair of variables to investigate would be mothers drinking alcohol during pregnancy and health problems in infants. A high correlation between these two variables would probably indicate a cause-and-effect relationship because medical research has accumulated a significant amount of data related to the effects of alcohol on fetuses. Since a controlled experiment is not possible, for obvious reasons, the certainty that the consumption of alcohol causes illness in the developing fetus is lower than it could be.

Unfortunately, reports of statistical correlations can be deceiving. For example, a newspaper headline reported that a research study showed a high correlation between student height and reading ability. In other words, taller students are better readers. What the research failed to note (or the newspaper failed to report) is that the study had been done with students of different ages. If the study had been done with students of the same age, there would have likely been no correlation between height and reading ability. If taller students read better than shorter students, it was probably because they were older, not simply because they were taller.

Using correlational studies, investigators can do valid science without doing experiments. They can find relationships between two or more variables by using databases that other researchers have prepared or by making their own observations and measurements through fieldwork, interviews, and surveys.

Observational Studies

The role of careful, systematic observations is often overlooked as a source of scientific knowledge. Science often progresses without the testing of hypotheses or theories. In many cases, hypotheses are generated after the evidence is collected through observation.

Often the purpose of scientific inquiry is simply to study a natural phenomenon with the intention of gathering scientific information to answer a question. Observational studies involve observing a subject or phenomenon in a structured manner—in a way that doesn't interfere with or influence the subject or phenomenon. Observational studies, like all scientific investigations, start with observations that lead to a question, but they may not have a specific hypothesis or plausible explanation. If a hypothesis is not created before the study, it may be generated after many observations, and modified as new information is collected over time.

Sciences such as astronomy, paleontology, and ecology rely heavily on observations because controlled experiments or correlational studies are often difficult, if not impossible, to conduct. For example, the question "Where do monarch butterflies go during the Canadian winter?" can only be answered by systematic observation.

In an observational study, the hypothesis or plausible explanation may not be posed at the beginning of the study, but after considerable evidence has been gathered. For example, the hypothesis that eventually led to Charles Darwin's theory of natural selection was created only after Darwin had made extensive observations during his voyages aboard the *Beagle*.

Like correlational studies, observational studies are done when an investigator cannot control the variables. The reasons for the inability to control the variables include safety, time, distance, cost, and ethics. Think back to the question "Where do monarch butterflies go during the Canadian winter, and how do we know?" Obviously, a scientist could not follow an individual butterfly, or even a group of butterflies, for months at a time to observe directly where butterflies go and how they get there (Figure 6).

A common observational approach used by scientists in such circumstances is a technique known as the capture-recapture method. In the butterfly study, butterflies were captured and tagged (Figure 7). The number on each tag, the date, and the location were then recorded. The butterflies were released back onto the flowers from which they were gathered. When a tagged butterfly was recaptured, the tag number, date, and location were recorded again.

In addition to the tagging, many student volunteers participated in the scientific research by observing monarch butterflies and then submitting their observations to one of the many groups across North America that study monarch butterfly migration. These organizations made all the observations available through their websites and other resources. The observations collected and shared in this way showed the annual migration routes for monarch butterflies, from their summer habitat in the northern United States and southern Canada to their winter habitat in Mexico (Figure 8). GO

To learn more about monarch butterfly migration, go to
www.science.nelson.com GO

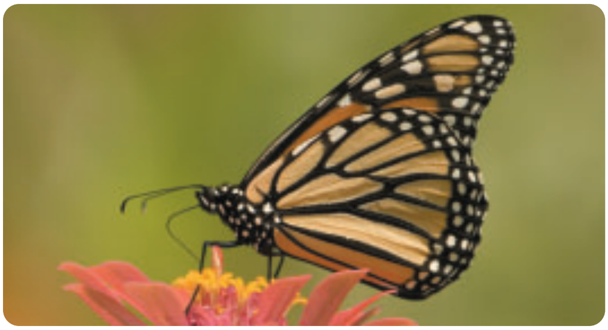


Figure 6 No other butterflies in the world migrate like the monarch butterflies in North America.

Figure 7 A small self-adhesive tag (9 mm in diameter) was placed on the underside of the hind wing. The tag position was close to the centre of gravity of the butterfly and did not appear to interfere with its flight or harm it.

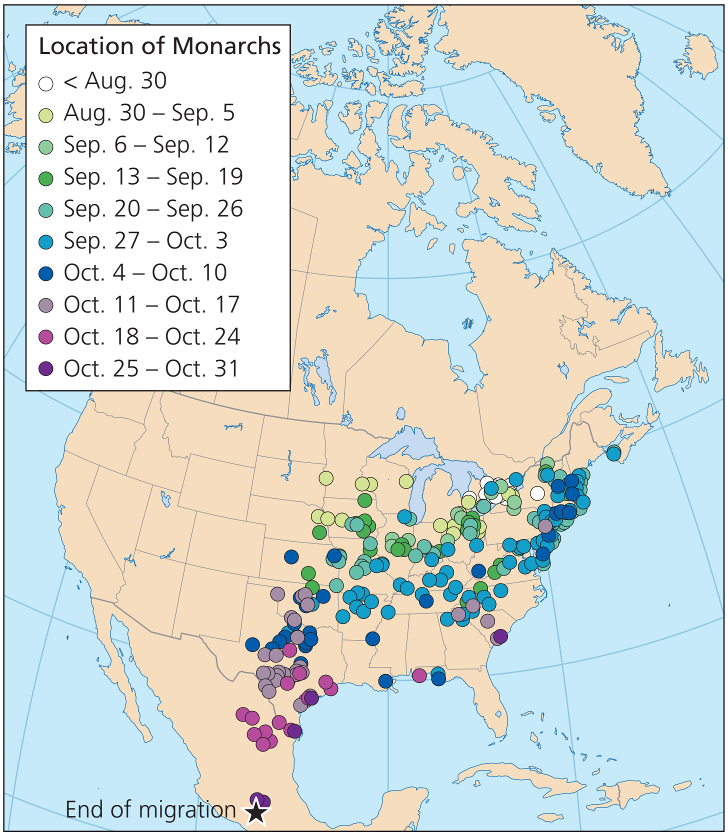


Figure 8 Data collected over time enabled scientists to map the migration route of monarch butterflies.

TRY THIS: *Completing the Cube*

Skills Focus: questioning, recording, observing, analyzing, evaluating, concluding

Scientists formulate hypotheses and theories by observing and analyzing evidence—using the scientific method. They draw conclusions based on the evidence. The more evidence that is available, the more confident they can be in their conclusions.

In this activity, you will analyze available evidence and draw a conclusion.

Materials: cube with numbers printed on its sides

1. Your teacher will place a cube on your table (Figure 9). You are not allowed to touch the cube!

Figure 9

2. In your group, discuss the cube and record any questions you have. What do you want to know about the cube?
3. Carefully observe the five visible sides of the cube, and record all your observations.
4. Based on your observations, draw a conclusion about what is on the bottom of the cube.

A. What evidence did you use to draw your conclusion?
B. How confident are you in your conclusion? Explain.
C. Is your conclusion a fact or a theory? Explain.
D. How is this activity like a scientific investigation?

LEARNING TIP
You can use a table to help you organize information from your reading. In preparation for reading pages 22 to 28, make a two-column table. In the first column, write the parts of a controlled experiment (see Figure 10 on page 23). In the second column, record important information in point-form notes. Include the terms in your notes.

The Controlled Experiment: An Everyday Example

Figure 10 on page 23 presents a flow chart that illustrates the general scientific method. While this flow chart shows a linear progression from Questioning to Communicating, there are normally many loops back through the process as scientific investigations proceed. At any point in the process, scientists can, and sometimes must, go back to an earlier step or back to the beginning to make revisions or improvements. Recall the definition of the scientific method on page 9.

Questioning

Scientific inquiry begins with observations. You, as a scientist, make an observation and ask questions such as "How?", "Why?", "What?", "Where?", and "When?" Asking a question is the actual starting point for your scientific research. You can apply the scientific method to an everyday problem. For example, you observe that the grass in a lawn is yellow, not as green as you would expect it to be. You pose a question: "Why is the lawn yellow rather than green?" If you are really interested in finding the answer to the question, you could approach it scientifically and follow a method that would hopefully lead you to the answer.

SAMPLE PROBLEM

Ask Appropriate Questions

Scientific discoveries always generate more questions. Suppose that a chemist has isolated a previously unknown compound from the bark of a yew tree. The chemist has determined the formula of the compound and its physical properties (for example, melting point, density, and reactivity). What questions might the scientist ask about the relationship between the compound and the yew tree, which could be the basis of further research?

Solution

The scientist could ask questions such as these:

- Is this compound found in all yew trees?
- If the compound is not found in all yew trees, then in which yew trees is it found? Is it only present in yew trees of a particular age, or size, or species? Is it only present in yew trees living in a particular climate, type of soil, or at a particular altitude?
- What function or role does the compound play in the yew tree?
- Is the compound produced by the yew tree? If so, where in the yew tree is the compound produced? How is the compound produced by the yew tree?
- At what point in the life of a yew tree is the compound first produced?
- At what point in the evolution of the yew tree was the compound first produced? That is, has the compound always been present in yew trees?
- Is the compound present in any other types of trees, other than the yew tree?

Practice

The Hubble Space Telescope has sent pictures of space back to Earth. In one of the pictures, astronomers detected a new object, which was not visible in previous pictures of this region of space. Write five questions that could guide the astronomers' further research.

Hypothesizing

General questions can be restated or you can pose follow-up questions. "Does the lawn need water?"; "Does the lawn need sunshine?"; "Does the lawn need fertilizer?" For argument's sake, let us assume that you are satisfied that the lawn does not need water or sunshine. So you are left with the question "Does the lawn need fertilizer?" Now the observation and the question can be restated as a hypothesis. A hypothesis is a possible explanation that accounts for the observations you have made. The most important characteristic of a hypothesis is that it must be testable. In other words, you must be able to design a procedure you can use to collect evidence that will either support your hypothesis or lead you to reject it as an explanation of your observations. You must also be able to identify two variables in your hypothesis. Thus, a hypothesis suggests a test of the relationship between two variables: an independent variable and a dependent variable. The hypothesis serves two functions: it suggests an explanation and it guides your investigation in search of support for your suggested explanation or a better explanation. Your hypothesis (possible explanation) then, is that the grass in your lawn is yellow (dependent variable) because it needs fertilizer (independent variable).

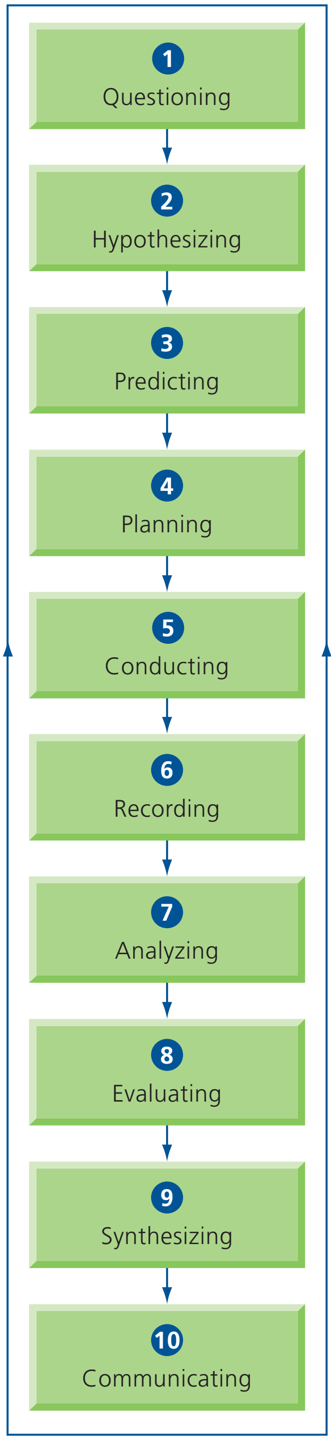


Figure 10 The scientific method is an effective way of answering questions about the natural world.

TRY THIS: *Identifying and Creating Hypotheses*

Skills Focus: analyzing, evaluating, hypothesizing, communicating

1. Identify each of the following statements as an observation, a fact, a hypothesis, or a theory.
- (a) On June 30, 1908, in Tunguska, Siberia, an explosion equivalent to about 15 million tonnes of TNT occurred.
- (b) The explosion in Tunguska, Siberia, on June 30, 1908, was caused by the collision of a black hole with Earth.
- (c) The explosion in Tunguska, Siberia, on June 30, 1908, was caused by a natural, extraterrestrial phenomenon and not by a human activity.
- (d) On June 30, 1908, a bright, fast-moving object was seen in the sky over Tunguska, Siberia.
- (e) The explosion in Tunguska, Siberia, on June 30, 1908, was caused by the collision of a comet with Earth.

2. Read each of the following statements, and indicate whether it is an appropriate scientific hypothesis. For each statement that you consider to be an appropriate scientific hypothesis, identify the independent and dependent variables.
- (a) Fertilizer affects how big a plant will grow.
- (b) If you buy expensive batteries, they will last longer.
- (c) There are other inhabited planets in the universe.
- (d) The voltage in a circuit determines how fast an electric motor will turn.
- (e) Hamsters are colour-blind.
- (f) Chocolate may cause pimples.
- (g) High temperatures cause children to misbehave.
- (h) Our universe is surrounded by another, larger universe, with which we can have absolutely no contact.
- (i) Temperature will affect the growth of crystals.
- (j) If fermentation rate is related to temperature, then increasing the temperature will increase gas production.

3. For each of the following questions, write a hypothesis that could be tested in an experiment.
- (a) How does sewage in a river affect the level of pollution in the river?
- (b) What is the relationship between the number of hours of light and the number of eggs that chickens will lay?
- (c) How does light affect the reproduction of mould on bread?
- (d) How does music affect the growth of plants?
- (e) How much acid is in soft drinks?
- (f) Which brand of paper towels absorbs the most water?

Predicting

A hypothesis enables you to make a prediction that can be tested. A hypothesis and a prediction go hand in hand. A hypothesis is an explanation of *why* something happens—the grass is yellow because it needs fertilizer. A prediction is a statement of *what* you think will happen—if I add fertilizer to the lawn, then the grass will turn green again. Thus, your prediction is based on the possible explanation offered by your hypothesis.

Your prediction can now be tested to determine if your hypothesis is an acceptable explanation.

Planning

Your next step is to plan an experiment to test your prediction. You need to think of all the steps in the procedure you will use. The design is the procedure, in which you plan to change one variable (the independent variable), measure the effect on another variable (the dependent variable), and, if possible, keep all other variables constant (controlled variables). In your lawn problem, you will add fertilizer to the lawn (the independent variable), observe its effect on the colour of the grass (the dependent variable), and try to keep all other variables (such as water and sunshine) constant.

If you want to approach your problem scientifically, there is another important consideration. Since you will be conducting a controlled experiment, you must have some way of knowing for sure that any change in the dependent variable (colour of the grass) was caused by the independent variable (fertilizer). Otherwise, if the grass turned green, you could never be certain that this was caused by the fertilizer. You need a control.

To have a control, you could split the lawn into two parts: one part gets the fertilizer (experimental treatment) and the other part does not (control). Everything else remains the same. The part that does not receive the fertilizer treatment acts as a control or standard that you can compare with the experimental setup. If the grass in the experimental half turns green and the grass in the control half remains yellow, you can be fairly confident that the fertilizer was the cause. Your prediction and your hypothesis would be supported.

Another consideration in the planning stage is identifying the materials and equipment that you will need to perform your experiment. For the lawn experiment, the list is fairly short: wooden stakes and string to divide the lawn in half, lawn fertilizer, fertilizer spreader, camera, paper, and pencil.

Always keep safety in mind during your planning. Do any of the materials or procedures pose a risk to you or others? For example, it might be wise to wear a mask while you are spreading the fertilizer on the lawn. It might also be wise to post a sign, advising others that fertilizer has been applied.

Scientific investigations require careful observations. You need to think carefully about what you are going to measure or observe and how you are going to record your observations. If possible, create tables to record your observations, especially when the observations involve measurements.

Conducting

After you have planned an experiment, you put your plan into action—you conduct the experiment. It is important to follow the procedure you developed during the planning stage. As you carry out the experiment, you may find it necessary to modify the procedure. You should record any modifications to the procedure in case you or someone else wants to repeat the experiment.

In your lawn experiment, you apply the fertilizer to half of the lawn, keep all the other variables constant, and make observations at regular intervals for a reasonable period of time.

Recording

As you carry out an experiment, you need to record your observations at regular intervals. Often, you will have to make quantitative (numerical) and qualitative (non-numerical) observations.

LEARNING TIP

Check your understanding of the terms qualitative and quantitative by explaining the differences to a partner.

An observation is information that you get through your senses. You observe that a rose is red and has a sweet scent, or you observe that the grass on a lawn is yellow. When people describe the qualities of objects and events, without any reference to a measurement, the observations are said to be **qualitative observations**. Common qualitative observations include the state of matter (solid, liquid, or gas), colour, and odour. These qualities cannot be measured directly but must be described in words. As you record the results of your experiments, be sure to include your qualitative observations.

Qualitative observations can be recorded using words or pictures. A camera would be an appropriate tool for recording qualitative observations. Sometimes, however, it is more appropriate to draw or sketch these observations.

Observations that are based on measurements or counting are **quantitative observations**, since they deal with quantities of things. The length of a rose's stem, the number of petals, and the number of leaves are quantitative observations.

For your lawn experiment, you will have to make qualitative observations, and photographs would be an appropriate way to record these observations. Simply take photographs of the experimental and control parts of the lawn at regular intervals during the experiment. Ensure that the photographs are labelled appropriately, and write notes to accompany each photograph.

Analyzing

While tables are useful for organizing your observations, they are usually not the final product of an investigation. Looking at your table and analyzing, or carefully studying, your qualitative and quantitative observations can usually give you a lot of information. As well, you can plot graphs to make better sense of your quantitative observations. Graphs make it easier to see patterns in your observations.

Analyzing your observations will also help you identify any errors in your measurements. Any measurement that is clearly very different from the others should be carefully checked. If the very different measurement is found to be caused by an error in measurement, then it should not be used in your analysis.

Arrange the pictures and accompanying notes on the experimental and control areas in sequence. This will provide a visual and written record of any changes that took place.

The goal of carrying out an investigation is to answer the question that you asked at the beginning. When you create a hypothesis or make a prediction, you are suggesting an answer to the question. This suggested answer is based only on the information that was available to you before starting the investigation. Analyzing the observations you recorded during the investigation may provide the evidence you need to answer the question with more certainty.

If the evidence gathered confirms the prediction, you can have more confidence that your hypothesis is acceptable. Remember, though, that it does not prove that your hypothesis is true. If the evidence gathered does not support your prediction, then you would likely think that your hypothesis is not an acceptable explanation. Don't worry if your hypothesis is not supported—scientists usually need to revise and repeat experiments many times. Remember that science is a repetitive process.

Learning that your hypothesis is not supported is just as valuable as learning that it is supported. For example, assuming you are satisfied that the design of your lawn experiment was appropriate, you would be more certain that it was not the lack of fertilizer that caused the grass to be yellow. You have eliminated one variable as a possible cause of your observations, and you now need a new or revised hypothesis.

Evaluating

It is always important to reflect on events in order to learn from them. This is one aspect of science that is sometimes neglected. You need to think about and evaluate two parts of the investigation: the design and procedure you followed, and the observations you made.

Once you have been through a scientific inquiry, you need to step back and think about what you did and how you did it. What went well? What were the challenges? What would you do differently if you were to go through the process again?

When reflecting on a scientific inquiry, you must judge how good the evidence is in order to decide whether they support your hypothesis or prediction. You need to identify the types and sources of errors that may have been made while the observations were being collected. Any sources of error should be identified in the conclusion, or discussion of your results, and should be used as the basis for improving the process the next time.

For example, when reflecting on your lawn experiment, you should think about several aspects of the process:

- Were there any flaws in the design? Were two sections adequate? Should you have divided the lawn into four, or six, or ten sections, and then selected half of the sections at random to receive the fertilizer treatment? Are you satisfied that all other variables (such as water and sunshine) were kept constant in all sections of the lawn?
- You should evaluate the observations you made. Did your observations (for example, your photographs and notes) accurately reflect the changes that occurred in the lawn during the investigation period? Was the evidence sufficient and convincing? Did it allow you to decide whether it supports the hypothesis or prediction?
- Were the materials and equipment of suitable quality to do the experiment? Did the fertilizer spreader spread the fertilizer evenly over the experimental area? Did the camera capture good quality photographs?
- Did you or your partners have the skills needed to use the equipment? Did you use the camera properly so that it captured good quality pictures?

Synthesizing

In the final step, you focus on two tasks: determining what you can do with the information obtained from the investigation, and deciding where the investigation might lead.

First you ask, "So what? Now that I've learned something, or gained some new knowledge, what do I do with it? How could the information obtained in this investigation be used?" You should think about if, and how, the new information can be applied to solve real-life problems. Did you learn something about lawn care that you could use in the future? Could you help any friends with their lawn problems?

Work in science seldom ends with a single experiment. Sometimes other investigators repeat the experiment to see if the evidence is the same. More often, the analysis and evaluation of one experiment raises more questions that can be used to create new, related experiments. The following guidelines may help you suggest further experiments:

- Review the evaluation of the evidence. You may suggest repeating the experiment using a new or improved design, better equipment, a revised procedure, or better skills.
- Review the design of the experiment, and focus on the variables. Can a controlled variable become the independent variable in another experiment? Can the dependent variable be changed or measured in a different way?
- Review your hypothesis or prediction. Look for new ways to test it. If the evidence did not support your hypothesis, suggest a new hypothesis that would lead to new experiments.

Communicating

One of the important characteristics of scientific inquiry is that scientists share their information with the scientific community. Clear and accurate communication is essential for sharing information.

TRY THIS: Getting Your Message Across

Skills Focus: recording, conducting, analyzing

Accurate communication is as important in science as it is in everyday life. In this activity, you will work with a partner to develop your communication skills.

1. You and your partner should each choose a common everyday task, such as tying your shoes (or tying a special knot), making a toasted cheese sandwich, going from your school to a sports store across the city, installing a piece of software on your computer, or copying music from your computer to your MP3 player.
2. Write a set of detailed instructions that should enable someone else to complete the task.
3. Exchange tasks with your partner, and read each other's instructions.
4. The test of successful communication is whether your partner can complete the task without asking any questions. If necessary, complete the task at home and report to your partner the following day.

A. Why is clear, accurate communication difficult?

B. What skills do you need in order to communicate clearly? What do you need to do to develop these skills?

C. What strategy did you use to make your communication as clear as possible?

D. What problems did your partner have with your instructions? What could you do in the future to avoid such problems?

The most common method for communicating with others about an investigation is by writing a lab report. A lab report describes the design of the experiment, how it was carried out, the results obtained, an analysis of these results, and any conclusions that can be drawn. A lab report should be written in detail and with clarity so that another person could use it as a set of instructions or pattern to conduct the same investigation.

A lab report is prepared after an investigation is completed. To ensure that you can accurately describe the investigation, it is important to keep thorough and accurate records as you carry out the investigation. Refer to the Skills Handbook, page 556, Writing A Lab Report.

TRY THIS: *Solving the Puzzle*

Skills Focus: conducting, observing, analyzing, communicating, hypothesizing

Scientists formulate hypotheses and theories by observing and analyzing evidence—using the scientific method. In this activity, you will assemble evidence over time and communicate with fellow scientists, or teams of scientists, to experience the nature of science and understand its challenges.

Materials: envelope containing pieces of a jigsaw puzzle

1. In your group, examine and try to assemble the pieces of a puzzle.
2. Propose a brief description of the complete puzzle picture based on the pieces of puzzle you have. Share your description with the class.
3. On your teacher's direction, join with another group and share your proposed description of the complete picture. Try to combine your puzzle pieces with the other group's puzzle pieces.
4. Revise your proposed description of the complete picture. Your revised description should also be shared with the class.
5. Keep combining your puzzle pieces with other groups until you have as complete a picture as possible. After each combination discuss and revise your description. Write a final description of the picture after all pieces of the puzzle are assembled.

A. Compare the process you followed in this activity with a scientific inquiry. Use the following terms in your comparison: *observation*, *scientific method*, *hypothesis*, *communication*, *evidence*, and *theory.*

B. What type of scientific inquiry is represented here? Explain.

C. What is the significance of having an incomplete puzzle?

D. What are some of the challenges you might expect during a scientific inquiry?

1A Investigation

Get in the Swing: Controlling Variables

In a controlled experiment, investigators investigate one independent variable at a time to determine its effect on the dependent variable. Other variables are kept constant while each variable is tested.

Question

What factor(s) determine the swing rate of a pendulum?

Prediction

In your group, brainstorm a list of factors that might affect the swing rate of a pendulum. Write a prediction about what factor(s) you think will affect the swing rate and how these factor(s) might affect the swing rate.

Hypothesis

Formulate a hypothesis to explain your prediction.

Experimental Design

In this investigation, you will identify and test the factors that might affect the swing rate of a pendulum. You will test each factor (variable) separately, while controlling the other factors.

Materials

- string
- paper clips
- metal washers
- stopwatch (or other timing device)
- protractor
- retort stand and clamp

Procedure

Part 1: Practice

1. Make a pendulum by tying one end of a piece of string to a paper clip (twisted to form a hook) and the other end to the clamp. Place two washers on the hook (Figure 1).

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
● Hypothesizing	● Recording	○ Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

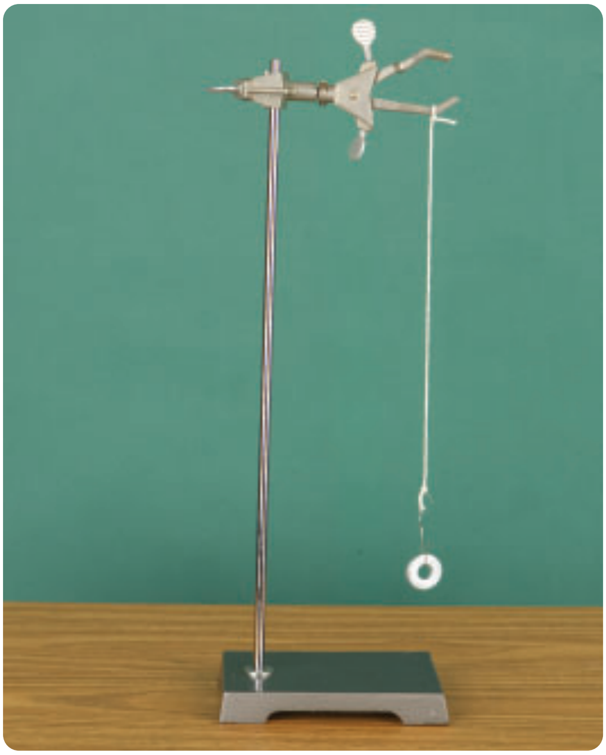


Figure 1 Step 1

2. Pull the washers to one side, and let the pendulum swing gently.
3. Determine the swing rate per minute. To determine the swing rate, count the number of swings your pendulum makes in 15 s and multiply by 4. (One swing is when the pendulum swings out and back to the starting point. Count to the nearest half swing.)
4. Record your result and compare it with the results of other students in the class.

Part 2: Does Mass Affect the Swing Rate of a Pendulum?

5. Make two pendulums, each 30 cm in length. Use one washer on one pendulum and two washers on the other pendulum.

6. Make and record a prediction about how mass affects the swing rate of a pendulum.
7. Pull the first pendulum to a 45° angle, and release it (Figure 2). Determine and record the swing rate of the pendulum.

Figure 2 Step 7

8. Repeat step 7 with the second pendulum.

Part 3: Does Arc Length Affect the Swing Rate of a Pendulum?

9. Use the pendulum with two washers from Part 2. Make and record a prediction about how the arc length (the angle that the pendulum is pulled to the side) will affect the swing rate of the pendulum.
10. Pull the pendulum to a 45° angle, and release it. Determine and record the swing rate.
11. Repeat step 10, but this time pull the pendulum to a 90° angle (horizontal). Determine and record the swing rate.

Part 4: Does Length Affect the Swing Rate of a Pendulum?

12. You will use the pendulum from Part 3. Make another pendulum, 45 cm in length, with two washers.
13. Make and record a prediction about how length will affect the swing rate of a pendulum.
14. Determine and record the swing rates of the two pendulums. Be sure to keep the other variables (arc length and mass) constant.

Part 5: Class Results

15. Make another pendulum, using a length of string determined by your teacher. Your class will have a variety of lengths from 20 cm to 50 cm.
16. Determine and record the swing rate of your pendulum. Your teacher will provide a table for recording the class results.

Analysis

(a) Were your predictions accurate in Parts 2, 3, and 4? Explain.

(b) Why was it necessary to do this Investigation in four parts?

(c) What were the independent and dependent variables in Part 2? What variables were controlled?

(d) What were the independent and dependent variables in Part 3? What variables were controlled?

(e) What were the independent and dependent variables in Part 4? What variables were controlled?

(f) Plot the results from Part 5 on a graph. Place the pendulum length on the x-axis and the swing rate on the y-axis. Describe the trend shown by your graph.

(g) What variable(s) affect the swing rate of a pendulum? What variable(s) do not?

Evaluation

(h) Did all the points on the graph fall exactly on a straight line? Explain.

(i) What were some possible sources of error in this Investigation?

UNIT

A

REPRODUCTION

Unit Preview

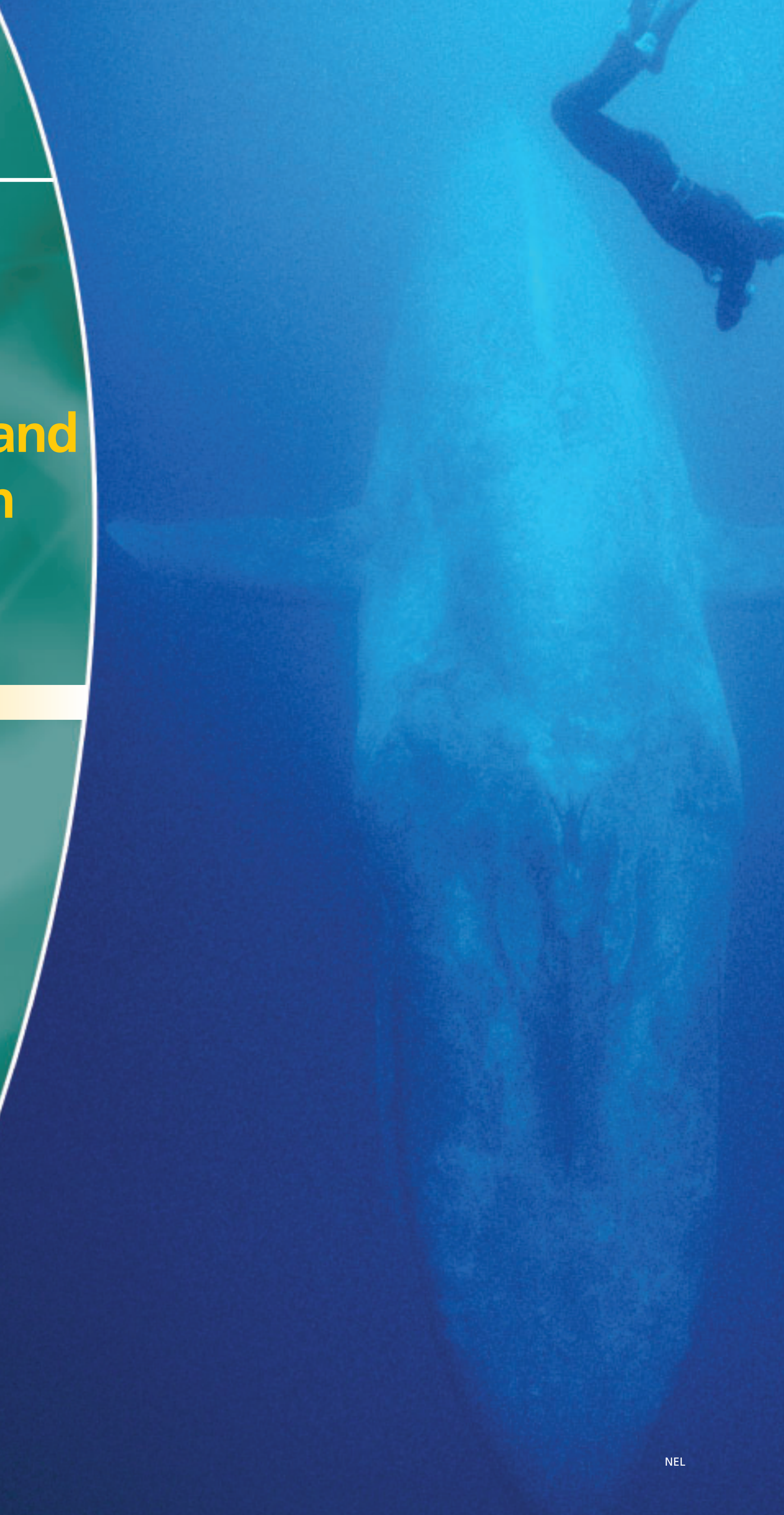
Your body is made of many trillions of cells that came from a single fertilized egg. How did this single cell produce all of these cells? How do cells grow, reproduce, and specialize to form tissues and organs? How do entire organisms reproduce?

The squid pictured here are reproducing and laying eggs. Each of these egg cases contains a single fertilized egg. What will happen to the eggs? How will the eggs change into adult squid? The fascinating processes of cell division and reproduction are controlled at the cellular level by the contents of the nucleus of each cell.

In this unit, you will learn about the processes of cell division and reproduction. You will also learn about the various methods that different organisms, including humans, use to reproduce and develop. Finally, you will learn about technologies that manipulate these processes for agricultural and medical purposes.

CHAPTER 2

Cell Growth and Reproduction



KEY IDEAS

- The functions of cell division are growth, repair, and reproduction.
- DNA in the nucleus plays a key role in normal cell functions and in cell division.
- The cell cycle includes the normal cell functions and cell division.
- Mutations in a cell's DNA can cause diseases, including cancer.
- Some organisms reproduce asexually through cell division.

Chapter Preview

Think about how you and your friends have changed over the last year. Have you or one of your friends had a growth spurt? Why hasn't everyone grown the same amount? Every living thing grows, but not at the same rate. What causes these differences in growth? Why don't you grow to the same size as the blue whale? Is there something that determines the characteristics of all organisms, including growth rates? Cell division is necessary for growth. Just like you and your friends, the blue whale and other giants on Earth, such as the Douglas fir tree, are made of cells. How old are their cells? Cell division replaces old cells. Do animal cells divide the same way that plant cells do? What directs a muscle cell to contract or a leaf cell to perform photosynthesis? Why are some types of cells more abundant than other types?

In this chapter, you will learn about deoxyribonucleic acid (DNA), the molecule that carries the instructions for cell division and determines the characteristics of cells, individuals, and species. You will also learn about the cellular basis of growth and repair. Organisms increase in size through cell division. Dead and damaged cells are replaced by cell division. Some organisms even reproduce entirely using cell division.

TRY THIS: Replacing Cells

Skills Focus: predicting, observing, measuring, recording

Materials: permanent marker

You lose millions of skin cells through daily wear and tear. These cells are constantly replaced.

1. Use the permanent marker to place a dot of ink on the back of your hand and on the palm of the same hand. The skin cells that absorb the ink will be permanently stained, since the ink is not water-soluble.
2. Predict which stain—the stain on your palm or the stain on the back of your hand—will disappear first. Record your prediction.
3. Observe the stained areas daily. Record your observations.

A. Explain your observations.

Do not use permanent markers if you may be allergic to the ink. Use food colouring instead. Use caution with the marker and food colouring, as they can stain clothing.

2.1 The Importance of Cell Division

Figure 1 Like all living things, humans grow throughout most of their life. Cell division allows living things to grow larger.

Have you ever peeled away the dead skin from a sunburn or a blister? What would you look like if every cut or scratch on your skin remained? Imagine the condition of your skin if dead skin cells were not replaced by new cells. Recall from Grade 8 science that new cells arise from pre-existing cells. Damaged cells are replaced through the process of cell division. Throughout your life, your body will undergo cell division to replace damaged or dead cells. Cell division slows down as you age, but it never entirely stops until you die.

Functions of Cell Division

There are three main functions of cell division: growth, repair, and reproduction.

Growth

All living things are composed of one or more cells. All organisms begin life as a single cell. Multicellular organisms, such as dogwood trees and humans, undergo cell division to increase their size. Why don't cells simply increase in size to grow? Recall from Grade 8 science that there are limits to the size of a cell. As a cell grows, the volume of the cytoplasm increases at a greater rate than the surface area of the cell. Once a cell grows beyond a certain size, it cannot function efficiently. It has to divide into two smaller cells that will perform the same functions. Thus, to increase in size (grow), a multicellular organism has to use cell division. In a multicellular organism, after the body has a certain number of cells, the cells begin to specialize and form tissues and organs (Figure 1).

Repair

Multicellular organisms repair damaged cells by cell division. You do not go through life with the same cells you started with at birth. Old and dead cells are replaced every second as millions of your approximately 100 trillion cells are damaged through normal body activities. This replacement of cells also occurs in other multicellular organisms. Look at a tree where a branch has been cut off. The inner cells of the bark divide to produce new bark tissue, which covers and protects the damaged cells where the branch was cut off (Figure 2).

(a) (b)

Figure 2 Both animals (a) and plants (b) use cell division to grow new cells over a cut. Where else would plants grow new cells to replace damaged cells?

Reproduction

Unicellular organisms, such as a paramecium, use cell division to reproduce (Figure 3). A single-celled bacterium uses cell division to form two identical bacteria. These new cells contain the same structures and carry out the same functions as the parent cell. Some multicellular organisms, such as a mushroom, also reproduce by cell division. You will learn more about cell division and reproduction in Section 2.6.

Did You KNOW?

Cell Lifespan

Human red blood cells live for approximately four months, whereas white blood cells live anywhere from less than one day to 10 years.

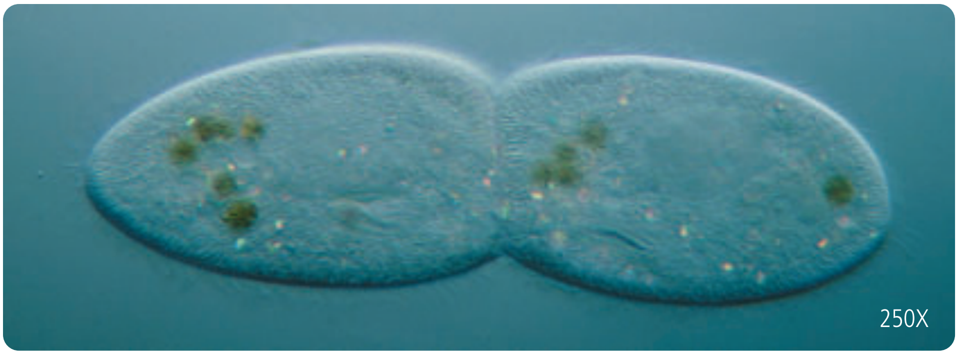


Figure 3 This single-celled paramecium is reproducing itself by cell division.

The process of cell division raises many questions. Why do some cells reproduce at different rates at different times? Skin cells can reproduce quickly to form calluses on your hands after a few hours of raking leaves or paddling a canoe. Why do fertilized eggs and bone marrow cells divide quickly whereas red blood cells are unable to divide at all? Why do cancer cells divide out of control? A great deal has been discovered through advances in technology, but there is much more to learn.

TRY THIS: *From One Cell to Trillions*

Skills Focus: recording, analyzing, predicting

Materials: calculator

The human body contains trillions of cells. They all came from a single cell. In this activity, you will investigate the number of cell divisions needed to form a human body.

Table 1

Number of divisions	Number of cells
0	1
1	2
2	4
3	

1. Copy Table 1 into your notebook, and complete it to help you answer the questions.
2. Calculate the number of cells after three, four, and five cell divisions.

A. How does the number of cells that are produced relate to the number of cell divisions that occur?

B. How many cells would there be after 25 cell divisions?

C. Make a prediction: How many cell divisions are needed to produce more than a trillion cells?

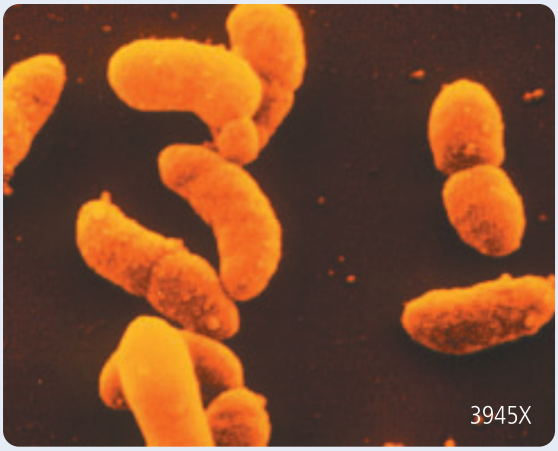
2.1 CHECK YOUR Understanding

1. Give three reasons why cells divide.
2. Explain how cell division is responsible for growth.
3. Why might scientists want to figure out a way to promote cell division in mature nerve cells?
4. Why do skin cells reproduce faster than other types of cells?
5. Give a location, other than human skin, where cells might reproduce quickly.
6. What evidence is there that all cells in your body do not reproduce at the same rate?
7. Examine the photographs in Figure 5. What function of cell division is shown in each photograph?

(a)

(b)

(c)



(d)

Figure 5

8. Doctors once transfused blood from young people into elderly people, believing that the younger blood would provide the elderly people with more energy. Do elderly people actually have older blood? Explain your answer.
9. Why do you think skin cells divide faster than muscle cells?
10. Do all cells undergo cell division? Give an example of cells that do not.
11. Explain why cells can only grow to a limited size.
12. Do larger organisms have larger cells? Explain.
13. List two organisms that use cell division to reproduce.
14. A colony of bacteria has 12 cells. Assuming that each cell divides and no cells die, how many cells would there be after six divisions?

2.2 Cell Structures Involved in Cell Division

Recall, from Grade 8 science, that cells are either eukaryotic (have a nucleus surrounded by a membrane) or prokaryotic (have no nucleus). Plants, animals, fungi, and protists have eukaryotic cells, and bacteria have prokaryotic cells. Both types of cells undergo cell division. In this section, you will focus on plant and animal cells. Although all the cell structures in animal cells (Figure 1(b)) and plant cells (Figure 2) are reproduced during cell division, some structures play a more active role than others. Before you look at the process of cell division, you need to look at the cell structures that have a role in cell division.

LEARNING TIP

Stop and think. As you look at each of the diagrams in this section, ask yourself, "What is the purpose of this diagram? How is it connected to other information on the page? How do the words in bold type help me interpret it?"

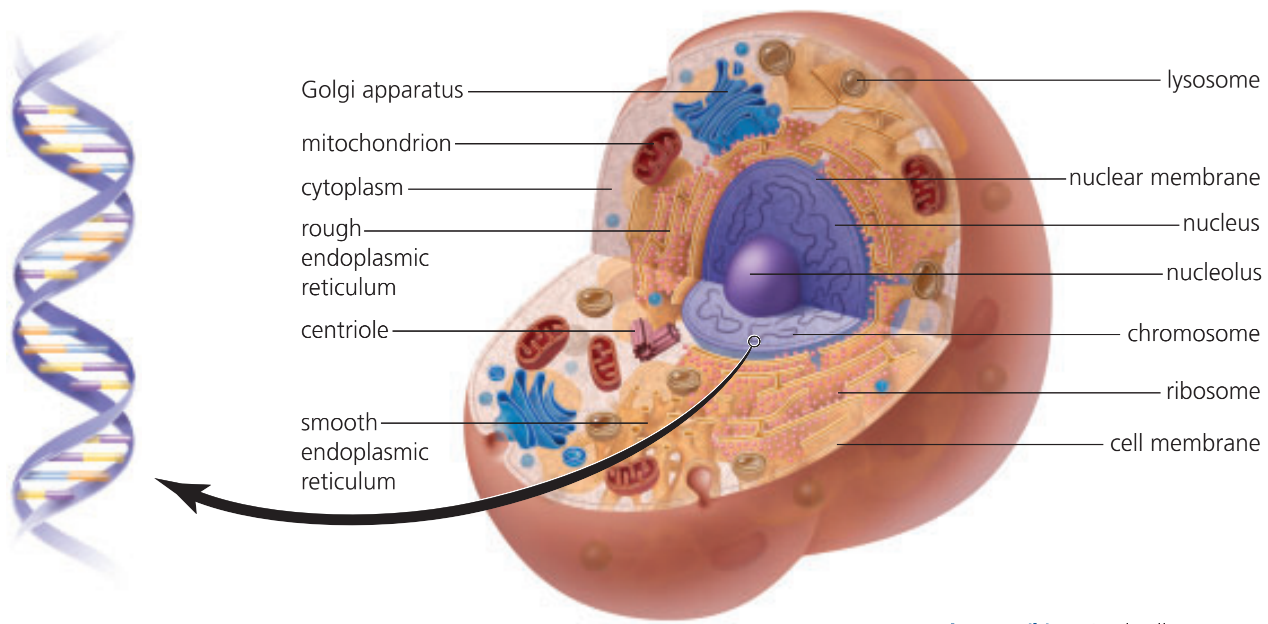


Figure 1(a) A short section of a DNA molecule, which makes up a chromosome

Figure 1(b) Animal cell structures

The Nucleus

The nucleus acts as the control centre of the cell. It directs all cell activities, including cell division. The nucleus is surrounded by the nuclear membrane. The **nuclear membrane** allows some materials to pass into and out of the nucleus. The nucleus contains several structures that allow it to perform its functions.

Chromosomes

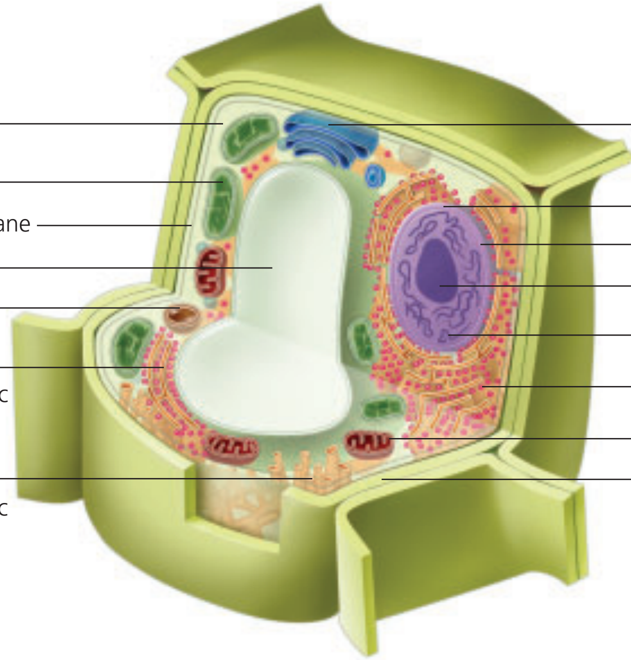
The material that directs all the activities of the cell is contained in the nucleus, in structures called chromosomes. Practically all human cells have 23 pairs of chromosomes. Chromosomes are made of **DNA** (deoxyribonucleic acid) and protein. DNA is a very long molecule that looks like a twisted ladder (Figure 1(a)). Each chromosome is made of one extremely long strand of DNA. The DNA provides the directions for all the cell structures and activities, including repairing worn and damaged cells and replacing dead cells.

Did You KNOW?

Chromosome Numbers

The number of chromosomes varies among living organisms. Humans have 23 pairs of chromosomes in each body cell, goldfish have 47 pairs, crayfish have 100 pairs, fruit flies have 4 pairs, and both dogs and chickens have 39 pairs.

Figure 2 Plant cell structures



Nucleolus

Another structure that is found in the nucleus of the cell is the nucleolus. The **nucleolus** is the site for the production and assembly of the ribosomes. Once assembled, the ribosomes move out of the nucleus and into the cytoplasm.

Ribosomes and Endoplasmic Reticulum

Ribosomes are tiny organelles in the cytoplasm. They make the proteins that the cell needs in order to function properly. Ribosomes are either free in the cytoplasm or attached to endoplasmic reticulum. Endoplasmic reticulum (ER) is a series of tubes and flattened sacs that transport materials throughout the cell. Endoplasmic reticulum that has ribosomes attached is called rough ER. Rough ER transports proteins throughout the cell. Endoplasmic reticulum that has no ribosomes attached is called smooth ER. Smooth ER manufactures and transports fats in the cell.

Cytoplasm

Inside the cell membrane is the cytoplasm, which contains all the organelles in the cell. Most of the cell's activities occur in the cytoplasm, and nutrients are absorbed, transported, and processed here. Inside the cytoplasm are tiny tubes called microtubules. Microtubules allow movement of the organelles within the cell and provide support for the cell. **Centrioles** (Figure 1(b)) are organelles that are made of special microtubules. They are found in almost all animal cells, and they are active during cell division. GO

If you would like to learn more about cell structures, go to **www.science.nelson.com** GO

2.2

CHECK YOUR Understanding

1. Look at Figure 3. How are the functions of the cell membrane and the nuclear membrane similar?

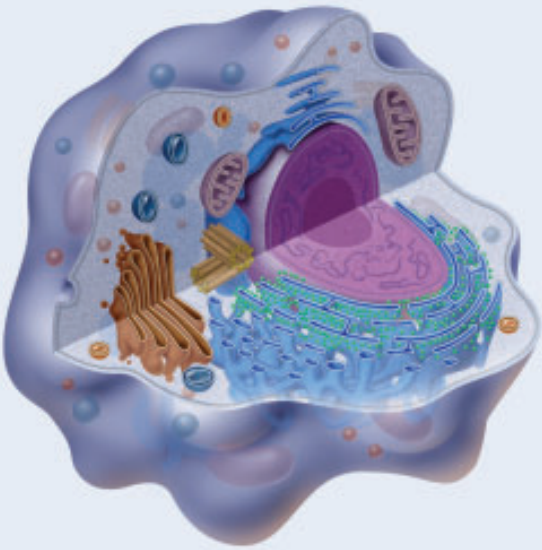


Figure 3

2. Explain how the nucleus and the nucleolus are different.
3. List the main structures that are found in the nucleus.
4. Describe the relationship between the nucleolus and the ribosomes.
5. List two different locations where ribosomes can be found.
6. How are some materials transported throughout the cell?
7. Explain the difference between rough and smooth endoplasmic reticulum.
8. What are chromosomes made of?
9. How many chromosomes are present in a normal human body cell?
10. Describe the shape of a DNA molecule.
11. Where is DNA located in the cell?
12. Identify structures A, B, and C in Figure 4.

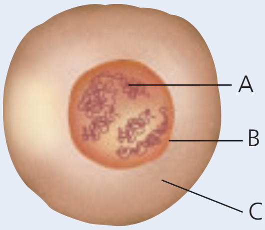


Figure 4

13. Compare plant and animal cells in terms of the organelles they contain.
14. (a) In which type of cells are you most likely to find centrioles?
    (b) When are centrioles the most active?
    (c) What are centrioles made of?
15. Identify structures A to E in Figure 5.

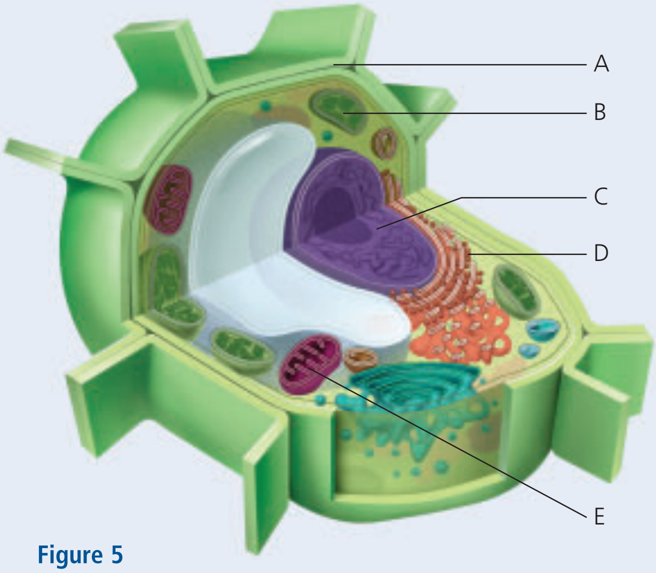


Figure 5

16. Where in a cell are the chromosomes located?
17. Describe two functions of the cytoplasm.

2.3 From DNA to Proteins

You have learned that the nucleus contains chromosomes, which contain DNA. DNA is a molecule that contains all the instructions to make, maintain, and repair cells. But how does DNA perform all these functions?

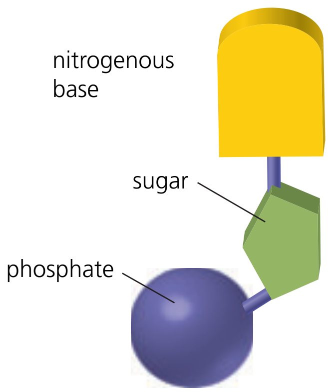


Figure 1 A nucleotide is composed of a sugar molecule, a phosphate molecule, and a nitrogenous base.

DNA Structure

In the previous section, DNA was described as looking like a twisted ladder. The ladder analogy is useful for explaining its structure. A DNA molecule is made of two strands of smaller molecules, called nucleotides. A **nucleotide** (Figure 1) is composed of a sugar molecule, a phosphate molecule, and a nitrogenous base molecule. The sides of the DNA ladder are made of the sugar and phosphate molecules joined to each other. The rungs of the ladder are made of pairs of nitrogenous bases, one from each of the strands. Each nucleotide has one of four different **nitrogenous bases**: adenine (A), thymine (T), cytosine (C), and guanine (G). Pairs of these bases form each rung of the DNA ladder (Figure 2). Adenine always pairs with thymine, and cytosine always pairs with guanine. Thus, a rung is made of either cytosine and guanine (C-G) or adenine and thymine (A-T). These are sometimes referred to as base pairs.

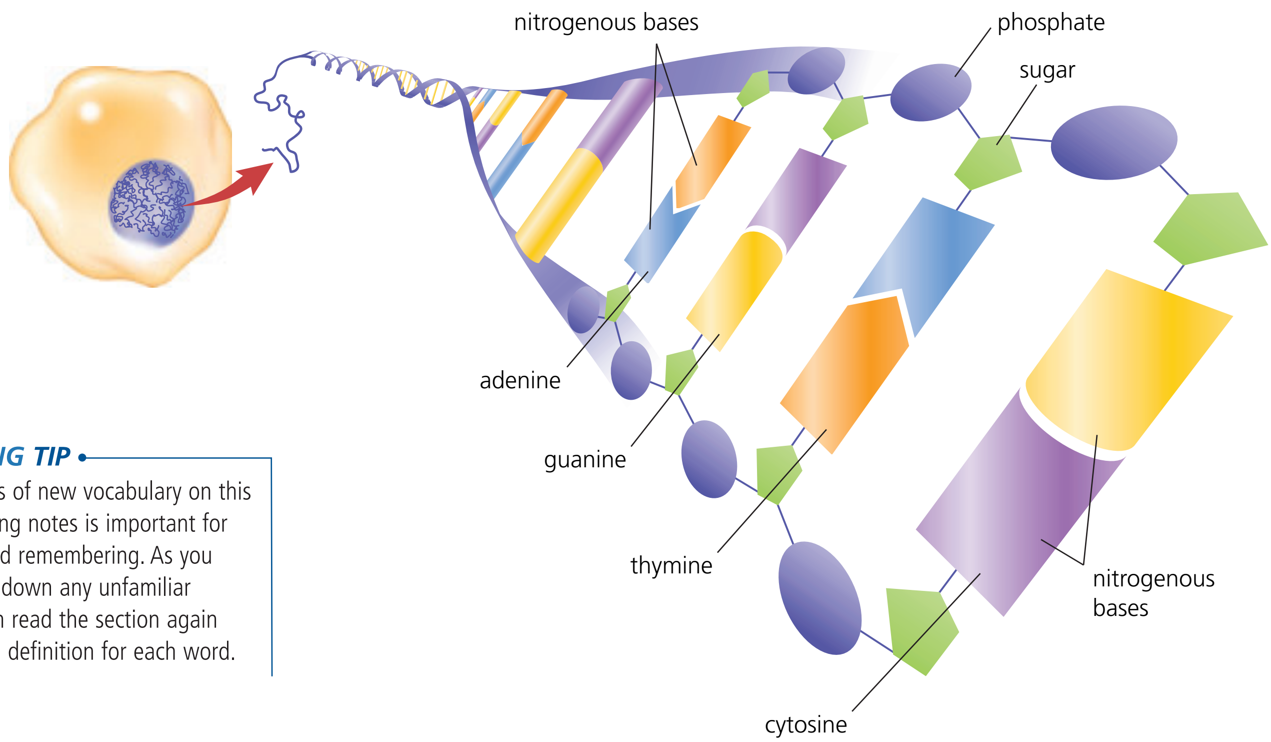


Figure 2 DNA molecules are made of two strands of nucleotides joined by their sugar and phosphate molecules and by their nitrogenous bases. The linked bases are called base pairs. A single chromosome can contain millions of base pairs.

LEARNING TIP

There is lots of new vocabulary on this page. Making notes is important for learning and remembering. As you read, write down any unfamiliar words. Then read the section again and write a definition for each word.

One of the things that make DNA so amazing is its ability to replicate, or copy, itself. Before a cell divides, each DNA molecule makes a copy of itself. Each DNA molecule splits in many places between the pairs of bases, like a broken zipper. New bases join up with the bases on each of the opened sides of the ladder to form two identical DNA molecules (Figure 3). Since adenine (A) always pairs with thymine (T), and cytosine (C) always pairs with guanine (G), the two new DNA molecules are identical. Each new DNA molecule has an old strand and a new strand. GO

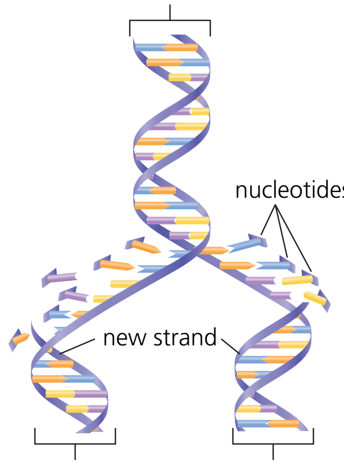


Figure 3 To replicate, a DNA molecule separates between the base pairs. Each separate side acts as a template for free nucleotides to join the opened strand.

If you would like to learn more about DNA replication, go to **www.science.nelson.com** GO

TRY THIS: *Measuring Your DNA*

Skills Focus: measuring, recording

Materials: calculator

The DNA in each human cell is coiled and fits inside the nucleus. If you stretched out the DNA from one typical human cell, it would measure about 2 m! There are about 100 trillion (100 000 000 000 000 or 1×10^{14}) cells in a human.

A. Calculate how many times your DNA would stretch to the Moon and back if it were removed from all your cells and arranged end to end. The distance from Earth to the Moon is approximately 380 000 km.

The Genetic Code

The bases in a DNA molecule are like the characters (numbers and letters) in a code. Think of codes that you are familiar with. For example, the Latin alphabet is a 26-character code that produces millions of words in several languages. The binary code (1 and 0) that computer languages use is a code that stores information. DNA has a four-character code. The four characters are DNA's nitrogenous bases: adenine (A), guanine (G), cytosine (C), and thymine (T). These bases combine to form "three-letter words" that are three bases long, for example, GGC or TAC (Figure 4). Each three-letter word codes for the production of one of 20 different amino acids. **Amino acids** are small molecules that are the building blocks of proteins. Different combinations of amino acids form different proteins. Proteins determine the characteristics of organisms. All the three-letter words in a cell's DNA form the instructions for all the body's cells to follow. This is the genetic code of all living organisms. It is sometimes called "the language of life." The genes of blue whales use the genetic code to produce blue whale characteristics. Human genes use the genetic code to produce human characteristics.

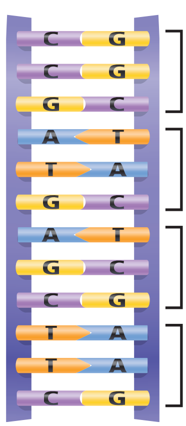


Figure 4 All the "words" of the genetic code, marked here by brackets, are three bases long. Most of the "words" code for an amino acid.

Did You KNOW?

The Human Genome

The Human Genome Project set out in 1990 to map all the genes in the human nucleus. The work was completed in 2003. Researchers now know that the human genome is made of approximately 3 billion DNA base pairs, which form 30 000 to 40 000 genes. Although researchers have identified many of the genes, they don't yet know the function of most of them, even some that have been identified and studied for years.

www.nelson.science.com GO

DNA to Genes

The DNA molecule in a chromosome is organized into genes. A **gene** is a short section of DNA that contains the instructions to make a specific protein. The instructions are determined by the order of the bases. All of an organism's genes (its entire DNA) is called the **genome**. The human genome is contained in the 23 pairs of chromosomes in the nucleus of almost every cell in the body.

Genes to Proteins

You have learned that DNA controls all the cell activities, as well as all the functions of the body and the characteristics of each individual. How does DNA, which is located in chromosomes in the nucleus of the cell, do all this?

There are several steps involved in making a protein from DNA, or protein synthesis. First the DNA segment that makes up a gene is used to make another molecule, called ribonucleic acid (RNA). RNA is very similar in structure to DNA. DNA, however, has a double strand, whereas RNA has only one strand. Then, in a process that is similar to the replication of an entire DNA molecule, a gene segment of DNA separates and an RNA molecule is constructed from one half of the DNA (Figure 5). The RNA molecule then carries the code from the gene, out of the nucleus, to a ribosome in the cytoplasm. The ribosome "reads" the instructions on the RNA and assembles the appropriate amino acids in the correct order to make the protein.

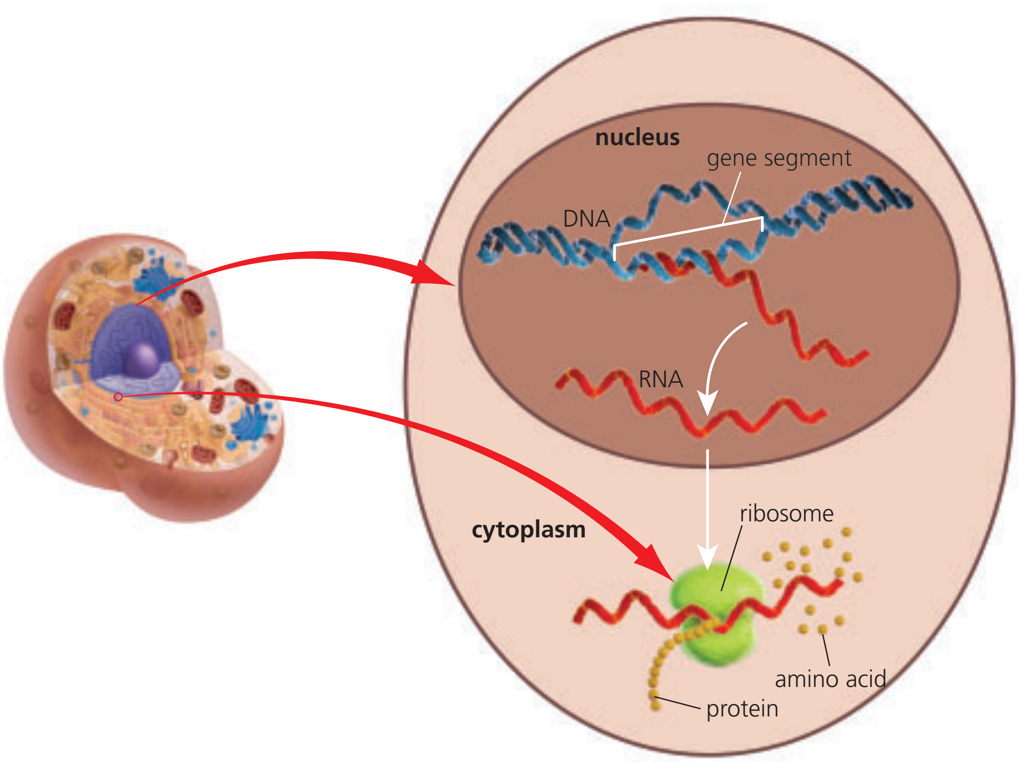


Figure 5 RNA acts as a messenger. It carries a gene's instructions from the nucleus to a ribosome in the cytoplasm.

Proteins have many functions. There is an enormous number of different types of proteins in the body. Enzymes are special proteins that control specific chemical reactions. Some hormones are made of proteins and act as messengers between cells. Table 1 shows several common proteins and their functions. The amino acids that make up proteins are either manufactured by your body or are obtained from the food you eat.

LEARNING TIP

After you finish reading the section called "Genes to Proteins," ask yourself, "How can I put what I have just read into my own words (paraphrase)?" Try explaining to a classmate how protein is made.

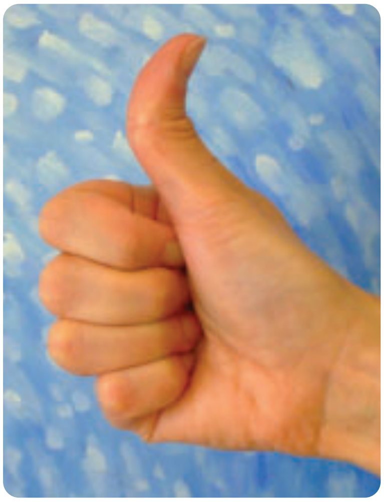
Table 1 Some common proteins and their functions

Protein	Function
hemoglobin	carries oxygen in red blood cells
insulin	controls the level of sugar in the blood
keratin	makes up hair and nails
collagen	holds tissue together, makes up bones
enzymes	control chemical reactions
antibodies	bind to foreign substances to protect the body against them
fibrinogen	helps blood clot
lactase	helps the body digest lactose (milk sugar)
growth hormone	stimulates growth (cell division)
prolactin	stimulates the production and release of milk from the mammary glands (see Chapter 4)
follicle stimulating hormone	stimulates egg and sperm production (see Chapter 4)

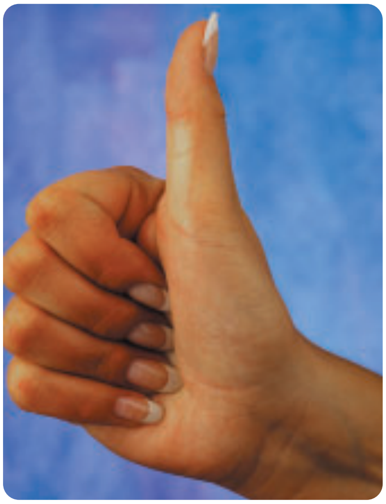
Genes and Variation

Genes are responsible for all the characteristics that make up a species. The number and type of genes differ among species. This is why fir trees are different from humans—humans don't have a gene to make needles, and fir trees don't have a gene to make hair. The DNA in organisms is similar, however. For example, 99.9 % of the DNA in the bacterium *E. coli* is also found in humans. Humans share 98 % of chimpanzee DNA and 35 % of daffodil DNA. The DNA that is unique to humans accounts for all the characteristics that are unique to humans.

All members of the same species have the same number and types of genes. We all have the genes that are responsible for making hair, nails, eyes, and every other human characteristic. If individuals from the same species have the same genes, why do they look different from one another? Why do some people have blue eyes and others have brown eyes? The answer is again in the genes. Within a species, there are different versions of the same gene. The different versions produce slightly different variations, or **traits**, for each characteristic. For example, in humans, one gene controls the characteristic of thumb shape. There are two different traits for this characteristic: straight or curved (Figure 6). Other characteristics, such as hair and eye colour, have several different versions. Also, some variations in characteristics are controlled by a number of different genes. Having different versions and



(a)



(b)

Figure 6 Thumb shape is a characteristic that is controlled by a single gene and has only two traits: the curved "hitch-hiker's thumb" (a) and the straight thumb (b).

LEARNING TIP
Think about the section called "Genes and Variation." Why do some people have curly hair and others have straight hair?

combinations of genes that control the characteristic partly explains why individuals, even close relatives, look so different. It is this unique combination of genes that you receive from your mother and your father that determines your characteristics. In the next two chapters, you will learn about the processes that produce the variations you see among all organisms. This variation allows individual organisms to adapt to changing environments.

TRY THIS: *Human Traits Survey*

Skills Focus: conducting, observing, recording, interpreting data

In this activity, you will survey your classmates to find out which of the following traits they have:

- Earlobes: Earlobes hang freely or are attached to the sides of the face (Figure 7).
- Thumb shape: Thumb curves when extended ("hitch-hiker's thumb") or is straight.
- Tongue: Tongue can be rolled like a U or cannot.
- Hair on middle section of fingers: Hair is present or absent.
- Dimples on face: present or absent
- Hairline: Hairline comes down into a widow's peak (a V) or is straight.

1. Create a table like Table 2 in your notebook. Use it to record your data for all the traits listed above.
2. Record whether each trait is present in each of your classmates.

A. Calculate the ratio for each trait.
B. List the traits that more students have.
C. Do you think the ratios would be the same or different in another class? Explain.
D. If possible, compare your class results with results from other classes.
E. Calculate the ratios for the combined classes.
F. Do you see any patterns in the ratios?

(a) (b)

Figure 7 Free earlobes (a) and attached earlobes (b)

Table 2

Trait		Present	Number of students	Ratio
Earlobes	free			
	attached			
Thumb shape	hitch-hiker			
	straight			
Tongue	rolls			
	does not roll			

2.3 CHECK YOUR Understanding

1. Describe how chromosomes and DNA are related.
2. The DNA molecule is shaped like a twisted ladder.
   (a) What are the sides of the ladder made of?
   (b) What are the rungs made of?
   (c) Name each of the molecules that make up the rungs.
3. Describe how the DNA molecule replicates.
4. Which base joins with each base listed below?
   (a) cytosine
   (b) thymine
   (c) adenine
   (d) guanine
5. What part of the DNA molecule determines the genetic code of an organism?
6. What is the human genome?
7. Identify the numbered structures shown in Figure 8.

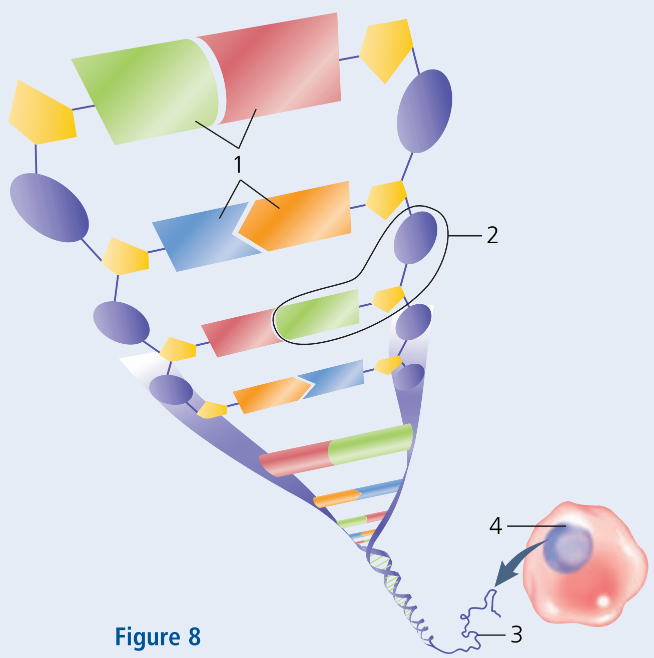


Figure 8

8. (a) Where are proteins made?
   (b) What are the building blocks of proteins?
9. What type of protein controls chemical reactions in your body?
10. (a) Name two types of structural proteins in your body.
    (b) Identify where each type of protein would be found.
11. Name and give the function of three proteins that are found in your blood.
12. Describe how DNA and genes are related.
13. How is the genetic code transferred from the nucleus into the cytoplasm?
14. How is RNA different from DNA?
15. Place the following events of protein synthesis in the correct order.
    (a) Ribosomes manufacture protein.
    (b) RNA is formed from a gene.
    (c) Part of a DNA molecule "unzips."
    (d) RNA carries the genetic code into the cytoplasm.
    (e) Amino acids attach to ribosomes.
16. Identify the structures labelled 1 to 3 in Figure 9.

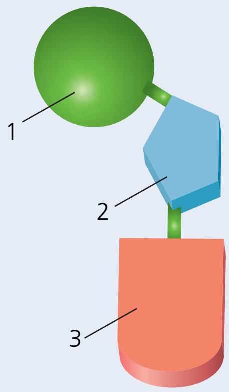


Figure 9

USING MITOCHONDRIAL DNA TO SOLVE MYSTERIES

Forensic scientists use the DNA found in mitochondria to help them identify human remains.

Dead bodies are not always easy to identify. For example, a body may have been burned or may have been left for a long time before being found. Often all that is left of a body is charred bits of bone, tangles of hair, or dried up patches of skin. The DNA in these samples is so damaged that regular DNA analysis is not possible. The only type of genetic material that can withstand extreme environmental conditions is found inside the mitochondria. Fortunately, there is technology that allows scientists to analyze mitochondrial DNA (mtDNA).

Mitochondria are tiny cellular organelles that use oxygen to break apart food molecules and release energy for the cell to use. When a cell undergoes cell division, the mitochondria divide and identical copies of the mitochondria are passed onto each of the resulting cells. This process is repeated over and over as an organism grows, so that all the cells in the organism have the same mtDNA.

During fertilization, when the egg and sperm join together, the mitochondria from the egg cell are retained but the mitochondria from the sperm cell are destroyed. Therefore, all mitochondria come from the mother. This means that all the fertilized egg's mitochondria are identical to the mother's mitochondria. As the fertilized egg divides, the cells produced have mitochondria that are identical to the mother's. The similarity of mitochondrial DNA in members of a family over many generations forms the basis of identifying human remains by forensic mtDNA techniques.

Scientists can identify victims by comparing mtDNA from the unidentified remains to mtDNA from possible female relatives. Panama, USA, Canada, Argentina, and Yugoslavia are just a few of the countries where human remains have been successfully identified using mitochondrial DNA analysis. In Panama, Yugoslavia, and Argentina, investigators from around the world worked together to identify the victims found in mass graves (Figure 1). While a lost relative can never be replaced, surviving family members get some degree of peace from knowing the fate of a family member and being able to provide a proper burial.

Figure 1 Forensic scientists investigate a mass grave.

2.4 The Cell Cycle

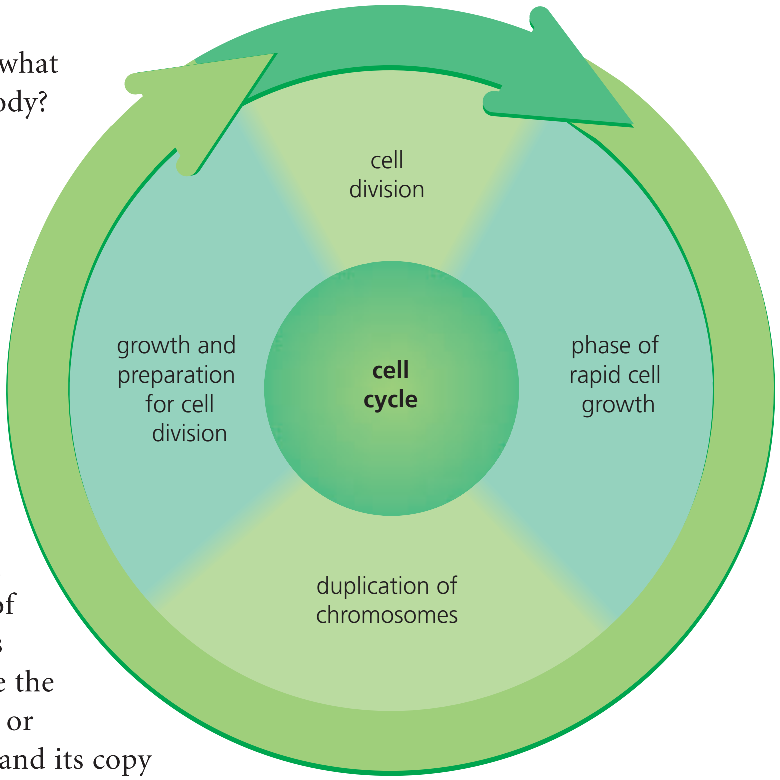


Figure 1 The circle represents the cell cycle of a eukaryotic cell. The light arrow represents the time the cell spends in interphase and the dark arrow represents the time in cell division. The labels indicate what is happening in the cell as the cycle progresses.

At this very moment, there are millions of cells undergoing cell division inside your body. But what about the rest of the trillions of cells in your body? What are they doing? Cells are not always dividing. The **cell cycle** is the sequence of events in the cell from one cell division to another (Figure 1). Just as you are growing and carrying out the normal functions of a human, most of the cells in your body are also growing in size or carrying out their normal functions. For example, muscle cells are using energy to contract. The cells that line your small intestine are absorbing nutrients from your digested food. This phase of growing and working is called **interphase**. A cell is in interphase for 90 % of the total time of the cell cycle. During interphase, the cell makes copies of each organelle in the cytoplasm. Once the cell is large enough, it will also make a copy of, or replicate, its chromosomes. Each chromosome and its copy are known as **sister chromatids**. Each sister chromatid carries identical instructions for the functions of the cell. Interphase and cell division make up the cell cycle.

Cell Division

Even though different cells have different functions, the process of cell division is extremely similar in all cells and in all organisms. In both the unicellular paramecium and the giant blue whale, for example, one cell (called the **parent cell**) divides into two genetically identical cells (called **daughter cells**). The main difference is that the paramecia daughter cells become two separate organisms, while the blue whale daughter cells continue to divide and stay interconnected to make up the cells of various tissues and organs.

Cell division is composed of two processes: mitosis and cytokinesis. **Mitosis** is the process that divides the nuclear material. **Cytokinesis** is the process that divides the cytoplasm and the rest of the organelles in half. Cytokinesis usually begins before mitosis is finished. Each daughter cell receives approximately half the cytoplasm and organelles, and will be about half the size of the parent cell.

Did You KNOW?

Suicide Cells

Certain cells are genetically programmed to die after a certain number of cell divisions. For example, the eyelids of newborn puppies form an unbroken layer of skin. Shortly after birth, the eyelid cells across the middle of the eye die, allowing the top and bottom eyelids to separate and the eyes to open.

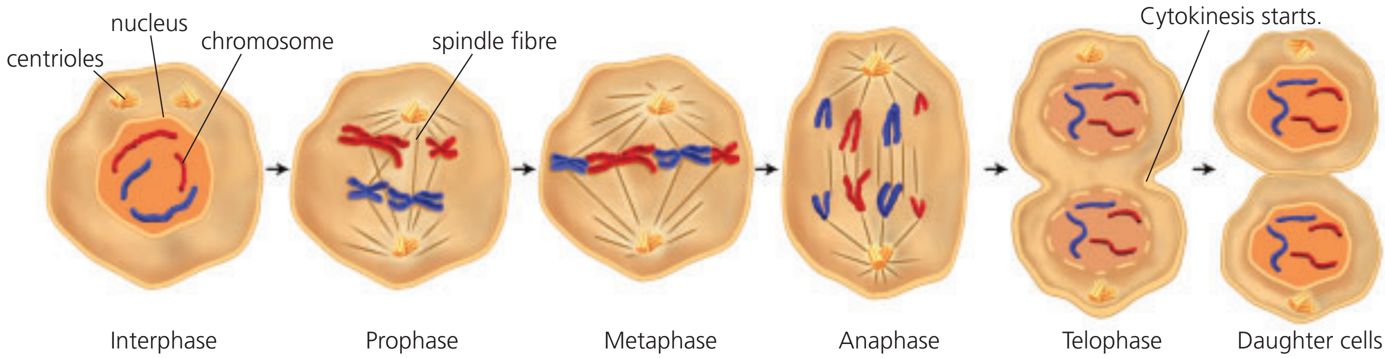


Figure 2 Mitosis and cytokinesis in an animal cell

The Stages of Mitosis

Mitosis is a continuous process, but, to make it easier to describe, we divide it into four stages: prophase, metaphase, anaphase, and telophase. Figure 2 shows the stages of mitosis and the process of cytokinesis in an animal cell. GO

If you would like to learn more about mitosis, go to **www.science.nelson.com** GO

1. Prophase

The first stage of mitosis is **prophase**. The sister chromatids that were formed during interphase have shortened and thickened, and are now visible with a light microscope. The sister chromatids become joined at or near the centre and look like an X (Figure 3). The nucleolus is no longer visible. The nuclear membrane breaks down and the chromosomes spread out in the cytoplasm. In animal cells, the centrioles, which were replicated during interphase, move to opposite poles of the cell and start to form spindle fibres. Spindle fibres are microtubules that grow toward the centre of the cell. The spindle fibres form the **spindle**, which moves the chromatids during the later stages of cell division.

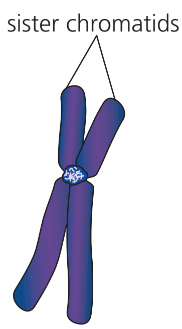


Figure 3 A single duplicated chromosome is made of two sister chromatids joined at or near the centre.

2. Metaphase

The second stage of mitosis is **metaphase**. The spindle is completely formed, and the sister chromatids attach to the spindle fibres. The sister chromatids line up along the middle of the cell, halfway between the poles of the cell.

3. Anaphase

Anaphase is the third stage of mitosis. In anaphase, the sister chromatids are pulled apart by the spindle and move toward the opposite poles of the cell. The chromatids are now called chromosomes again.

4. Telophase

The last stage of mitosis is **telophase**. The new chromosomes have reached the opposite poles of the cell. During telophase, the events of prophase happen in reverse: two nuclear membranes form, the spindle disappears, the chromosomes lengthen and get thinner, and the nucleoli reappear. Mitosis is now complete. The original nucleus has divided into two genetically identical nuclei. 2A *Investigation*

2A *Investigation*

Observing Cell Division in Plant and Animal Cells

To perform this investigation, turn to page 64.

In this investigation, you will look at onion root tip and whitefish embryo cells under a microscope to observe the stages of cell division.

Cytokinesis

Cytokinesis is the second process in cell division. It begins at the end of mitosis, during telophase. Cytokinesis divides the cytoplasm into two daughter cells. It is visible in animal cells by an indentation or pinching of the cell membrane and cytoplasm between the two new nuclei. The new daughter cells are now in interphase.

Cytokinesis is different in plant cells and animal cells. In plant cells, there is no indentation in the cell membrane. Membrane-bound vesicles form between the two nuclei (Figure 4). The vesicles fuse together to form the cell plate. The cell plate grows outward toward the cell membrane, forming a new cell membrane for each daughter cell, as well as the cell wall between the two new membranes. 2B *Investigation*

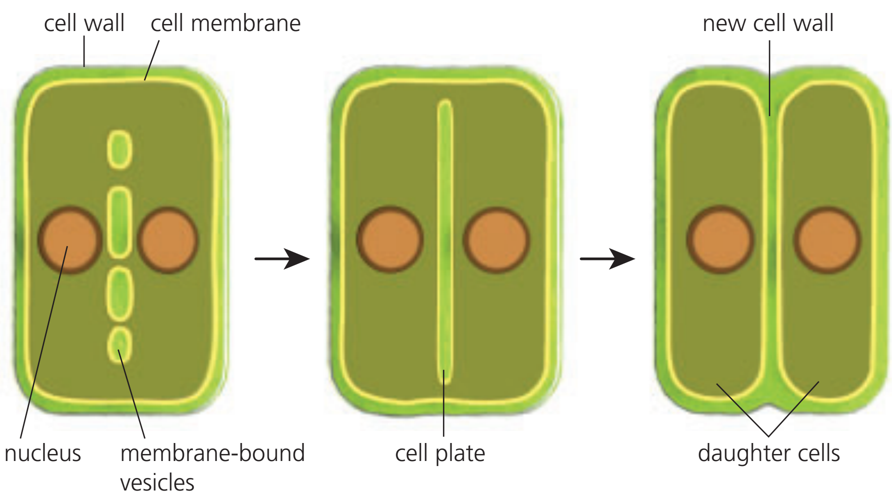


Figure 4 In plant cell cytokinesis, the cell plate forms new cell membranes and a new cell wall between the daughter cells.

LEARNING TIP

Making study notes is important for learning and remembering. Read this section again, and look at the headings. Turn each heading into a question, and then read to answer it. Record your answers in point form under each heading.

2B ***Investigation***

Determining the Rate of Cell Division in Plants and Animals

To perform this investigation, turn to page 66.

In this investigation, you will take another look at an onion root tip and a whitefish embryo under a microscope to determine the percentage of cells that are dividing. You will use what you learn to make a cell division clock.

TRY THIS: *A Model of Cell Division*

Skills Focus: creating models, observing, communicating

Materials: craft materials, such as modelling clay, pipe cleaners, wool, twist ties, string, rubber bands, and paper clips

This activity is intended to help you understand the continuous process of cell division.

1. Work with a partner to build a model of a cell. Your model must allow the chromosomes to be moved to show the stages of mitosis.
2. Your model must also be large enough to allow the chromosomes to move to the opposite poles of the cell.

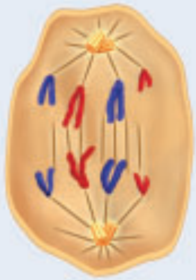
A. What event has to happen before mitosis begins? When does this event happen? What are the structures called now?

B. At each stage of mitosis, stop and describe to your partner what is happening.

C. Rearrange your cell model to show both animal cytokinesis and plant cytokinesis. Describe to your partner how each is different.

2.4 CHECK YOUR Understanding

1. What are the stages of the cell cycle?
2. When does the cell cycle start? When does it end?
3. Approximately what percentage of the cell cycle is interphase?
4. What event must occur before mitosis can begin?
5. How do the daughter cells compare with the parent cell?
6. What stage are the daughter cells in immediately following cell division?
7. A normal human body cell has 46 chromosomes. After mitosis, how many chromosomes should be in each daughter cell?
8. Identify the stages of mitosis, labelled A to D, in Figure 5.



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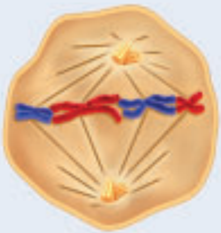

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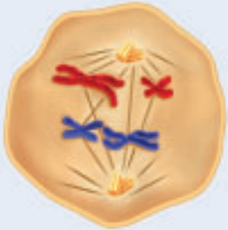


D

Figure 5

9. (a) List the stages of mitosis in their correct order.
   (b) Describe one feature that identifies each stage of mitosis.
10. Why is it necesary for a cell to duplicate its nuclear material?
11. What is the duplicated nuclear material called?
12. Why is telophase sometimes described as reverse prophase?
13. Use a table to compare and contrast cytokinesis in an animal cell with cytokinesis in a plant cell.
14. A human red blood cell has no chromosomes. How does this affect the red blood cell's ability to divide?
15. Interphase used to be described as a "resting stage." Explain why this is inaccurate.
16. No nuclei are found in the cells of the outermost layer of your skin. A company claims that its moisturizer can restore and rejuvenate these cells.
    (a) Would these skin cells be capable of producing other skin cells? Explain why or why not.
    (b) Evaluate the company's claim.
17. (a) Identify the dividing cells in Figure 6 as plant or animal cells.
    (b) Which of the processes involved in cell division is happening in each of the cells?

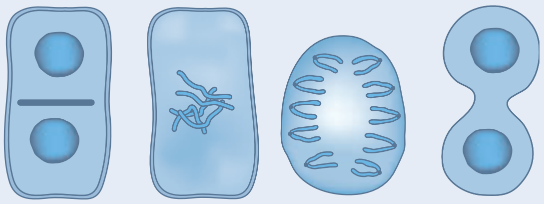


Figure 6

2.5 Changes to a Cell's DNA

The DNA that is found in almost every cell in your body forms your genetic code. It acts like the operating system of the cell, and it controls all your body's functions. What happens when the DNA is altered?

LEARNING TIP

Skim (read quickly) to get a general sense of Section 2.5. Examine the headings, and scan for words in bold. Ask yourself, "What information is important here?"

Mutations

In Section 2.3, you learned that the DNA in each gene provides the instructions to make a specific protein. The ribosomes in the cytoplasm assemble different amino acids in a specific order, according to the DNA's instructions. If the DNA in a gene has been changed in some way, the DNA's repair mechanism will often repair the damage. If the change in the DNA is not repaired, then the RNA molecule that is constructed will contain instructions that are altered. The altered instructions may direct the ribosomes to put the amino acids together in a different order, which will cause a change in the structure of the protein. For example, a change in the DNA in the hemoglobin genes may change the shape of the hemoglobin molecule. A change in the DNA, or the genetic code of a cell, is called a **mutation**. Mutations can be classified as beneficial, neutral (cause no effect), or harmful.

Genetic diseases are caused by harmful mutations. A harmful mutation in a gene's DNA causes changes in the protein that is produced, which in turn causes changes to how the body functions. For example, cystic fibrosis (CF) is a genetic disease that affects many parts of the body. A common symptom of CF is a buildup of thick mucus in the lungs (Figure 1). CF is caused by a mutation in a gene known as the CFTR gene. The normal CFTR gene codes for a protein that helps move certain chemicals into and out of the cell. When the gene has a mutation, the shape of the protein changes, and it no longer does its job properly. The change in the shape of the protein causes the many symptoms of CF. GO

Did You KNOW?

A Beneficial Mutation

In Japan, a type of bacterium has been found that gets its nutrition from digesting nylon! This ability is caused by a beneficial mutation. Nylon was invented in 1935. Before that year, the mutation would not have been beneficial to the bacterium.

If you would like to learn more about mutations, go to **www.science.nelson.com** GO

Figure 1 People with cystic fibrosis often get lung infections due to excess mucus in the lungs.

LEARNING TIP

Make connections to your prior knowledge. Ask yourself, "What do I already know about cancer?" Consider the information you have learned in school, read on your own, or observed and experienced.

Insulin is a protein that the body needs to control the amount of sugar in the blood. It is produced by special cells in the pancreas. In people that have diabetes, the cells that produce insulin have either stopped producing it or produce insulin that doesn't work. Why does this happen? The DNA in the cells that produce insulin has been altered, so the instructions for making insulin have been altered. As a result, the cells cannot produce insulin from the instructions, or the instructions produce insulin molecules that do not work.

Cancer

Harmful mutations may cause cancer. **Cancer** is a disease in which cells divide very rapidly and uncontrollably. A mutation in the genes that control the cell-division process in the cell cycle causes cell division to go out of control. Some types of cells have a shorter cell cycle than others. The length of the cell cycle is unique to each type of cell and is determined by the DNA. If a mutation happens in the DNA that controls the cell cycle in a bone cell, the bone cell starts to divide much more quickly than normal bone cells do. The mutation gets passed on to the daughter cells, since the DNA of the parent cell is duplicated in the daughter cells. So the daughter cells divide uncontrollably as well.

Figure 2 A wart is a benign tumour on the skin. Benign tumours usually cause no harm.

Characteristics of Cancer Cells

As the cancer cells keep dividing, they accumulate in abnormal masses called tumours. There are two types of tumours: benign and malignant. **Benign tumours** are masses of cells that grow but stay in one place and usually do not interfere with the normal functioning of the surrounding tissue or organ (Figure 2). Warts are benign tumours. Benign tumours can usually be removed by surgery. **Malignant tumours** invade the surrounding tissues and interfere with the normal functions of the tissues and organs.

Rapidly dividing cancer cells use up more nutrients than normal cells, but they do not carry out the functions of normal cells. Figure 3 shows normal cells and cancer cells. The cancer cells have highly visible enlarged nuclei because they are constantly dividing. Most normal cells stay in contact with neighbouring cells and cannot divide if they are separated from the neighbouring cells. Cancer cells, however, can keep dividing if they are separated from their neighbours. Cancer cells can separate and spread to other parts of the body. There, they continue to divide out of control, causing tumours in the new locations. The spread of cancer cells away from their original location is called **metastasis**.

Did You KNOW?

Not Just Humans Get Cancer

Many other organisms besides humans can get cancer. Sunflowers and tomatoes often develop a type of cancer called a gall. This is a plant tumour caused by viruses, bacteria, fungi, or insects. There is evidence of cancerous tumours in dinosaur bones as well as in the cells of linen (made from the flax plant) found wrapped around ancient mummies.

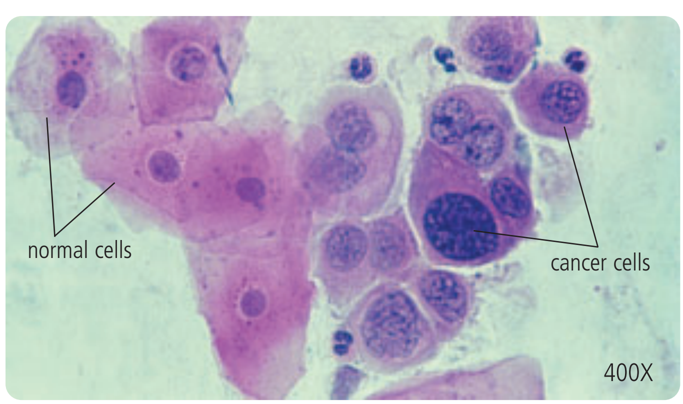


Figure 3 Normal cells, and cancer cells. Notice the enlarged nuclei in the cancer cells.

Causes of Cancer

Any substance that can cause cancer is called a **carcinogen**. Scientists have discovered many carcinogens such as asbestos, certain pesticides, X-rays, some viruses, and many of the chemicals found in tobacco (Figure 4(a)). The environment contains a variety of carcinogens, many of which are by-products of industrial processes (Figure 4(b)). Many carcinogens, however, remain unknown. Avoiding known carcinogens decreases the chances of developing cancer. By not smoking and avoiding second-hand smoke, people reduce their exposure to the carcinogenic chemicals in tobacco smoke. By reducing time spent in the sun and/or wearing sunscreen, people reduce their exposure to the carcinogenic ultraviolet rays found in sunlight. Figure 5 shows risk factors that are associated with cancer. As well as these risk factors, your own genetic makeup influences your chances of getting cancer.

LEARNING TIP

Look at Figure 5. How do the parts of the circle graph relate to each other? How does the legend help to explain the information in the graph?

(a) (b)

Figure 4 Cigarette smoke (a) contains over 60 known carcinogens. PCBs (b) are one of a family of chemicals, some of which are known carcinogens. PCBs have been banned in Canada for many years, but they remain in the environment for a very long time.

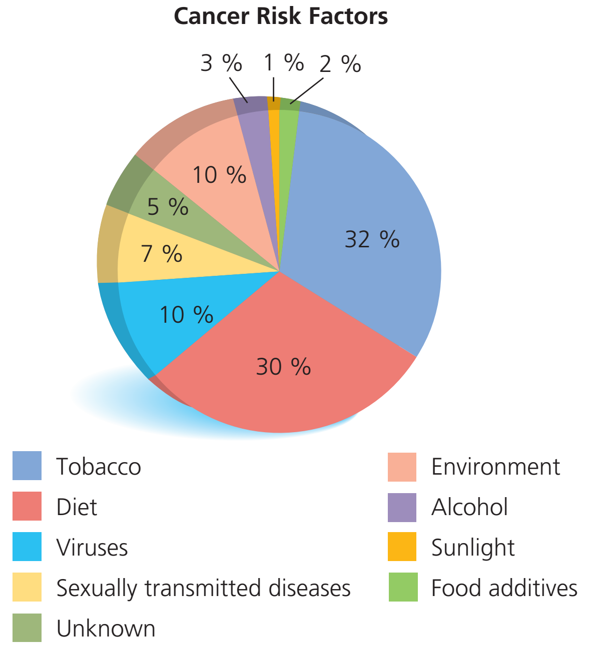


Figure 5 Estimates of risk factors are calculated in percentages.

Treating Cancer

Some cancers can be treated quite successfully if they are diagnosed early. Surgery can remove tumours before the cells metastasize. Radiation can be used to kill cancer cells by disrupting cell division in the rapidly dividing cancer cells. Chemotherapy involves using drugs to stop the cancer cells from dividing. Sometimes combinations of these treatments are used to treat a cancer patient. Unfortunately, chemotherapy and radiation also kill some fast-growing healthy cells, such as skin and hair cells, in addition to the cancer cells. This is why radiation therapy and chemotherapy can produce some unpleasant side effects, such as radiation burns, hair loss, nausea, and vomiting.

Did You KNOW?

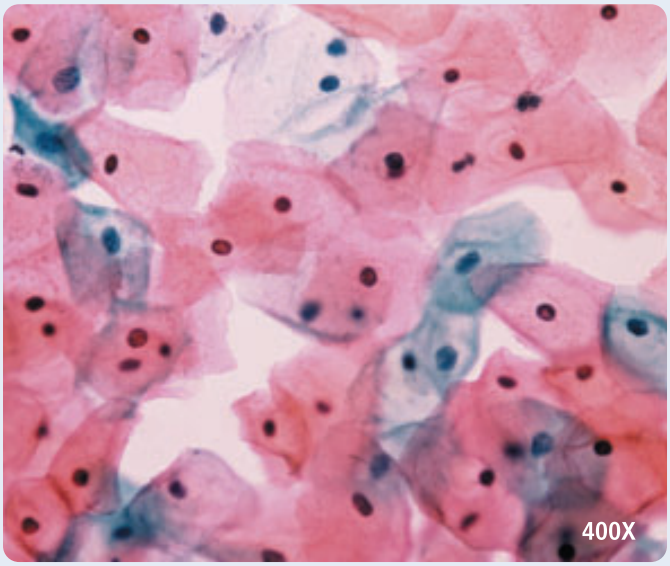
Sunburns

After repeated sunburns, it can take 10 to 30 years for skin cancer to develop. Take a sun-sense quiz and find out more about cancer.

www.science.nelson.com GO

2.5 CHECK YOUR Understanding

1. What disease may result from a harmful mutation?
2. Which part of the cell does cancer affect?
3. Why do some normal cells have different lengths of cell cycles? Give two examples.
4. Describe two characteristics of cancer cells.
5. What characteristic of cancer cells allows cancer to spread to other areas of the body?
6. What is a carcinogen? Give two examples of known carcinogens.
7. Explain why not all mutations cause cancer.
8. (a) Explain the difference between a benign tumour and a malignant tumour.
   (b) Give an example of a benign tumour.
9. What is a common treatment for benign tumours?
10. Examine the photos of cells in Figure 6.
    (a) Which photo shows cancerous cells?
    (b) What characteristic of cancer cells makes them easy to identify with a microscope?
    (c) Explain how this characteristic relates to the behaviour of cancer cells.



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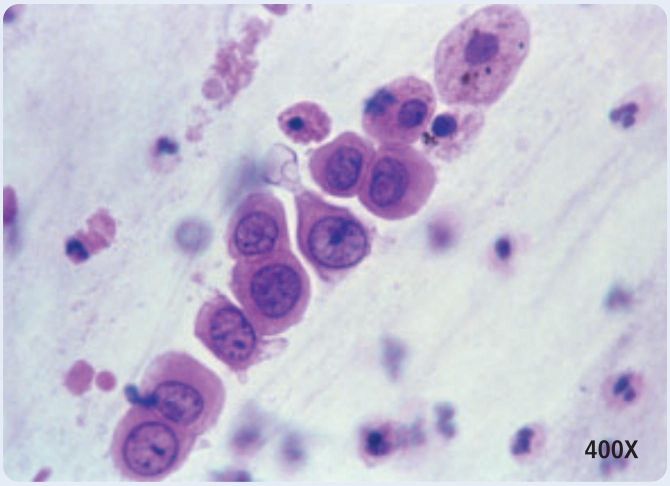

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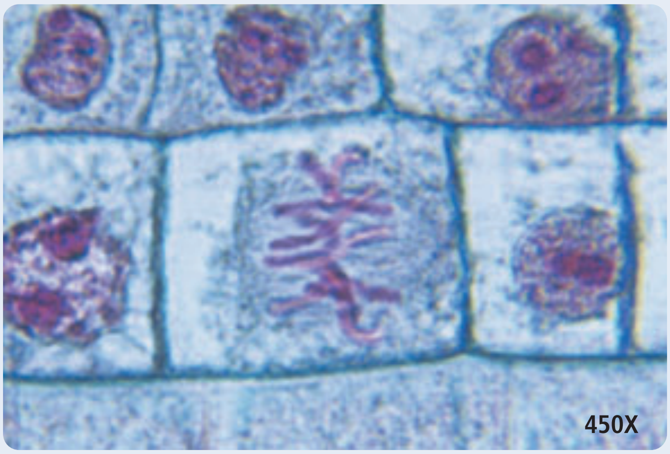


C

Figure 6

11. Why are cancers that metastasize more dangerous than cancers that do not?
12. Explain the differences between radiation and chemotherapy.
13. How does radiation affect cancer cells?
14. The percentage of people getting cancer is increasing. Considering the known causes, how can this increase be explained?
15. Explain why cancer treatment may cause burns and hair loss.

2.6 Cell Division and Asexual Reproduction

As you have learned, cell division plays a vital role in the life of all living things. All living things reproduce, and some use cell division as their method of reproduction.

There are two types of reproduction: sexual and asexual. In **sexual reproduction**, two separate organisms (parents) contribute genetic information, usually in specialized sex cells (an egg cell and a sperm cell). The sex cells combine to produce a **zygote**, the first cell of the new organism. **Asexual reproduction** involves only one parent. All the offspring that are produced by asexual reproduction are identical to the parent. Figure 1 compares sexual and asexual reproduction at the cellular level.

LEARNING TIP

Check your understanding of sexual and asexual reproduction. In your own words, explain to a partner how they are different.

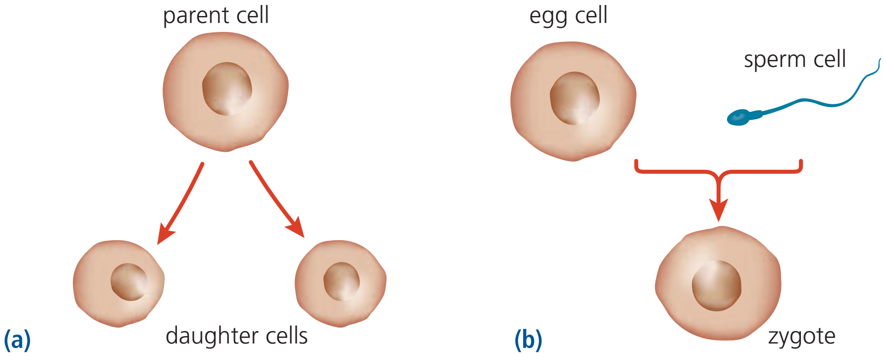


Figure 1 In asexual reproduction, (a), one parent cell divides into two identical daughter cells. In sexual reproduction (b), two cells, one cell from each parent, join to form one cell, called a zygote, which has the genetic material from both parent cells.

Types of Asexual Reproduction

From a simple bacterium to a daffodil plant, many different species use many different types of asexual reproduction to produce offspring. The offspring are clones. **Clones** contain DNA that is identical to the DNA of the parent and are therefore genetically identical. Ususally, the parent chromosomes and DNA are replicated in interphase. Cell division divides the genetic material and the cytoplasm between the two daughter cells.

Binary Fission

In **binary fission**, the parent undergoes cell division to produce two genetically identical daughter cells, or offspring (Figure 2). The offspring are smaller than the parent cell, but all the necessary structures are present. Only single-celled organisms (such as bacteria), some protists (such as amoebas), and some algae use binary fission to reproduce.

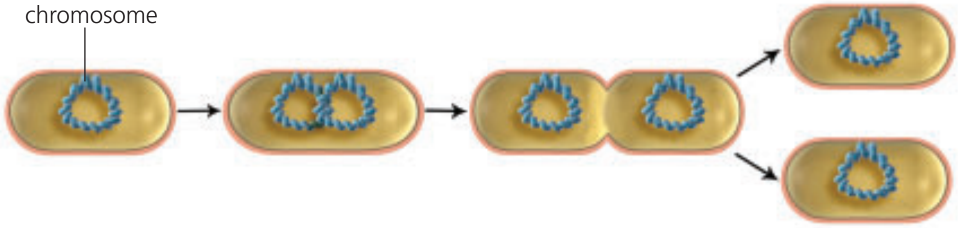


Figure 2 Binary fission in a bacterium

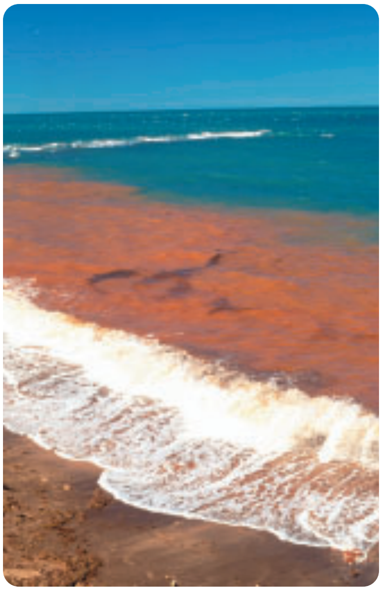


Figure 3 A population explosion of a protist called a dinoflagellate causes a red tide.

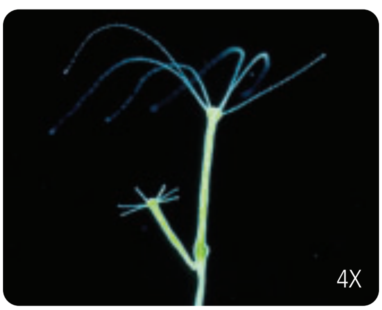


Figure 4 Budding in a hydra

Binary fission allows for rapid population growth under ideal conditions. Bacteria can double their population every 20 minutes. If the bacterium is one that causes a disease, this increase in numbers can produce an infection. Certain protists, called dinoflagellates, take advantage of good conditions in the ocean. The resulting population explosion is called a red tide (Figure 3). The dinoflagellates produce toxins that can kill fish, as well as humans, if the fish or humans consume clams or mussels that have eaten the dinoflagellates.

Budding

In **budding**, the offspring begins as a small growth on the parent, called a bud. The bud continues to undergo cell division and grow in size before breaking off from the parent. Budding occurs in single-celled organisms, such as yeast, as well as in multi-cellular organisms, such as the hydra (Figure 4), which is related to jellyfish and anemones. Since the initial daughter cells of the bud are genetically identical to the parent, the large bud that eventually breaks off will also be identical to the parent.

Vegetative Reproduction

When plants reproduce asexually, the process is called **vegetative reproduction**. Some plants, such as strawberries, send out runners. A runner is a type of stem that grows horizontally along the surface of the soil. A runner grows its own roots and can become an independent plant, like the spider plant shown (Figure 5(a)). Some trees and shrubs, such as aspen and lilac, send out shoots from the base of a trunk or underground stems, which grow into new plants. Cuttings from some plants can also grow their own roots and become new plants. Bulbs, from which daffodils and crocuses develop (Figure 5(b)), and tubers, such as potatoes (Figure 5(c)), are other forms of vegetative reproduction. The new plant clones are genetically identical to the parent plant.

Figure 5 Vegetative reproduction in plants: runners on a spider plant (a), crocuses sprouting from bulbs (b), shoots forming on a potato tuber (c).

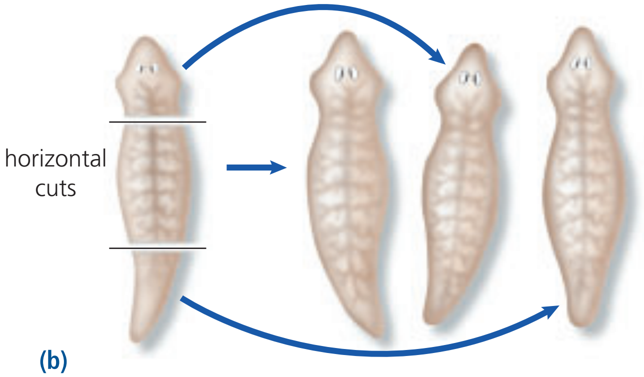
Fragmentation

In **fragmentation**, a small part of an animal breaks off and grows into a new organism. A fragment can grow into a complete animal. Whether an entire new animal grows from the fragment depends on how much of the original parent is contained in the fragment. The fragment of a sea star (Figure 6(a)), for example, must contain part of the central disk in order to produce a new organism. The original parent animal can regrow the lost fragment.

Reproduction after fragmentation cannot happen without regeneration. Regeneration is the ability to regrow a body part, a tissue, or an organ. Some flatworms, such as planaria (Figure 6(b)), can regenerate an entire organism from a small fragment. The genetic material of the new offspring is identical to the genetic material to the parent.

LEARNING TIP
Headings and subheadings act as a guide for your reading. To check your understanding as you read, turn each heading into a question and then answer it.

(a)



(b)

Figure 6 Fragmentation in a sea star (a) and a planarian (b). The sea star is growing three new legs from a fragment. Each section of the planarian will grow into a complete organism.

Spore Formation

Many fungi (such as moulds, puffballs, and mushrooms), algae, and non-flowering plants (such as ferns), reproduce by forming large numbers of spores (Figure 7). **Spores** are cells with thick cell walls. They are similar to seeds, but they are produced by cell division and grow into organisms that are genetically identical to the parent organism. Organisms that form spores may also reproduce sexually.

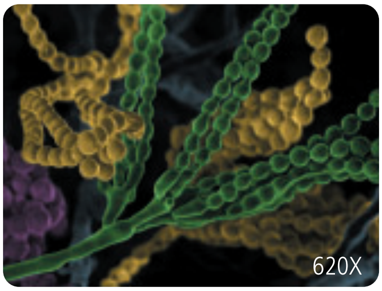


Figure 7 A magnified view of spore-bearing parts in the fungus Penicillium.

Characteristics of Asexual Reproduction

Even though there are different types of asexual reproduction, all of them have characteristics in common:

- Only one organism is needed to reproduce.
- All the offspring are genetically identical to each other and to the parent organism.
- A single organism can produce large numbers of offspring.

2.6 CHECK YOUR Understanding

1. At the cellular level, how is asexual reproduction different from sexual reproduction?
2. What is cloning? Why are all the offspring of asexual reproduction called clones?
3. What process must occur before asexual reproduction begins?
4. Explain why the population of an asexually reproducing organism can increase rapidly.
5. Use a Venn diagram to compare asexual reproduction with cell division.
6. Identify the method of asexual reproduction in each of the following situations.
   (a) A new tree begins to grow from the root of a nearby tree.
   (b) A single-celled protist pinches into two cells.
   (c) A mushroom disperses hundreds of small particles. Each particle can grow into a new mushroom.
   (d)

Figure 8

7. Use a dictionary to define "binary" and "fission." How do these definitions explain this type of asexual reproduction?
8. How are budding and vegetative reproduction similar?
9. (a) What is the difference between binary fission and budding?
   (b) How are these two types of asexual reproduction similar?
10. Describe two types of vegetative reproduction.
11. How is spore formation different than the other types of asexual reproduction?
12. (a) Explain the difference between fragmentation and regeneration.
    (b) Give an example of an animal that can do both.
13. Many organisms that reproduce asexually also reproduce sexually. What are some advantages of asexual reproduction?
14. Why is having only one parent both an advantage and a disadvantage of asexual reproduction?
15. Under certain conditions, bacteria can reproduce every 20 minutes. If a population started off with a single bacterium, calculate how many bacteria would be present in six hours.
16. Oysters are a major part of the diet of sea stars. Oyster harvesters used to try to kill sea stars by cutting them up and throwing them back into the ocean. Why did this practice not reduce the number of sea stars?
17. Some lizards easily lose pieces of their tails, which they can later regenerate. Explain how this process benefits the lizard.

2.7 Explore an Issue

DECISION MAKING SKILLS

- ○ Defining the Issue
- ● Researching
- ● Identifying Alternatives
- ● Analyzing the Issue
- ● Defending a Decision
- ● Communicating
- ● Evaluating

Beyond Dolly—Cloning Mammals

Humans have long been interested in cloning living things. Cloning is a type of asexual reproduction in which a single cell or part of an organism is used to grow a new, genetically identical organism. This new organism is a clone of the parent organism. As you have learned, cloning happens naturally in organisms that reproduce asexually. All their offspring are genetically identical.

There are many science fiction stories that have cloning as the central theme. While most science fiction is a mix of science and vivid imagination, recent scientific advances have made cloning possible in animals that cannot naturally form clones of themselves. Dolly the sheep (Figure 1) is an example of a successful clone of a mammal.

Figure 1 Dolly was the first mammal to be successfully cloned from a body cell.

The Issue: Reproductive Cloning of Mammals

Because of advances in reproductive technologies, scientists are able to clone mammals from a single body cell of an existing mammal. Some people believe that this has the potential to solve many medical problems and diseases for humans. Scientists might also be able to clone animals with organs that humans would not reject. The organs could be harvested and used for transplants. As well, scientists might be able to produce clones of endangered species. These clones could be produced and introduced into their natural habitats. Cloning livestock could help to solve the shortage of food in some countries.

Not everyone agrees with cloning, however. Some people believe that this technology could create more problems than it would solve. New diseases could result. Animals with harmful mutations could be born. Animals would be discarded after their valuable parts were harvested. There have been claims that humans have been successfully cloned, although there is no direct evidence that this has happened. These claims have generated a lot of media attention. Evidence of human cloning, however, has not been properly reported to the scientific community.

Statement

Scientists should not be permitted to clone mammals because this will lead to attempts to clone humans.

Background to the Issue

In 1952, scientists first developed techniques that allowed them to clone tadpoles. In 1958, Frederick Stewart excited the scientific world by growing the first complete carrot plant from a single root cell. Even though scientists could clone frogs, they were unable to develop techniques to clone mammals. Then, in 1997, Scottish scientist Ian Wilmut cloned a sheep, which he named Dolly. Even though Dolly died in 2003, she is probably the most famous clone to date. Dolly was a normal female sheep, grown from a single cell of another sheep. She even gave birth to several lambs conceived in the normal way. Since then, other mammals have been cloned.

The Cloning Process

Dolly was created through a process that involved several steps (Figure 2). First, Wilmut and his team removed a body cell from the udder of one adult female sheep and an egg cell from another adult female sheep. They removed the nucleus from the egg cell and replaced it with the nucleus of the udder cell. They then used an electric shock to stimulate cell division in the new cell. Once the new cell had divided several times, they inserted the new embryo (developing organism) into the uterus of a third sheep. (The uterus is the organ in which the embryo develops.) The embryo continued to develop, and the sheep gave birth to Dolly.

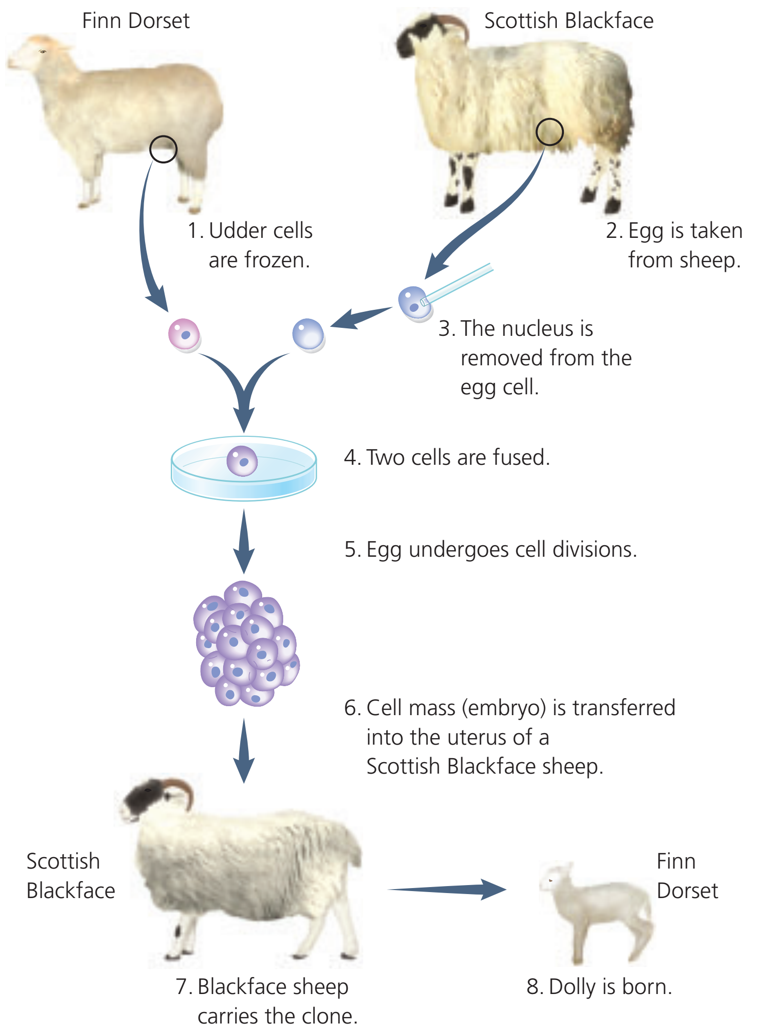


Figure 2 The cloning process involves combining the nucleus of a body cell with the cytoplasm of an egg cell.

LEARNING TIP

A concept map (Figure 2) is a collection of words or pictures, or both, connected with lines or arrows. For more information on concept maps, refer to the Skills Handbook.

The cloning process appears to be quite simple. Cloning a sheep, however, posed many biological and technical challenges. It took years of research and technical innovations to develop a process that could produce a sheep clone.

Make a Decision

1. Carefully read the statement and the background information. Consider each of the sample arguments provided in Table 1.

Table 1 Arguments on Reproductive Cloning of Mammals

Point	Counterpoint
Cloning mammals is not natural, and any artificial production of animals could cause problems, such as diseases, for the natural environment.	Other types of artificial cloning occur all the time, and diseases have not been introduced into the natural environment.
The time and money spent on research into cloning mammals could be better used to discover cures and treatments for existing human diseases.	Cloning could save money and time by reproducing valuable domestic mammals, such as cows that produce high yields of milk.
Successful cloning of mammals could lead to attempts to clone humans.	Scientists would only use human clones to save lives.

2. In your group, discuss the statement on page 61 and decide whether you agree or disagree with it. Look at the points and counterpoints in Table 1. You can expand on these arguments or generate new arguments.
3. Search for information about current mammal cloning in agriculture or attempts to clone humans and the concerns they raise. Use the information you find to support your position. Look in newspapers, a library periodical index, or on the Internet.

www.science.nelson.com GO

Communicate Your Decision

Your teacher will organize a classroom debate. Choose one person from your group to be the group's spokesperson. Prepare a reference sheet for your spokesperson. In your reference sheet, include all the main points that you want your spokesperson to make. For each of your arguments, consider arguments that the other side may counter with and be prepared to respond to them.

At the end of the debate, the class will vote on the issue. Be open-minded and willing to change your position. Vote for the most convincing arguments. Your teacher will conduct the vote and announce the results.

2A Investigation

Observing Cell Division in Plants and Animals

In Sections 2.1 and 2.4, you learned why and how cells undergo cell division. In this investigation, you will observe cell division using prepared slides and compare the process of mitosis in plant and animal cells.

INQUIRY SKILLS		
○ Questioning	● Conducting	● Evaluating
● Hypothesizing	● Recording	● Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

Question

Are there differences between plant and animal cell division?

Prediction

Predict any differences you may observe between plant and animal cell division.

Experimental Design

The dividing plant cells you will examine are from onion root tips. The animal cells are from whitefish embryos. The prepared slides show cells in various stages of cell division. Since the cells have been "frozen in time," you will not be able to observe the continuous process from prophase to telophase in any one cell.

Materials

- prepared slide of an onion root tip
- microscope
- prepared slide of a whitefish embryo

LEARNING TIP

To review how to use your microscope or how to make biological drawings, refer to the Skills Handbook.

Procedure

1. Obtain a prepared slide of an onion root tip, and place it on the microscope stage.
2. Focus the image under low power using the coarse-adjustment knob. Find cells that appear to be dividing. These will be toward the root cap, the narrower end of the specimen (Figure 1).

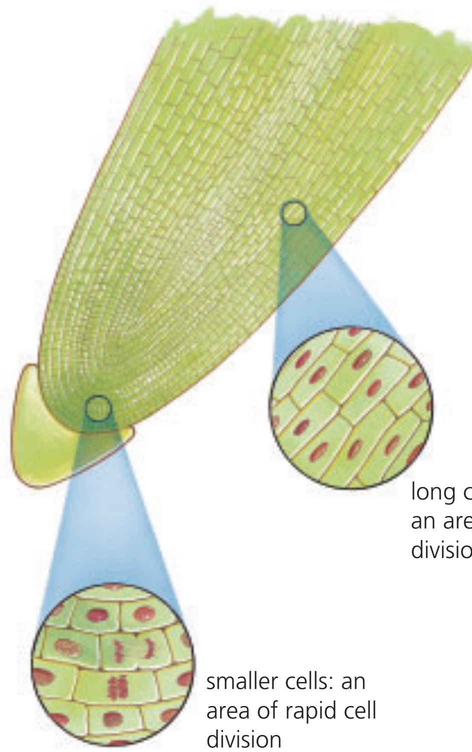
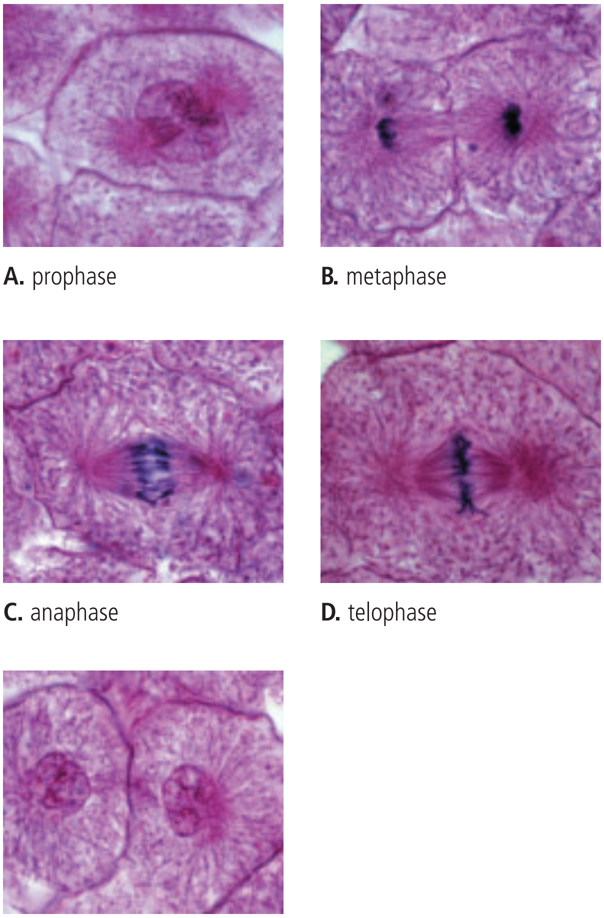


Figure 1 Step 2

3. Once you have centred the dividing cells in the field of view, rotate the nosepiece to the medium-power lens. Focus the image using the fine adjustment knob. Locate cells that are dividing. What do you observe that identifies the dividing cells?
4. Carefully rotate the high-power lens to above the specimen. Focus the image using the fine adjustment knob. Move the slide to locate cells in each phase of mitosis.
5. Draw and label a cell in each phase of mitosis. Label the structures that you can identify. These may include the nucleus, chromosomes, spindle, cell plate, and cell wall. Draw and label only the cell structures that you actually observe under the microscope. Write the name of the mitotic phase below each cell drawing.

6. Rotate the nosepiece to the low-power objective lens, and remove the slide.
7. Place the whitefish embryo slide on the stage. Focus the image using the coarse-adjustment knob. Use the photographs in Figure 2 to help you.
8. Once you have located cells that are dividing, repeat steps 3, 4, and 5.
9. Compare your diagrams with your classmates' drawings. Explain to each other any stages that one of you included but the other did not. Try to find any stages or structures that you could not locate on your own slide on your classmates' slides.
10. Rotate the low-power objective lens into place, and remove your whitefish slide.



A. prophase **B.** metaphase **C.** anaphase **D.** telophase **E.** daughter cells

Figure 2 Cell division in a whitefish embryo (magnification: 450X)

Analysis

(a) What differences did you observe between plant and animal cell division? Use a table to compare the appearance of the dividing plant cells with the appearance of the dividing animal cells.

(b) Did your observations support your prediction? Explain.

(c) Were any stages of mitosis easier or more difficult to identify? Explain why.

(d) Which cell structures were the easiest to locate?

Evaluation

(e) Why did you use plant root tips and animal embryos to view cell division?

(f) Explain why the cells you viewed did not continue to divide.

(g) How are the differences in cell division in plant and animal cells related to the differences in the structures of plant and animal cells?

(h) List one feature of each stage of mitosis that you observed that helped you identify the stage.

Synthesis

(i) Where else in plants and animals would you expect to observe rapidly dividing cells?

(j) Why do biologists use dividing cells to determine the number of chromosomes in an organism?

(k) How can knowing the stages of mitosis help scientists?

(l) If a cell has 12 chromosomes, how many chromosomes will each daughter cell contain?

2B Investigation

Determining the Rate of Cell Division in Plant and Animal Cells

An understanding of why and how cells undergo cell division is important to many fields of science. One of these fields is agriculture. A great deal of money is spent on chemicals to increase plant growth. Scientists can calculate the efficiency of these chemicals by studying rates of cell division.

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
● Hypothesizing	● Recording	● Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

Question

Can you tell how fast an organism is growing by looking at its cells?

Hypothesis

Write a hypothesis about how you can tell the rate at which an organism is growing by observing prepared slides.

Prediction

Predict what you will observe in the cells of an organism when it is growing.

Experimental Design

In Investigation 2A, you observed cell division and compared the process of mitosis in plant and animal cells. In Part 1 of this investigation, you will examine prepared slides of plant and animal cells under a microscope and determine the percentage of cells that are dividing. In Part 2, you will determine the rate of cell division by making a cell-division clock.

Materials

- microscope
- prepared slide of an onion root tip
- prepared slide of a whitefish embryo

LEARNING TIP

If you need to review how to write a hypothesis, refer to Chapter 1.

Procedure

Part 1: Determining the Percentage of Cells That Are Dividing

1. Focus the onion root tip slide under the low-power lens using the coarse-adjustment knob. Locate dividing cells, and centre them in the field of view.
2. Rotate the medium-power lens into place. Focus and centre the dividing cells.
3. Notice that the cells form lines that are roughly parallel to one another. Choose a line of cells with many cells in various stages of mitosis. Count 20 cells. Record the number of cells, in these 20 cells, that are in mitosis.
4. Calculate the percentage of cells that are dividing. For example, if you counted 10 cells dividing, you would calculate the percentage as follows:

$$\text{Percentage of cells dividing} = \frac{10}{20} \times 100\ \% = 50\ \%$$

5. Repeat steps 3 and 4 for two other lines of 20 onion cells. Record your results in a table.
6. Rotate the low-power lens into place, and remove the slide from the stage.
7. Predict whether the onion root tip or the whitefish embryo will have a greater percentage of dividing cells. Record your prediction, and give reasons for it.
8. Repeat steps 1 to 5 using the whitefish embryo, but instead of looking for a line of dividing cells, look for an area of dividing cells.

Part 2: Designing a Cell Division Clock

9. Focus the onion root tip under the low-power lens using the coarse-adjustment knob. Locate dividing cells, and centre them in the field of view.
10. Rotate the medium-power lens into place. Focus and centre the dividing cells.

11. Rotate the high-power lens into place, and locate one cell that is dividing. Determine which stage of mitosis it is in. Copy Table 1 into your notebook to record which of the four mitotic stages the cell is in.

Table 1

Stage	Number of cells	Percentage of cells in stage (%)
prophase		
metaphase		
anaphase		
telophase		

12. Move your slide, and repeat step 11 until you have recorded information for 20 dividing cells. Make sure that you do not include any cells in interphase.
13. For each stage, use the formula in step 4 to calculate the percentage of cells, and record the values in your table.
14. Repeat steps 9 to 13 using the whitefish embryo slide.
15. Calculate the length of time that cells spend in each stage of mitosis. It usually takes between 12 and 16 hours to complete mitosis. You will use 12 hours to make the calculations easier. To calculate the number of hours spent in each stage, multiply the percentage of cells by 12 hours. For example, suppose that you found 40 % of the 20 cells in metaphase:

    Time spent in metaphase $= 40\ \% \times 12\ \text{h} = 4.8\ \text{h}$
16. Draw two circles to represent two clocks: one for the onion root tip cells and one for the whitefish embryo cells.
17. Use the data you collected to create clocks that indicate the amount of time spent in each stage of mitosis.

LEARNING TIP

A clock is a type of circle (or pie) graph. Refer to the Skills Handbook for help constructing a circle graph.

Analysis

(a) Which areas of the onion root tip have the greatest amount of cell division?

(b) Were there any differences in the rates in the three areas of the whitefish embryo? What do you conclude from this?

(c) Which has the greater percentage of dividing cells, the onion root tip or the whitefish embryo?

(d) Do your results support your hypothesis?

(e) Was your prediction correct? Explain.

(f) What do your clocks indicate about the time spent in the different stages of mitosis in the plant and the animal cell samples?

Evaluation

(g) Describe possible sources of error in this investigation.

(h) How could you improve the procedure for this investigation?

(i) Are there stages missing from your cell clock? If so, identify them.

Synthesis

(j) What is the benefit of knowing the rate of cell division in various organisms?

(k) Describe a different method that you could use to calculate the rate of growth in living things.

(l) Although mitosis is divided into stages to make it easier to discuss, the process is continuous. Which of your observations suggest that mitosis is a continuous process?

(m) Choose one of the cell division rates you determined in this investigation. Draw a circle graph that shows the percentages of cells dividing and not dividing.

(n) Technology allows scientists to count cells much faster than you did in this investigation. Suggest a method for counting cells using technology.

CHAPTER 2

Review

Cell Growth and Reproduction

Key Ideas

The functions of cell division are growth, repair, and reproduction.

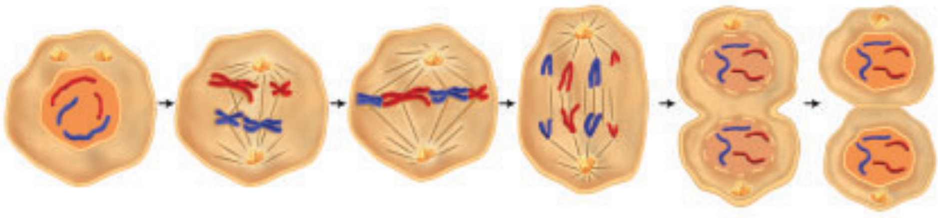
- Cell division produces new cells to increase the size of the organism.
- Cell division produces new cells to replace damaged and old cells.
- Cell division is the method that some organisms use to reproduce.

DNA in the nucleus plays a key role in normal cell functions and in cell division.

- The nucleus contains the nucleolus and the chromosomes.
- DNA is contained in the chromosomes in the nucleus of each cell and carries the genetic information to direct all the activities in the organism.
- Genes are segments of DNA on a chromosome. They carry the instructions to make proteins. This information results in individual characteristics.
- RNA is a copy of a gene segment of DNA. RNA carries the instructions from genes in the nucleus to the ribosomes, where proteins are made.
- Once a cell is large enough to divide, DNA replicates before cell division begins.

The cell cycle includes the normal cell functions and cell division.

- Cells spend most of their time in interphase, growing and performing their specific functions.
- Cell division includes mitosis and cytokinesis.
- The stages of mitosis are prophase, metaphase, anaphase, and telophase.
- Cytokinesis divides the cytoplasm in two and is different in animal and plant cells.
- The products of cell division are two genetically identical daughter cells.

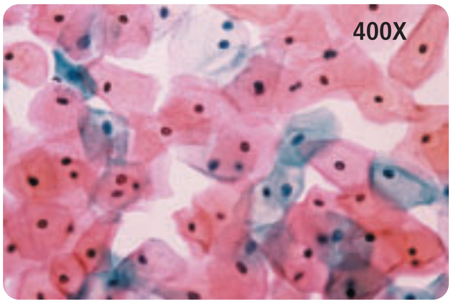


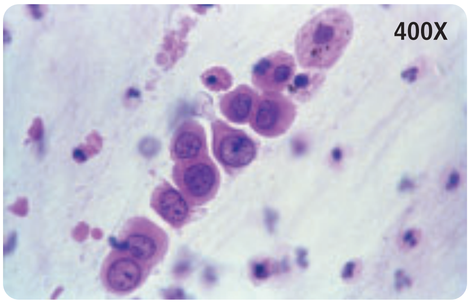
Vocabulary

nuclear membrane, p. 39
DNA, p. 39
nucleolus, p. 40
centrioles, p. 40
nucleotide, p. 42
nitrogenous bases, p. 42
amino acids, p. 43
gene, p. 44
genome, p. 44
traits, p. 45
cell cycle, p. 49
interphase, p. 49
sister chromatids, p. 49
parent cell, p. 49
daughter cells, p. 49
mitosis, p. 49
cytokinesis, p. 49
prophase, p. 50

Mutations in a cell's DNA can cause diseases, including cancer.

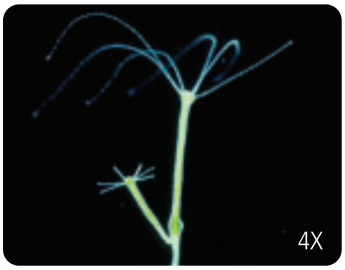
- Certain factors can cause mutations in a cell's DNA. Mutations in genes change the instructions that the genes contain. This can cause diseases such as cystic fibrosis and diabetes.
- Mutations in the genes that control cell division can cause cancer.
- Out-of-control cell division produces masses of cells, called tumours, that can interfere with normal body functions.
- Treatments for cancer include surgery, radiation therapy, and chemotherapy.





Some organisms reproduce asexually through cell division.

- Asexual reproduction involves only one parent.
- The offspring of asexual reproduction are genetically identical to the parent and to each other.
- Different types of asexual reproduction include binary fission, budding, vegetative reproduction, fragmentation, and spore formation.



spindle, p. 50
metaphase, p. 50
anaphase, p. 50
telophase, p. 50
mutation, p. 53
cancer, p. 54
benign tumours, p. 54
malignant tumours, p. 54
metastasis, p. 54
carcinogen, p. 55
sexual reproduction, p. 57
zygote, p. 57
asexual reproduction, p. 57
clones, p. 57
binary fission, p. 57
budding, p. 58
vegetative reproduction, p. 58
fragmentation, p. 59
spores, p. 59

Review Key Ideas and Vocabulary

1. Cells are constantly being replaced by new cells. Why are cells replaced, and where do the new cells come from?
2. Which process is responsible for increasing the number of cells in your body?
   (a) interphase
   (b) respiration
   (c) cell division
   (d) cell growth
3. Which type of asexual reproduction is used by bacteria?
   (a) budding
   (b) fragmentation
   (c) regeneration
   (d) binary fission
4. Which list gives the stages of the cell cycle in the correct order?
   (a) interphase, cytokinesis, prophase, metaphase, anaphase, telophase
   (b) prophase, anaphase, metaphase, telophase, cytokinesis, interphase
   (c) interphase, prophase, metaphase, anaphase, telophase, cytokinesis
   (d) cytokinesis, prophase, metaphase, anaphase, telophase, interphase
5. Which of the following terms refers to a substance that can cause cancer?
   (a) tumour
   (b) carcinogen
   (c) mutation
   (d) metastasis
6. Which of the following terms refers to the number of genes in an organism?
   (a) genome
   (b) chromosome
   (c) zygote
   (d) protein number
7. Which of the following lists gives the steps of protein production in the correct order?
   (a) RNA → DNA → ribosome → cytoplasm → protein
   (b) DNA → RNA → cytoplasm → ribosome → protein
   (c) ribosome → RNA → DNA → cytoplasm → protein
   (d) DNA → RNA → protein → ribosome → cytoplasm
8. What parts of your body undergo cell division more often than other parts? Explain your answer.
9. Identify the parts of the DNA molecule, labelled A to C, in Figure 1.

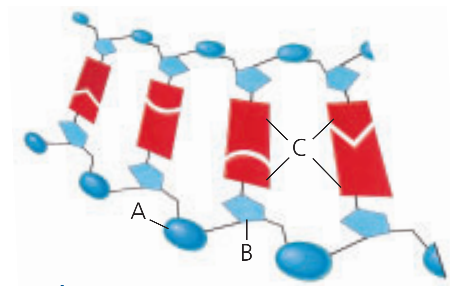


Figure 1

10. How are the daughter cells of a multicellular organism different from the daughter cells of a unicellular organism?
11. What occurs at the cellular level to cause cancer?
12. How is asexual reproduction different from sexual reproduction?
13. Why is the genetic material of a cell duplicated before cell division begins?
14. Identify the type of asexual reproduction in each of the following situations
    (a) A multicellular marine alga is broken up by a wave. Each piece of the alga grows into a new organism.
    (b)

Figure 2

    (c)

Figure 3

    (d)

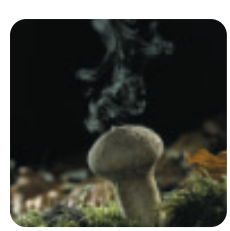


Figure 4

Use What You've Learned

15. An organism is composed of 280 cells. If each cell divides, how many cells would be present after eight divisions?

16. The following cells all divide faster than other average cells. Explain why.
(a) the roots of a pine seedling
(b) a tadpole developing into a frog
(c) human cheek cells
(d) white blood cells in the blood of a person with chicken pox

17. Use the circle graph in Figure 5 to answer the following questions.

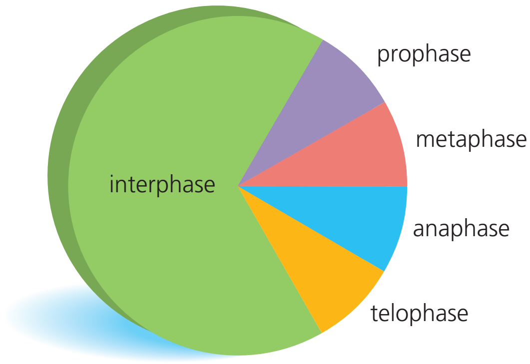


Figure 5

(a) In which stage does growth occur?
(b) In which stage do double-stranded chromosomes become single-stranded chromosomes?
(c) During which stages is the cell undergoing cell division?
(d) When does the genetic material get replicated?
(e) During which stage would cytokinesis begin?
(f) During which stage would the cell plate begin to form?

18. (a) If a parent cell has 12 chromosomes, how many chromosomes will each daughter cell have following mitosis?
(b) Predict a possible outcome for each daughter cell if all the chromosomes moved to only one pole of the cell during anaphase.

19. Explain how a plant nursery could make use of one type of asexual reproduction.

20. Compare RNA and DNA molecules in terms of their structure, function, and location.

21. Explain how genes can cause a range of eye colours.

Think Critically

22. Your body does not have all the cells you had when you were a baby. What has happened to those cells?

23. Describe several ways in which industries could use information on the rate of cell division in certain organisms.

24. Certain herbicides (chemicals that kill plants) make plant cells divide faster than normal for a species. Why would these herbicides kill weeds? (Hint: Think about what cells are doing when they are not dividing.)

25. Why do some pesticides cause cancer?

Reflect on Your Learning

26. Cloning of mammals is a scientific and technological achievement, but it raises many concerns. Did the discussion of reproductive cloning of mammals change your opinion about the pros and cons of using this technology? Explain why or why not.

27. The stages of mitosis are named so they can be more easily discussed. Cells do not stop between stages. What observations did you make in your investigations to suggest that mitosis is a continuous process?

Visit the Quiz Centre at
www.science.nelson.com GO

CHAPTER

3

Sexual Reproduction

KEY IDEAS

- Meiosis is the process that produces sex cells.
- Sexual reproduction involves the joining of genetic material from two parents.
- Sexual reproduction creates the incredible diversity among members of the same species.
- There are advantages and disadvantages to both asexual and sexual reproduction.
- Organisms use a variety of strategies to ensure the success of sexual reproduction.
- Scientists have used their knowledge of sexual and asexual reproduction to develop reproductive technologies.

Chapter Preview

As you look around your neighbourhood, you will notice the incredible variety of traits among the different organisms. Where did all this variety come from? Most organisms, like these dogs, demonstrate similarities as well as differences. These similarities and differences are the result of sexual reproduction.

Some organisms can reproduce both asexually and sexually. What would be the advantages of this? Why do living things reproduce in so many ways? Does sexual reproduction have advantages over asexual reproduction? How does sexual reproduction occur in plants? Where are the sex cells in other organisms? Do all living things that reproduce sexually have separate males and females? If not, how do they reproduce sexually? Are there advantages to having both male and female sex cells in one individual?

In this chapter, you will learn about sexual reproduction and the diversity it produces. Different species use different methods to reproduce sexually. Specialized organs in many organisms are designed to ensure successful reproduction and the survival of the offspring. Reproductive technologies allow humans to use the mechanisms of sexual reproduction to enhance the productivity of domestic organisms.

TRY THIS: *Observing Pollen*

Skills Focus: observing, recording

Materials: paint brush, flowers with pollen, depression slides, cover slips, hand lens, microscope, pollen grains soaked in 10 % sucrose solution, disposable masks (as required)

The male sex cells in a flower are contained in the pollen, which is found on the stamen of the flower. The sex cells in the pollen grains will fertilize the egg cells of the flower. (The parts of a flower are summarized in Figure 4 on page 85.)

Students who are sensitive to pollen should wear a disposable mask.

1. Using a fine paint brush, brush some of the pollen from the flower onto a depression slide. Cover the pollen with a cover slip. Observe the slide with the hand lens and then with the microscope.
2. Using the pipette, place a drop of the pollen grain liquid onto a depression slide and cover it. Observe the slide with the hand lens and then with the microscope.

A. Draw a pollen grain from each sample.

B. Describe any differences you observe.

3.1 Meiosis

LEARNING TIP
Scan the titles, headings, and subheadings, as well as the words in bold type. Make predictions about what you expect to learn in Chapter 3.

In Chapter 2, you learned that the offspring of parents that reproduce asexually are genetically identical to each other and to the parents. You also learned that asexual reproduction involves cell division and sexual reproduction involves sex cells joining to produce a zygote. In this section, you will find out how the sex cells are formed.

Multicellular organisms that reproduce sexually have two types of cells: somatic cells and sex cells. **Somatic cells**, also called body cells, reproduce by cell division and make up the vast majority of an organism's cells. Human somatic cells have 23 pairs of chromosomes, for a total of 46 chromosomes. The sex cells are also called **gametes**. Gametes have half the chromosomes of the parent cell. Gametes make up an extremely tiny fraction of an organism's cells. Male gametes are called **sperm**, and female gametes are called **eggs** or **ova** (singular: ovum) (Figure 1).

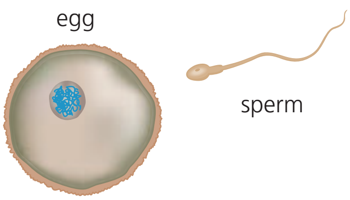


Figure 1 Sperm cells are much smaller than egg cells and have a very different shape.

Chromosome Numbers

In general, individuals of the same species have the same number of chromosomes. Goldfish have 94 chromosomes, fruit flies have 8, and humans have 46. If sexual reproduction involves the fusing of genetic material from two individuals, then why doesn't the resulting offspring contain twice the number of chromosomes as the parents? To maintain the same number of chromosomes from generation to generation, there needs to be a way to reduce the number of chromosomes that are passed on from each parent. The process that produces gametes, which have half the number of chromosomes as the parent, is called **meiosis**.

Meiosis happens only in the cells that produce gametes. These cells are called reproductive cells. Meiosis is sometimes called "reduction division" because it reduces the chromosome number by half. Each fruit fly gamete (Figure 2) contains four chromosomes—half of the genetic material of the parent. Cells with half the chromosome number of the parent are called **haploid**, symbolized with a single *n*. Cells that have a complete set of chromosomes are called **diploid** symbolized as 2*n*.

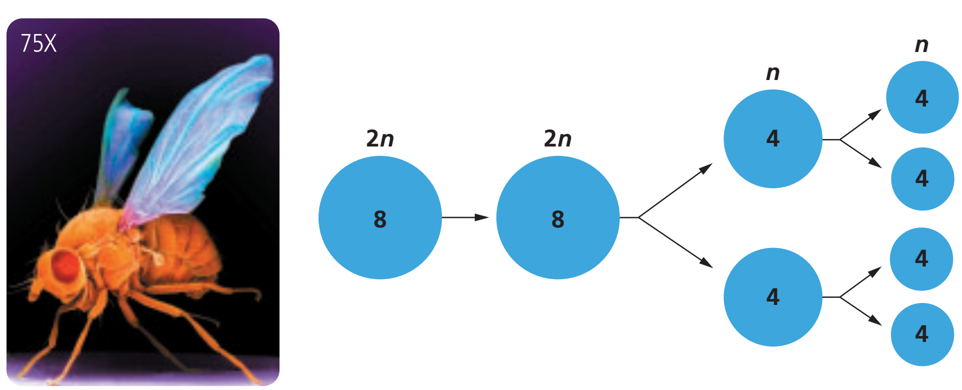


Figure 2 Fruit fly somatic cells have eight chromosomes (diploid or 2*n*) and are produced by mitosis. Fruit fly gametes have four chromosomes (haploid or *n*) and are produced by meiosis.

Homologous Chromosomes

Diploid (2*n*) somatic cells have their chromosomes arranged in pairs. Each chromosome has a corresponding chromosome, forming a pair. The pairs of corresponding chromosomes are called **homologous chromosomes** (Figure 3). The genes on one of the chromosomes in the pair correspond to the genes on the other chromosome in the pair. In fruit flies, for example, one chromosome has a gene for eye colour. The corresponding chromosome also has a gene for eye colour in the same location. Homologous chromosomes come from the parents. Each parent contributes one half (*n*), of the chromosomes. Each fruit fly parent contributes four chromosomes to the offspring.

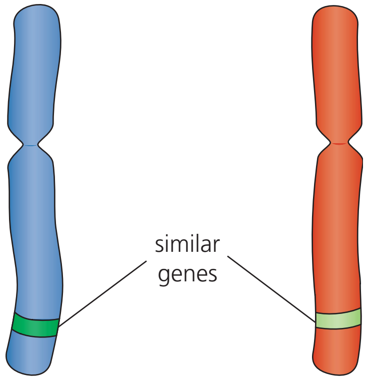


Figure 3 Both chromosomes in a pair of homologous chromosomes carry genes that code for the same characteristic. One chromosome in the pair comes from the female parent, and the other chromosome comes from the male parent.

Did You KNOW?

Polyploidy

Have you noticed that some blueberries in fruit markets are almost twice as big as those found in the wild? Cultivated blueberries have four copies of each chromosome instead of the usual two copies. This 4*n* condition is called polyploidy. Polyploidy produces larger plants and larger fruits. Other food plants, such as wheat, plums, and grapes, can also have more than the usual 2*n* chromosome number.

The Stages of Meiosis

Meiosis is actually composed of two phases, meiosis I and meiosis II, and produces four haploid gametes (Figure 4 on the next page).

The first phase, **meiosis I** (Figure 4(b)), is similar to mitosis (Figure 4(a)) during interphase and prophase. During interphase, the chromosomes replicate to form joined sister chromatids. During prophase, the chromosomes shorten and thicken, and become visible with a light microscope. The chromosomes behave differently than in mitosis, however, during metaphase and anaphase. Recall that during metaphase, in mitosis, the sister chromatids line up along the middle, or equator, of the cell. During anaphase, the sister chromatids separate and are pulled to opposite ends, or poles. In meiosis I, the homologous chromosomes (each joined to its sister chromatid) pair up along the equator. Then, during anaphase in meiosis I, the pairs of homologous chromosomes separate and move to opposite poles along with their sister chromatids. The sister chromatids do not separate in meiosis I. Meiosis I results in two daughter cells, but each has only one of the homologous chromosomes, with its sister chromatid still attached.

LEARNING TIP

Active readers adjust their reading to fit the difficulty of the text. If you find a topic difficult to understand, divide the reading task into smaller chunks, read more slowly, and reread. Reread the section on meiosis as many times as you need to, before you move on.

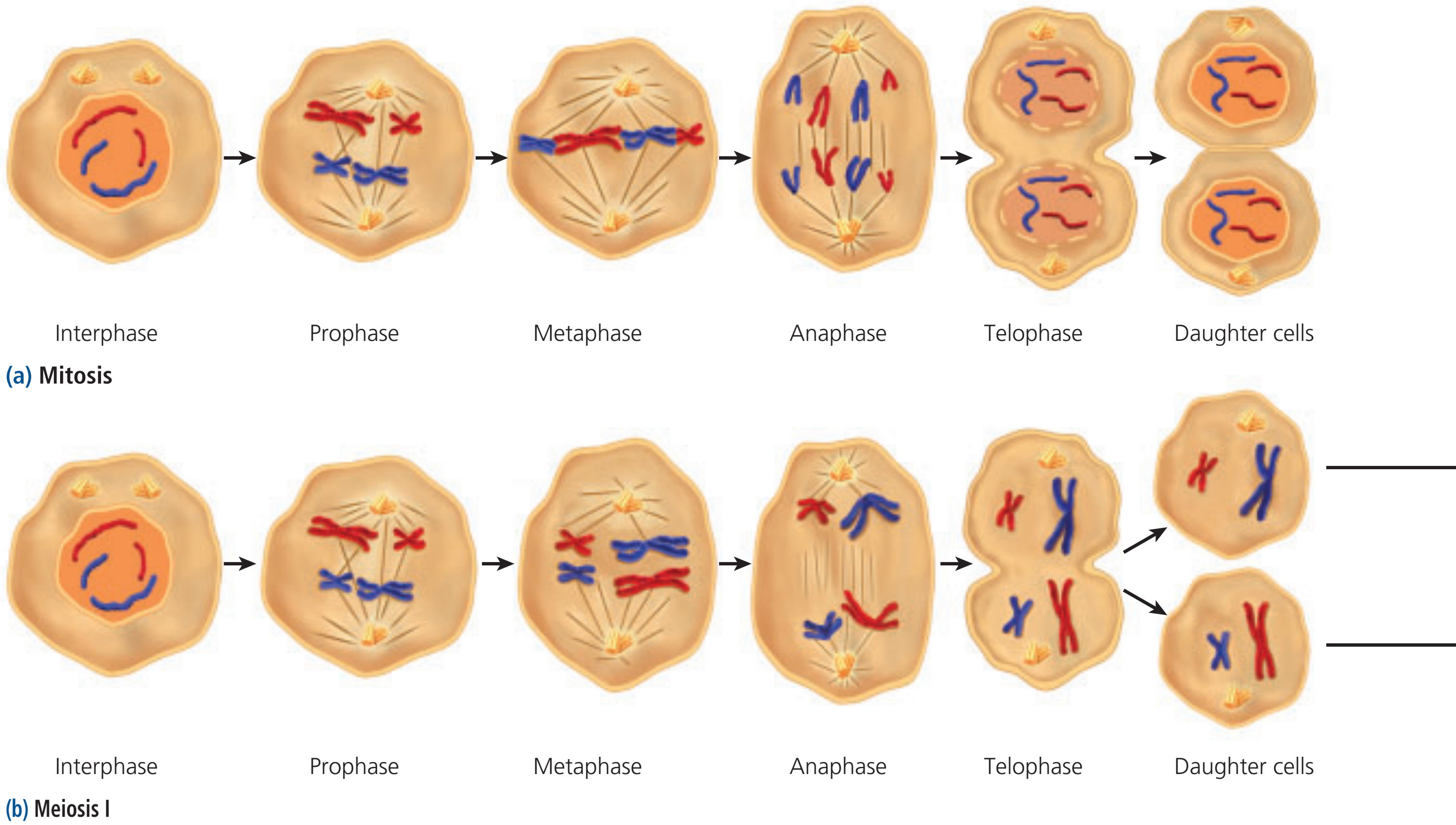


Figure 4 Mitosis (a) results in two diploid daughter cells with the same number of chromosomes as the parent cell. The sister chromatids have separated. Meiosis I (b) results in two daughter cells, each with half the chromosomes of the parent cell. Notice that the sister chromatids are still attached. These cells undergo meiosis II (c).

Recall that, in mitosis, the sister chromatids separate into two daughter cells, each with the same number of chromosomes as the parent cell.

During the second phase of meiosis, **meiosis II** (Figure 4(c)), the sister chromatids in the two daughter cells line up at the equator of the cell. Each chromatid is pulled to the opposite pole. The nuclear membranes reform, and cytokinesis occurs, resulting in four haploid daughter cells called gametes. This second phase is similar to mitosis, in which the sister chromatids separate. But since meiosis II starts with two daughter cells, which both divide in two, four daughter cells are produced. Mitosis and meiosis are compared in Table 1. GO

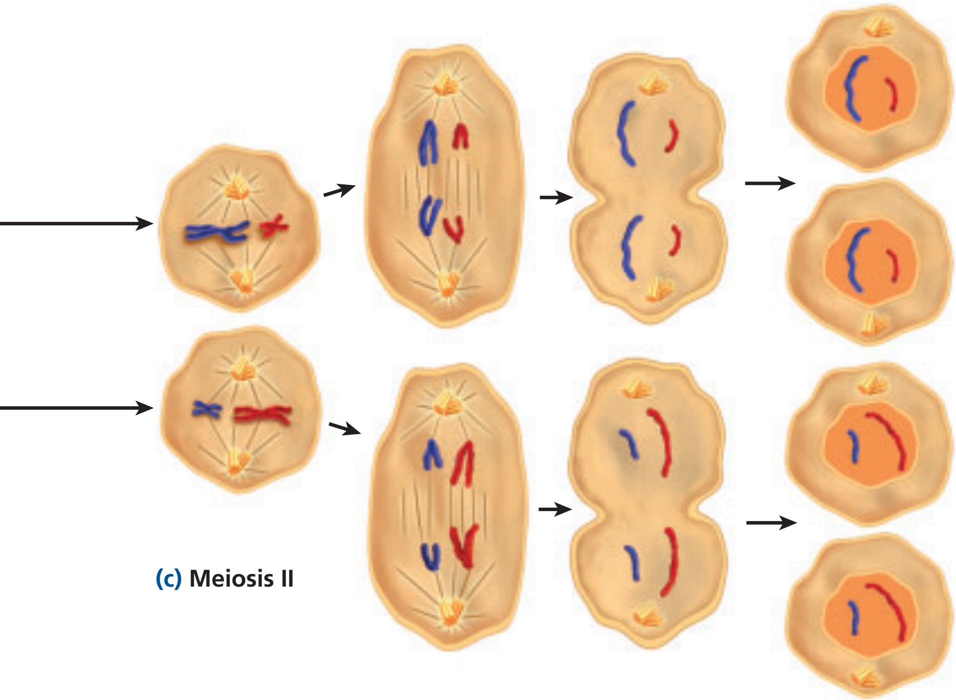
LEARNING TIP

Check that you understand the differences between mitosis and meiosis (summarized in Table 1) by explaining them to a partner.

To learn more about meiosis, go to **www.science.nelson.com** GO

Table 1 A comparison of mitosis and meiosis

	Parent cell (chromosome number)	Sister chromatids …	Number of daughter cells	Number of chromosomes in daughter cells
mitosis	$2n$	separate during anaphase	2	$2n$
meiosis	$2n$	stay together in meiosis I, but separate in meiosis II	4	n



(c) Meiosis II

TRY THIS: Comparing Meiosis and Mitosis

Skills Focus: creating models, observing, communicating

Materials: craft materials, such as pipe cleaners, wool, modelling clay, twist ties, string, rubber bands, and paper clips

In Chapter 2, you built a model of mitosis to help you understand that it is a continuous process. Here you will build a model to illustrate the process of meiosis.

1. Work with a partner to build two models. One will show the stages of meiosis and the other, the stages of mitosis. Use two different colours or shapes to distinguish between the homologous chromosomes. To simplify your models, build only four chromosomes (two homologous pairs). Be sure that your models are large enough to allow the chromosomes enough room to be moved to the opposite poles of the cell. Also, be sure that you use enough materials to demonstrate both meiosis I and meiosis II.
2. Describe to your partner how meiosis I and meiosis II are different from mitosis.

A. What has to happen before meiosis begins? When does this occur? What are the structures called now?

B. What is the end product of meiosis?

C. What is the end product of mitosis?

3.1 CHECK YOUR Understanding

1. How do somatic cells and sex cells differ from each other? How are they similar?
2. Name the two types of gametes.
3. Describe homologous chromosomes in terms of the number of genes and the type of genes they have.
4. Explain how the terms *haploid* and *diploid* are related.
5. What types of cells are haploid? What type of cells are diploid?
6. A chicken has 78 chromosomes in each somatic cell. How many chromosomes are in one of its gametes?
7. How many pairs of homologous chromosomes are in a human somatic cell? How many pairs are in a fruit fly somatic cell?
8. If an organism has 18 chromosomes, how many homologous pairs does it have?
9. What are the two phases of meiosis called?
10. Why is meiosis sometimes called "reduction division"?
11. What are the end products of meiosis?
12. How are mitosis and meiosis similar? How are they different?
13. In mitosis, the sister chromatids separate during anaphase. When do they separate in meiosis?
14. Copy Table 2 into your notebook, and complete it.
15. Identify Figure 5 as mitosis or meiosis. Explain your answer.

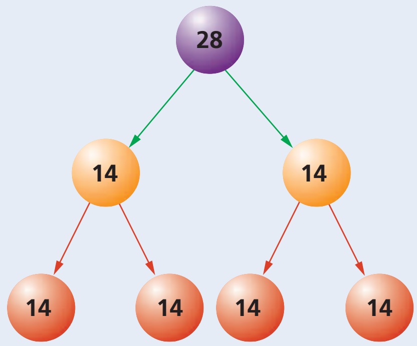


Figure 5

16. During which phase of meiosis do the sister chromatids form?
17. Why is meiosis necessary for sexual reproduction?

Table 2

	Chromosome number				
Organism	**Parent**	**Diploid**	**Somatic cell**	**Haploid cell**	**Gametes**
human		46			
chimpanzee				24	
cat			38		
guinea pig					32
horsetail	216				

3.2 Sexual Reproduction and the Diversity of Life

Meiosis is only the first stage of sexual reproduction. It produces gametes. To reproduce sexually, however, the gametes that are produced by one organism have to join with the gametes that are produced by another organism of the same species. In this section, you will take a closer look at sexual reproduction and learn why it is so important.

LEARNING TIP

Adjust your reading pace. Pause after reading each paragraph on this page.

Fertilization Produces Diploid Cells

The joining or fusing of two gametes is called **fertilization** (Figure 1). Recall that meiosis produces haploid daughter cells (n), called gametes, which contain half the genetic material of the parent cell. When two haploid gametes fuse during fertilization, the resulting diploid cell has a complete set of chromosomes ($2n$). The first diploid cell of the offspring is called the zygote.

$$\textbf{sperm } (n) + \textbf{egg } (n) = \textbf{zygote } (2n)$$

The zygote receives half of its chromosomes from each parent. For example, human gametes have 23 chromosomes. After fertilization, the resulting zygote has 46 chromosomes or 23 pairs of chromosomes. This first cell of the new organism will undergo cell division to increase in size. Each new cell will contain the same genome as the zygote.

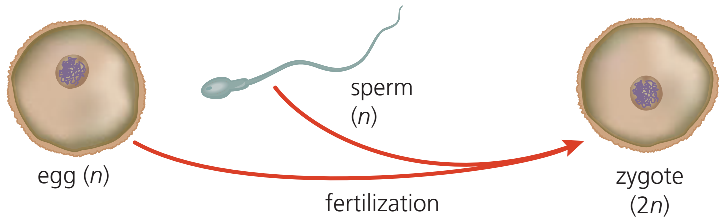


Figure 1 Fertilization is the fusion of haploid gametes (sperm and egg) to produce a diploid zygote.

Diversity Among Offspring

There is a vast amount of variation, or **diversity**, among the different species. For example, mosses look very different from butterflies or elephants. Within a species, there is also a vast amount of diversity. The dogs pictured in the Preview, on pages 72 and 73, look slightly different from one another. Look around your classroom and observe some of the obvious differences among individual humans. Some of your classmates are taller or shorter than you are and have different-coloured hair, skin, and eyes. Even though you may resemble members of your immediate family, there are differences. Sexual reproduction accounts for all this variation.

Each gamete contributes one half of each pair of homologous chromosomes in the zygote. Having homologous chromosomes produces the variation among individual members of the species. Even though each homologous

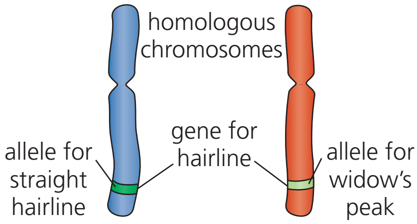


Figure 2 The different forms of a gene are called alleles. In any one individual, there are only two alleles for every gene—one allele on each homologous chromosome.

chromosome has a corresponding gene, these genes may be slightly different from one another. The different forms of the same gene are called **alleles** (Figure 2). In humans, for example, homologous chromosomes may contain two different alleles for the gene that controls the shape of the hairline: one chromosome has the allele for a widow's peak and the other chromosome has the allele for a straight hairline (Figure 3). The allele for a widow's peak is dominant. A **dominant allele** will express its trait (the trait will show up in a person's appearance) if it is present. The allele for a straight hairline is recessive. A **recessive allele** will only be expressed if both chromosomes contain the recessive allele. If an individual has one of each allele, the dominant trait is expressed.


(a)


(b)

Figure 3 Humans can have either a widow's peak (a) or a straight hairline (b).

Figure 4 These horses are both roans. They have two colours of hairs in their coats. One has a mix of black hairs and white hairs. The other has a mix of brown hairs and white hairs.

In carnations, when a plant has one allele for red flowers and one allele for white flowers, the result is pink flowers. This is incomplete dominance: two different alleles produce a mixture of the traits. Codominance occurs when both traits are expressed in one individual. An animal born with an allele for white hair and an allele for red hair will have a roan-coloured coat, with a mix of white hairs and red hairs (Figure 4). In both cases, each parent has contributed only one of its two alleles in its sperm cell or egg cell.

Some characteristics are controlled by more than one gene or there are more than two alleles of the gene. In these cases, the combination of the two alleles from both parents can produce an entirely different trait in the offspring. Eye colour in humans is one example. The amount of pigment and the pattern of pigment in the eye are controlled by several genes. The incredible process of sexual reproduction produces the different combinations that account for the vast diversity among living things.

Comparing Sexual and Asexual Reproduction

Sexual reproduction is much more complicated than asexual reproduction. Does this complexity mean that sexual reproduction is better than asexual reproduction? Both methods of reproduction have existed for millions of years, and both methods have advantages and disadvantages.

Advantages and Disadvantages of Sexual Reproduction

The most important advantage of sexual reproduction is that the offspring are genetically different from their parents and from each other. This variation allows individual organisms to adapt to changes in the environment. If the environment changes in some way, there will be a few individuals who have small differences that allow them to survive in the new environment. They will survive to reproduce and pass on the traits that helped them survive to their offspring. For example, throughout human history, there have been outbreaks of new diseases, which have killed large numbers of people. In each outbreak, however, some people who were exposed to the disease were able to fight it. They survived to reproduce and passed on their ability to fight the disease to their children.

A disadvantage of sexual reproduction is that an individual needs to find a mate. Without a mate, no offspring can be produced. Sexual reproduction also tends to produce fewer offspring than asexual reproduction. As well, sexual reproduction can be a lot slower. Most organisms that reproduce sexually have to grow and develop before they start to produce gametes. For example, female orcas need to grow and develop for eight to ten years before they can reproduce (Figure 5).

Figure 5 This juvenile orca, seen swimming above its mother, will not be able to reproduce for several years.

Advantages and Disadvantages of Asexual Reproduction

There are several advantages of asexual reproduction. If a parent does well in its environment, the offspring will also do well in the same environment because the offspring are genetically identical to the parent. Another advantage is that only one parent is necessary. A parent does not have to find a mate in order to reproduce. Therefore a parent can reproduce frequently, and can produce a large population in a relatively short time. For example, a bacterium living in your gut has a warm environment with plenty of food. It can take advantage of these conditions and reproduce itself very rapidly, about every 20 minutes. Through binary fission, it can produce millions of offspring in just 24 hours. This rapid reproduction means that all the daughter cells can take advantage of the same good conditions.

Producing genetically identical offspring can also be a disadvantage. If the environment changes, all the offspring will be affected the same way as the parent. For example, when you take an antibiotic, all the millions of important bacteria produced through binary fission in your gut are killed if they have no resistance to the antibiotic.

Table 1 summarizes the features of asexual and sexual reproduction.

Table 1 A comparison of asexual and sexual reproduction

Feature	Asexual reproduction	Sexual reproduction
Number of parents	one	two
Number of offspring	usually many	few to many
Variety of offspring	genetically identical	genetically different
Speed of reproduction	usually fast	usually slow
Timing	anytime, once mature	once mature, only when a mate is available

Did You KNOW?

Cool Kittens

The environment influences many genetic traits. Fur colour in Siamese cats is influenced by temperature. The kittens are born white. The cooler parts of the body (face, ears, paws, and tail) will turn a darker colour than the rest of the body as the kittens grow.

LEARNING TIP

Tables help readers identify specific information quickly. As you study Table 1, ask yourself, "How is the information organized?" Think about what is being compared. Ask yourself, "What is the basis of the comparison between asexual and sexual reproduction?"

3.2 CHECK YOUR Understanding

1. What are the two types of gametes? Where is each produced?
2. How does a zygote form?
3. What process occurs immediately after a zygote forms?
4. What process produces each of the following?
   (a) gamete
   (b) zygote
   (c) more skin cells
5. Explain the difference between an allele and a gene.
6. How many alleles for a trait are contained in each of the following?
   (a) gamete
   (b) zygote
   (c) parent
   (d) offspring
7. In pea plants, flowers can be purple or white. In carnations, flowers can be red, white, or pink. Which situation is an example of incomplete dominance?
8. Give one reason why the puppies in Figure 6 are not identical to either parent.

Figure 6

9. For each photograph in Figure 7, identify the type of reproduction, asexual or sexual, that is indicated.

(a)

(b)

(c)

(d)

Figure 7

10. Explain why genetically different offspring might have a better chance of survival than genetically identical offspring.
11. Why do asexually reproducing organisms often produce many offspring?
12. Give one advantage and one disadvantage to producing an offspring from only one parent.
13. Give one advantage and one disadvantage to producing an offspring from two parents.

3.3 Methods of Sexual Reproduction

In Chapter 2, you learned about several types of asexual reproduction. Now you will learn about several methods of sexual reproduction, used by different organisms. These methods range from a simple exchange of genetic material between cells to complex fertilization processes involving specialized structures.

Conjugation

Some organisms that reproduce asexually by binary fission can also reproduce sexually by conjugation. **Conjugation** occurs when two unicellular organisms transfer or exchange some of their genetic material. Conjugation only happens in some bacteria and certain protists, such as Paramecium. The details of conjugation are slightly different in different species. In the bacteria *E. coli*, one cell copies an extra piece of its DNA, called a plasmid, and donates the plasmid copy to another cell (Figure 1). Both the daughter cells then reproduce asexually by binary fission. The offspring they produce contain the same amount of DNA as the parent cell. Conjugation increases the diversity of individuals in unicellular species. This may be a factor that helps some bacteria become resistant to antibiotics. They survive the antibiotics and pass on their resistance to their offspring.

LEARNING TIP
Check your understanding of conjugation by explaining Figure 1 to a partner.

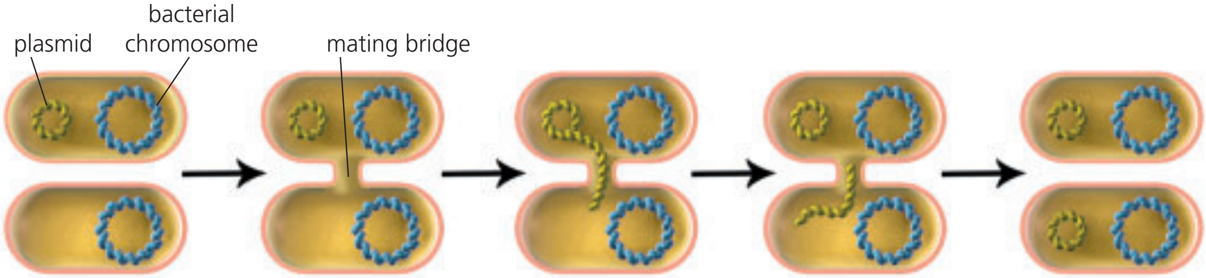


Figure 1 Conjugation is a form of sexual reproduction used by bacteria to transfer genetic material in the form of a plasmid. Two bacteria cells line up, side by side, and a mating bridge forms between them. One bacterial cell transfers a replicated plasmid to the adjacent cell. The cells then separate.

Hermaphrodites

Plants and some animals are attached to one location throughout their life and rarely come in contact with other members of their species. Other animals, such as earthworms, may only contact a few other members of their species during their travels. If the other individual encountered is not the opposite sex, reproduction cannot take place. To get around this situation, some species are hermaphrodites. A **hermaphrodite** is an organism that produces both male and female sex cells in the same individual. Hermaphrodites can mate with any other member of their species to produce offspring.

If you would like to learn more about earthworms, go to **www.science.nelson.com** GO

Earthworms are hermaphrodites. All earthworms produce both eggs and sperm. They cannot fertilize their own eggs, however. To reproduce sexually, two earthworms attach, exchange sperm, and then separate (Figure 2). The sperm cells are stored in a special sac until the eggs are ready. Within a few days, fertilization takes place in a mucus ring secreted by the clitellum, the thickened band on an earthworm. The ring becomes a cocoon for the fertilized eggs and slips off in the soil. The baby earthworms hatch about a week later. GO

Figure 2 Hermaphroditic earthworms reproduce sexually. Two earthworms attach and transfer sperm to each other. Both parent earthworms can produce offspring.

TRY THIS: *Two Sexes in One*

Skills Focus: observing, measuring, recording

Materials: living earthworms, magnifier (lens or loupe), dissecting microscope

Earthworms are hermaphrodites. Each organism has both male and female reproductive systems. In this activity, you will examine an earthworm and find its reproductive structures.

1. Examine your earthworm specimen. Identify the anterior (head) end and the posterior (tail) end. The pointed end is the anterior end. It has an extra lobe of tissue over the mouth.
2. Earthworm structures are located on specific segments. Count the segments to the clitellum, the obvious swelling on the earthworm. Make a drawing of your earthworm, and label the clitellum.
3. Look for openings on the ventral (underside) side of the earthworm. You may need to use a magnifier. On segment 14, there is a pair of pores that lead to the female reproductive system. These female pores may be difficult to find because they are in the grooves. The male pores on segment 15 are easier to find. Locate the male pores. Label the male and female pores on your drawing.
4. Join another group. Line up your two earthworms, anterior to posterior, so that the ventral surfaces are touching.

A. Where are the male and female pores when the two clitella are aligned?

B. What are the advantages of being a hermaphrodite?

Figure 3 Adult sponges are fixed to one location and contain both male and female reproductive structures.

Aquatic hermaphrodites, such as sponges (Figure 3) and barnacles, are fixed to one location for most of their lives. These animals often produce sperm and eggs at different times. This prevents the sperm from fertilizing the animal's own eggs, which would produce identical offspring. In sponges, the sperm are released into the water and are carried by water movement to other sponges. Fertilization occurs internally after the sperm enter the sponge's central cavity through tiny pores. The baby sponges, called larvae (singular: larva), are mobile and are released into the water. They swim to other locations, anchor themselves to the bottom, and grow. Barnacles have a penis, which extends into a neighbouring barnacle to deposit the sperm. The barnacle larvae are expelled into the water and are carried by water currents to other locations.

Flowering Plants

Most flowers contain both male and female reproductive organs, and so are hermaphrodites. The male reproductive structure is the **stamen** (Figure 4). The stamen is made of the **filament**, a stalk that supports the anther. The **anther** is the top of the stamen and produces pollen. **Pollen** grains contain the male gametes. There are usually several stamens on each flower. The female reproductive structure is the **pistil**. The top of the tube-like pistil is the stigma. The sticky **stigma** receives a pollen grain, which will travel down the tube-like **style** to the **ovary**, where the eggs are contained. Surrounding the male and female structures are petals. **Petals** are the coloured leaf-like structures of most flowers. The organisms that pollinate flowers are attracted to the coloured petals. At the base of the flower, where it joins the stem, are sepals. **Sepals** are tiny leaf-like structures that protect the flower while it is in the bud stage. 3A *Investigation*

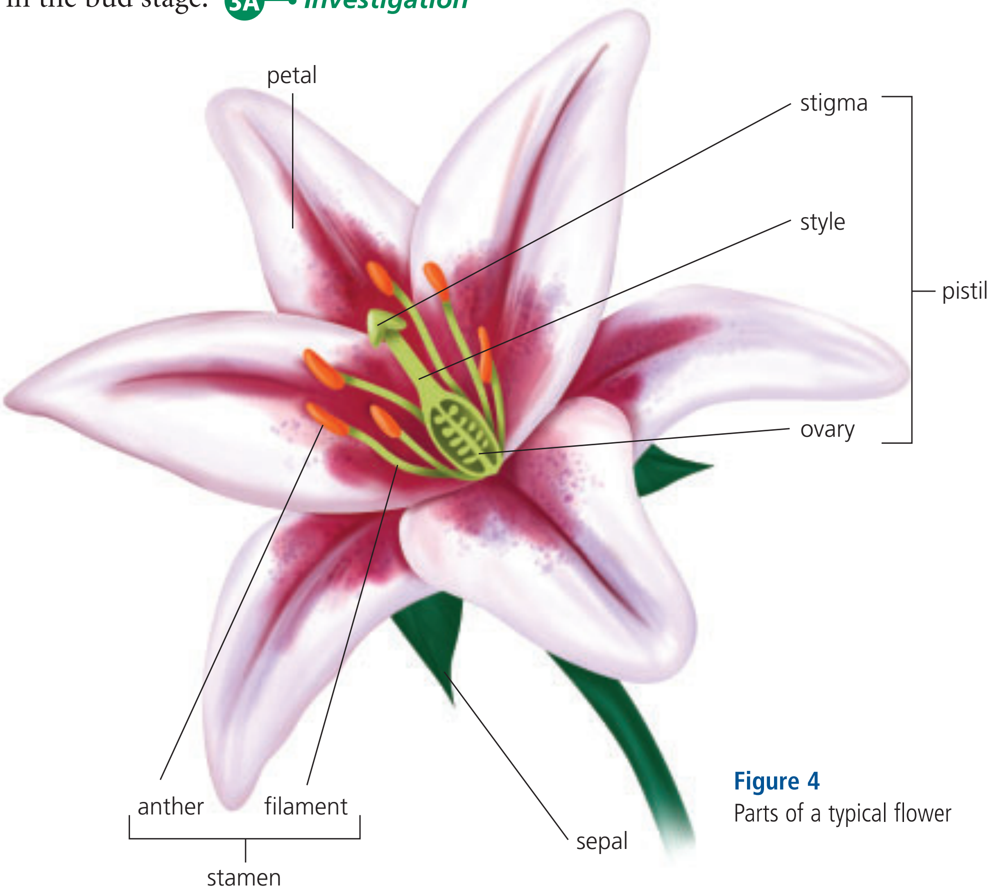


Figure 4
Parts of a typical flower

In most sexually reproducing organisms, the sperm cells move to the eggs. In flowering plants, the sperm cells are contained in the pollen grains. **Pollination**, the process by which pollen is moved from the male structures to the female structures, occurs in a variety of ways. Pollen can be moved from the male structure of one flower to the female structure of another flower by wind, insects, birds, or mammals. This is called cross-pollination. Some plants can pollinate themselves. The pollen produced by a flower can pollinate other flowers on the same plant. This is called self-pollination. Fertilization follows pollination. The fertilized egg, or zygote, develops into a seed in the ovary of the flower. GO

3A *Investigation*

Examining Flowers

To perform this investigation, turn to page 98.

In this investigation, you will investigate the structures of several different types of flowers.

LEARNING TIP

Look closely at Figure 4. Examine each part of the diagram, and check that you understand what it shows. Refer to the words in bold for more information.

If you would like to learn more about the parts of a flower, go to
www.science.nelson.com GO

Separate Sexes

Many complex animals and some plants have separate female and male individuals. The females produce eggs, and the males produce sperm.

Not all plants have male and female reproductive structures in the same flower. Conifers, such as pine and fir trees, have separate male and female cones on the same plant (Figure 5). Some species have separate male and female flowers on the same plant. Other species, such as poplar trees, have separate male and female flowers on separate plants.

In animals that have separate sexes, there are two methods of fertilization: external fertilization and internal fertilization.

Figure 5 Male and female cones are found on the same fir tree. The larger female cone contains the developing seeds.

External Fertilization

In many aquatic animals, such as salmon, the female releases her eggs into the water and the male then releases his sperm over the eggs. Since the sperm and the eggs unite outside the body, this method is called **external fertilization** (Figure 6). Hundreds or even thousands of eggs and sperm are produced to ensure that enough will unite and grow to be adults. Both the gametes and the developing young are vulnerable to environmental conditions and predators. GO

If you would like to learn more about a salmon's life cycle, go to
www.science.nelson.com GO

(a)

(b)

Figure 6 After a female sockeye salmon (top) lays eggs in a nest she made in the gravel, the male (bottom) fertilizes the eggs (a). The eggs are fertilized externally when the male releases sperm (seen here as a milky substance) over the eggs (b).

Did You KNOW?

Slim Chance of Survival

Female salmon lay between 2500 and 7500 eggs in a nest. Because of the many hazards they face, only four or five fertilized eggs from a nest will survive long enough to reproduce.

www.science.nelson.com GO

A spectacular reproductive event occurs in coral reefs. Coral reefs are made of millions of tiny animals, called corals. Each animal builds a hard shell. These shells fuse together to make up a reef. Reproduction occurs when the males and the females both release their eggs and sperm into the ocean at the same time. Fertilization is by chance, as millions of tiny cells fill the water and are carried by the movement of the water (Figure 7).

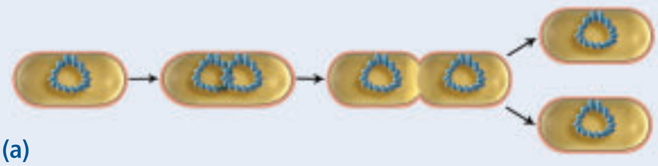
Figure 7 Thousands of coral animals each release an egg to be fertilized.

Internal Fertilization

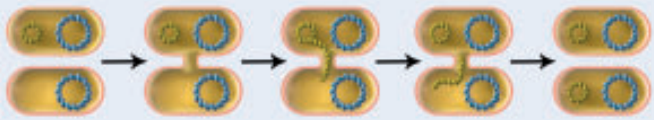
Some aquatic animals, such as sharks, and most terrestrial (land) animals, require the sperm from the male to be deposited inside the body of the female. These animals have specialized reproductive structures to accomplish this. (The reproductive structures of humans are discussed in Chapter 4.) Since the union of the sperm and the egg occurs inside the female, this method is called **internal fertilization**.

3.3 CHECK YOUR Understanding

1. Look up the word *conjugation* in a dictionary. Why is *conjugation* a good word to describe this type of reproduction?
2. Name the method of reproduction used by each bacterium shown in Figure 8. Give one advantage of the method.



(a)



(b)

Figure 8

3. How does being a hermaphrodite help an earthworm reproduce?
4. Do earthworms use internal or external fertilization?
5. Give an example of how an organism prevents its sperm from fertilizing its own eggs.
6. List the flower structures, labelled A to E, in Figure 9. Indicate which structures are male and which are female.
7. Describe two ways that pollen from one flower reaches another flower of same species.
8. List some environments where external fertilization occurs.
9. Describe some risks of external fertilization, and explain how organisms that use this method have adapted to each risk.
10. During which stages of the life cycle are salmon most vulnerable to predators?
11. Explain why organisms that use internal fertilization often produce fewer offspring than organisms that use external fertilization.
12. Use a Venn diagram to compare internal and external fertilization. Your comparison should address the following areas: sex cells, egg, sperm, fertilization, zygote, mother, father, offspring.
13. Which method of fertilization—internal or external—do most flowers use?
14. An earthworm produces both eggs and sperm. What advantage does the earthworm gain by fertilizing the eggs of another earthworm, rather than its own eggs?

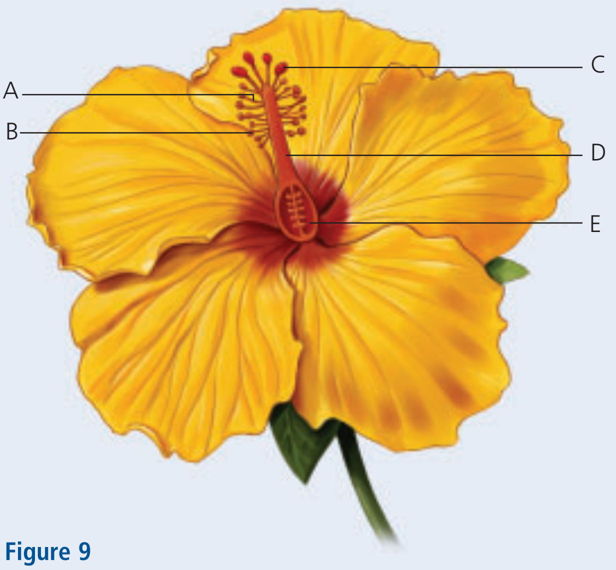


Figure 9

3.4 Development of the Zygote

3B Investigation

Examining Seeds

To perform this investigation, turn to page 100.

In this investigation you will dissect corn and bean seeds to identify the embryo and other seed structures.

LEARNING TIP

As you read about seed and fruit formation in a tomato plant, use the labels, lines, and arrows in Figure 1 to follow the explanation.

Once sperm and egg have fused to form a zygote, the zygote divides and becomes an **embryo**. The embryo is the developing organism. The embryos of sexually reproducing organisms are protected when they develop inside seeds, eggs, or the mother. 3B *Investigation*

Seeds

In plants, the ovary becomes the fruit. Figure 1 shows how seeds and fruit are formed in a tomato plant. Once the egg has been fertilized in the ovary of the flower, it is called a **seed**. The seed contains the embryo, as well as stored food. This food nourishes the developing plant until it is able to produce its own food using photosynthesis. The food in the seed is in the form of starch or sugar. Much of the world's food comes from the seeds of three plants: corn, rice, and wheat (Figure 2). Sometimes the fruit that surrounds the seeds contains sugar and tastes sweet. Apples and tomatoes are fruits we eat because of their sweet taste.

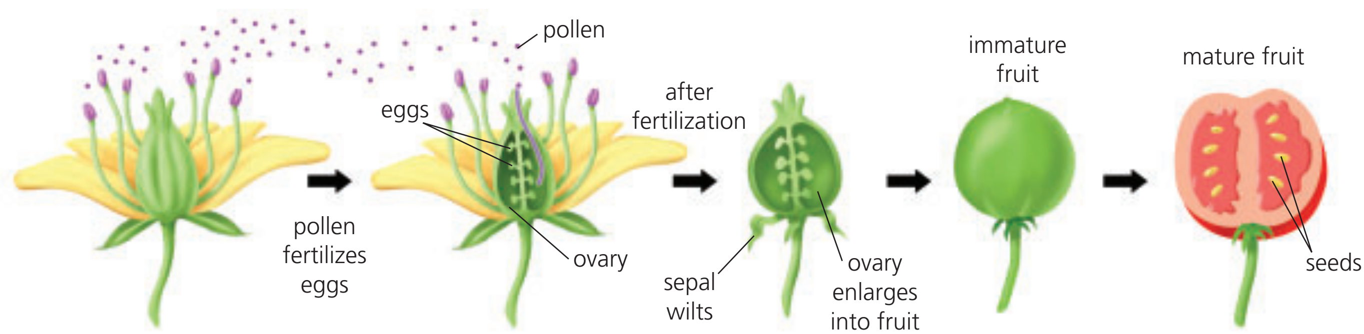


Figure 1 Seed and fruit formation in a tomato plant

Figure 2 Plant seeds, such as these corn seeds, are a source of food.

Seed Anatomy

Flowering plants produce two different types of seeds. Seeds contain seed leaves, called **cotyledons**. Bean plants are called dicotyledons because they produce seeds with two seed leaves. Corn plants are called monocotyledons, because they produce seeds with only one cotyledon.

Bean and corn embryos both contain structures that will develop into the main structures of a plant (Figure 3). Once the seeds **germinate**, or start to grow, they will use the food in the cotyledons. In a corn seed, the endosperm supplies food. The **radicle** is a part of the embryo that will develop into the roots. The **epicotyl** becomes the stem and the leaves. In beans, the **hypocotyl** pushes up through the soil and protects the epicotyl. The cotyledons get smaller as the embryo grows and the food is used up. Once the first leaves develop, the cotyledons will drop off (Figure 4). In corn, epicotyl grows up straight up through a tube.

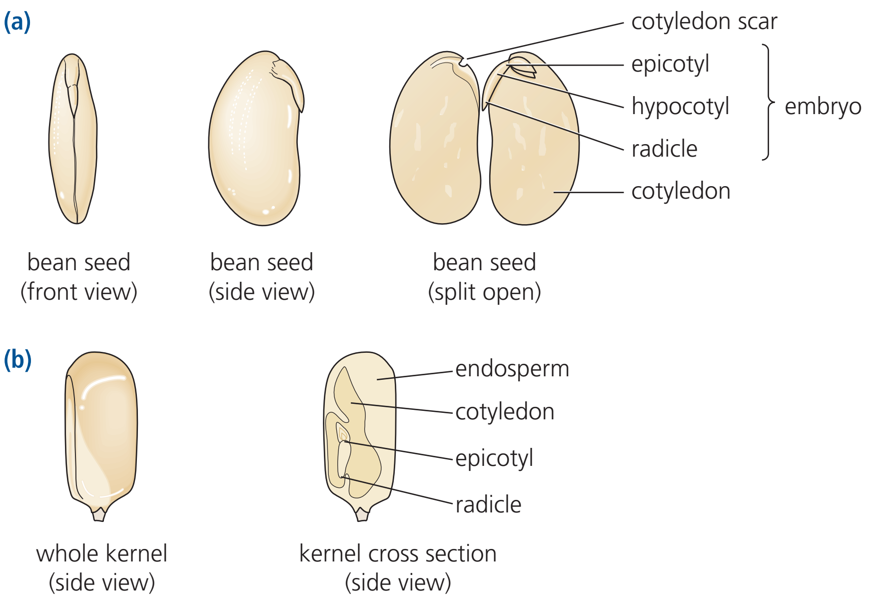


Figure 3 Anatomy of a bean seed (a) and a corn seed (b).

Did You KNOW?

It Doesn't Float

The world's heaviest seed comes from the fruit of the coco de mer palm tree, which grows in the Seychelles Islands. A mature seed can reach a mass of 17.6 kg. The fruit takes six to seven years to ripen and the seed takes two years to germinate.

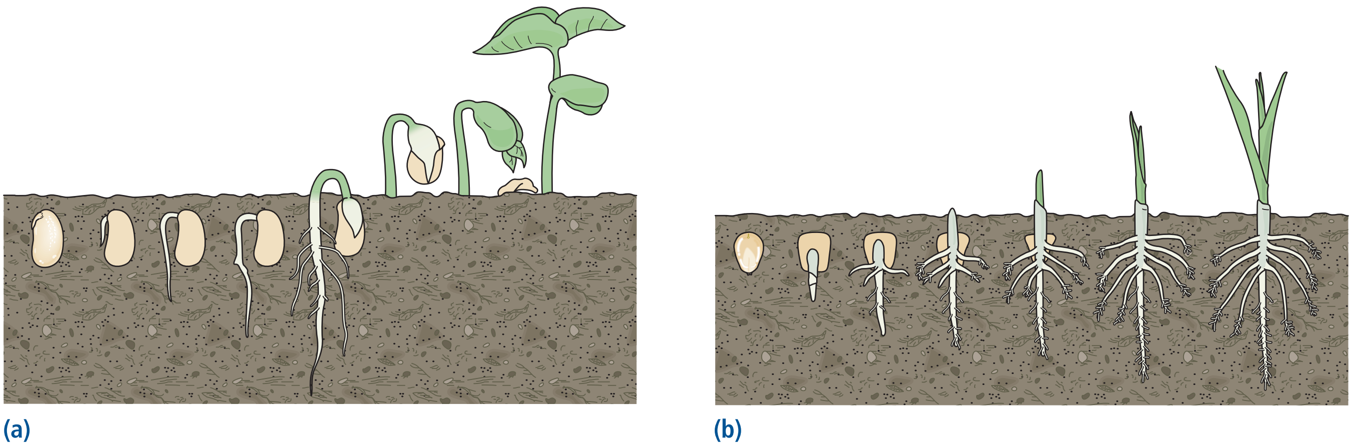


Figure 4 Germinating bean (a) and corn (b) seeds

Eggs

The vast majority of animals lay eggs. Eggs that are laid contain the zygote, some nutrients, and a mechanism for protection, such as a shell, a jelly-like substance, or an egg case (Figure 5). Some animals, such as tapeworms, produce a single egg case that contains thousands of embryos. The eggs of reptiles and birds contain a single embryo surrounded by a shell. This type of egg is called an amniotic egg. Figure 6 shows the structures in an amniotic egg. The embryo is cushioned by the amnion, which is a fluid-filled sac. The yolk sac stores food for the embryo. The allantois holds wastes produced by the embryo. The chorion, along with the allantois, controls the movement of gases and wastes in and out of the egg. Albumen also cushions the embryo and is an additional source of food.

(a) (b) (c)

Figure 5 Sea turtles lay eggs that have soft shells (a). Each frog's egg (b) is surrounded by a jelly-like substance. A tapeworm produces an egg case (c), the circle at the end of the worm. Each egg case contains thousands of eggs.

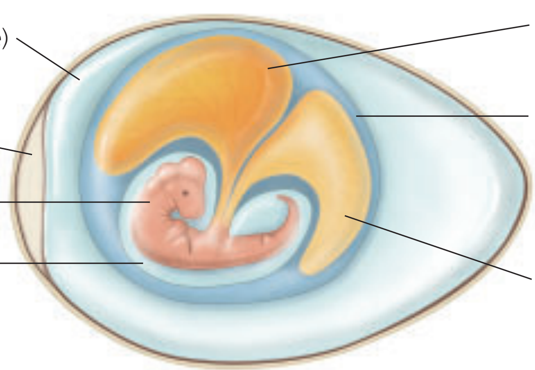


Figure 6 This amniotic egg is a self-contained environment in which the embryo develops.

Did You KNOW?

All Eggs Are Not Equal

The largest egg is the ostrich egg. It has a mass of 1.5 kg. The smallest egg is about 3000 times smaller than the ostrich egg. It has a mass of half a gram and belongs to the bee hummingbird.

Just as there are many types of eggs, there are many levels of parental care of the eggs. Birds keep their eggs warm by sitting on them or insulating them with their feathers. Sea turtle mothers dig a hole in the sand, lay the eggs, bury them, and leave. When the eggs hatch, the hatchlings must dig their way to the surface and then crawl down the beach to the ocean. Many do not survive. Adult parasitic tapeworms live in the intestines of animals (Figure 5(c)). They release egg cases that contain thousands of eggs. The egg cases break open, and the eggs are released into the grass in the feces of the animals. The eggs are protected from drying out, but may be eaten by other grazing animals. The eggs that are eaten will travel to the intestines, where they will develop into adults and feed on digested matter.

Mammals that lay eggs are known as monotremes (Figure 7). There are only three living species of monotremes: the duckbill platypus and two species of spiny anteater. All the species live either on the continent of Australia or on the island of New Guinea. Like birds, these mammals care for their eggs during incubation. The platypus lays its eggs in burrows and incubates them until they hatch. The spiny anteater lays its eggs in its pouch, where they are incubated.

(a) (b)

Figure 7 The short-beaked spiny anteater (a) and the duckbill platypus (b) are egg-laying mammals.

Embryos Develop in the Mother

The embryos of all mammals, except the spiny anteaters and platypus, develop inside the mother.

Marsupials include kangaroos, koalas, and opossums. These animals' embryos do not develop for very long inside the mother's uterus, so the young are born very tiny and immature. The young actually climb from the birth canal through the mother's fur into a pouch, where they attach to a nipple of a mammary gland (Figure 8). Even after they are mature enough to leave the pouch, they return to it for feeding and security.

The embryos of placental mammals, such as humans, develop inside the mother for much longer than the embryos of marsupial mammals. The word placental comes from the word **placenta** (Figure 9), which is the organ that develops around the **fetus** (developing offspring) and connects to the mother. The fetus is attached to the placenta via the **umbilical cord**, which carries wastes out of the fetus and nutrients into the fetus. You will learn about the development of a human fetus in Chapter 4.

Figure 8 When marsupial mammals leave the womb and enter the pouch, they still resemble embryos.

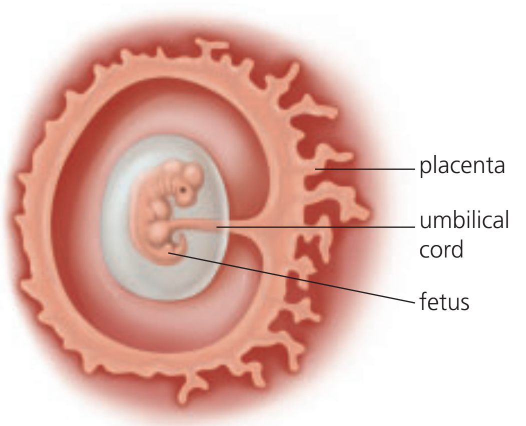


Figure 9 The umbilical cord connects the fetus to the placenta.

3.4

CHECK YOUR Understanding

1. Name three ways that embryos are protected in sexually reproducing organisms.
2. What are two forms of nutrition that are found in plant seeds?
3. Identify the seeds in Figure 10 as monocotyledons or dicotyledons.

(a) (b) (c) (d)

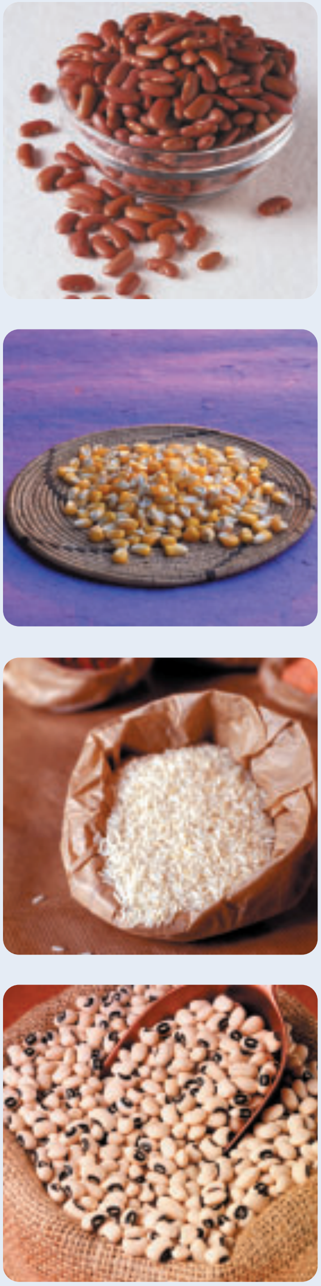


Figure 10

4. What conditions are necessary for germination?
5. (a) What structure in a seed develops into a stem?
   (b) A seed can be a monocot or a dicot. Explain the difference between the two.
6. List three types of egg protection.
7. (a) List two species of egg-laying mammals.
   (b) In what parts of the world would you find these mammals in the wild?
8. Describe the path of the eggs of a parasitic tapeworm.
9. What are the similarities between the mammals in Figure 11?

(a) (b)

Figure 11

10. List two structures associated with the placenta.
11. If plants can produce their own food during photosynthesis, why does a plant seed contain nutrients as well as the embryo?
12. Compare the three types of mammals in terms of where the embryo develops.
13. Compare the development of the zygotes of a bird, a tapeworm, and a horse by listing the advantages and disadvantages of each method of reproduction in a table.

3.5 Reproductive Technologies in Agriculture

Scientists use their understanding of asexual and sexual reproduction to enhance agricultural crops. Populations of both wild and domestic animals are being managed by humans through the use of reproductive technologies. In fact, most of the foods you eat are the result of reproductive technologies.

LEARNING TIP

Headings act as guidelines for reading. Check your understanding as you read. Turn each heading into a question, and answer your question.

Selective Breeding

The most commonly used reproductive technique is selective breeding. In **selective breeding**, two plants or two animals of one species that have desirable traits are bred with each other. The breeder then selects the offspring that show the desirable traits of the parents and breeds them with other individuals with the same traits. After selectively breeding individuals over several generations, all the offspring will have the desirable traits (Figure 1). For example, beef cattle have been selectively bred to produce high quality and quantity muscle (meat). Canola plants, whose seeds are used to produce a cooking oil, have been selectively bred to improve the quality of the oil.

(a)

(b)

Figure 1 Selective breeding is used to improve many traits. Canola (a) can be bred to withstand cold weather. Beef cattle (b) can be bred to produce more meat.

Artificial Vegetative Reproduction

Other techniques take advantage of the ability of many plants to reproduce vegetatively, without sexual reproduction. If growers have a plant that has desirable traits, they can take cuttings from it and grow new plants from the cuttings. The drawback to cuttings is that only so many cuttings can be taken from a plant. Scientists have developed a quicker way to produce plant clones. They remove individual cells from a desirable plant and place them in bottles or Petri dishes that contain nutrients and growth hormones (Figure 2). Once the seedlings have grown roots, they are planted in soil. The advantage of this type of cloning is that many more clones can be produced from a single plant.

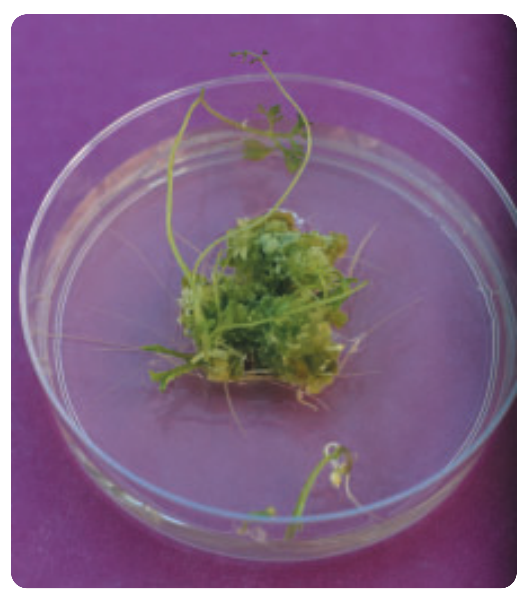


Figure 2 Shoots and roots have started to develop from a few cells that were taken from a carrot plant and placed in a growth medium in this Petri dish.

LEARNING TIP

Photographs play an important role in reader comprehension. As you study Figure 3, ask yourself, "What do these photographs show?" Then move on and look at each photograph.

Another technique is grafting, which is commonly used for fruit trees (Figure 3). Grafting involves attaching a branch from a desirable tree onto the trunk of another tree that may have excellent roots but poor fruit. The bark of the grafted branch will fuse with the bark of the root tree. The branch will grow and eventually produce fruit. Grafting allows growers to turn one good tree into thousands of copies. Most varieties of apples, grapes, and peaches are produced by grafting.

Figure 3 For grafting to work, plants must have a tissue called cambium in their bark. Not all plants have this tissue.

Artificial Insemination and In Vitro Fertilization

Sometimes domestic animals cannot conceive in the normal way as quickly or as often as farmers would like. A technique called **artificial insemination** is used. A veterinarian collects sperm from a male animal and inserts it into a female animal of the same species. This technique is used extensively in agriculture to breed domestic animals with desirable traits. Most dairy cows are conceived using artificial insemination. This technique is also used in zoos to maintain or increase the population of endangered species. In both situations, sperm is collected from the desired male and frozen. It is then transported to female animals in far away farms or zoos. The sperm is inserted into the female's vagina immediately following ovulation. Thus, the sperm of one champion bull can fertilize the eggs of many cows in different locations.

In vitro fertilization is a process that builds on artificial insemination. The sperm and several mature eggs are collected from male and female animals with desired traits and fertilization occurs in a lab, in a Petri dish. (*In vitro* means "in glass.") Once the eggs are fertilized, the embryos can be inserted into many different female cows. These cows are surrogate mothers because they are not genetically related to the embryo. The advantage of in vitro fertilization is that it produces many more embryos than would be produced naturally.

Hatcheries

Fish hatcheries use technology to ensure a higher rate of survival in wild fish populations. For example, wild salmon use external fertilization, which means that relatively few eggs are actually fertilized. Just before they are ready to reproduce, male and female fish are caught. The eggs and sperm are collected and mixed together in a container (Figure 4). The fertilized eggs are incubated in special trays that have a constant supply of cold running water. Once the eggs hatch, the young are fed at the hatchery before they are released into the wild. This process produces a much greater number of young salmon than would occur naturally.

Figure 4 Hatcheries increase the success rate of external fertilization. Here sperm is being squeezed out of a male fish into a bowl of eggs that have been collected in the same way.

Recombinant DNA

Recombinant DNA technology involves combining genes from different individuals or different species into a single molecule of DNA. Biotechnology companies use this technology to produce certain characteristics in organisms or to produce substances from organisms. For example, human growth hormone, which is used to treat some forms of dwarfism, was originally extracted from the pituitary glands of dead people. Now bacteria that contain recombinant DNA produce it. The human gene that codes for growth hormone is inserted into a bacterial cell. The bacterium incorporates the new strand of DNA into its cytoplasm as a plasmid. This new genetic material directs the bacterial cell to produce human growth hormone. Through cell division, the new DNA is replicated in millions of daughter cells. Each daughter cell produces human growth hormone. The growth hormone is then collected. Bacteria are the organisms that are most commonly used to produce drugs, including insulin for diabetics and vaccines to prevent hepatitis B.

Did You KNOW?

Aerostar

Over a million doses of sperm from the famous Canadian Holstein bull, Aerostar, have been used to artificially inseminate cows all over the world. Aerostar's female offspring were among the world's highest milk producers. Born in Ontario in 1985, Aerostar spent his productive years at the B.C. Artificial Insemination Centre in Langley. Aerostar died in 2004. Many of his male offspring are now producing excellent dairy cows.

www.science.nelson.com GO

TRY THIS: A Model of Recombinant DNA

Skills Focus: creating models, recording

Materials: 2 jars with lids containing ticker tape that has coloured markings, scissors, clear tape

In this activity, you will use jars and ticker tape to simulate recombinant DNA technology.

1. Open the lid of Jar 1, the donor cell's nucleus. Remove a loop of DNA 1. The red gene has been selected for removal. Cut out the red segment.
2. Open the lid of Jar 2, the receiving cell's nucleus. Remove a loop of DNA 2. Notice that there is no red segment in the chromosome. Find the green segment, which represents the gene that will be replaced. Cut out the green segment.
3. Tape the red segment to the open ends of DNA 2. Place the loop back in Jar 2, and close the lid. Remove the label, and replace it with the label "Jar 3."

A. Why did you relabel Jar 2?

B. Explain why Jar 1 no longer represents a complete nucleus.

C. Why is the term "gene splicing" sometimes use to describe recombinant DNA technology?

D. Summarize this model in a labelled diagram.

Genetic Engineering in Agriculture

Organisms with genes that have been intentionally altered are called **genetically modified organisms (GMOs)**. Many food crops have been genetically modified to resist spoilage or disease, to delay ripening, or to improve their nutritional content.

In the 1960s, Canadian scientists used selective breeding to improve the colour and flavour of the oil produced by Canola plants. Recently, GM canola plants that resist drought and disease have been developed.

Figure 5 Some GM crops have been developed to resist a herbicide called Roundup.

If you would like to learn more about this court case, go to **www.science.nelson.com** GO

Controversies can arise with GM crops. A variety of canola has been genetically engineered to resist a particular herbicide (Figure 5). Once the seedlings are a certain height, the fields are sprayed with the herbicide, which kills the weeds but not the canola. A company has patented the seed and sells it at a very high price. One farmer was sued by the company that owns the patent. He had the herbicide-resistant plants growing on his land. The company claimed that the farmer did not purchase the seeds. The farmer claimed that he did not intend to grow the herbicide-resistant plants. The pollen from the adjacent fields of canola must have fertilized his plants so that he, too, had resistant plants. The Supreme Court of Canada ruled that the farmer had violated the company's patent. However, since the farmer's profit was no greater than if he had not used the seed, the Court ruled that he did not have to pay the company's technology fees. GO

This case, and others, leads to the concern that GMOs could pass their DNA to wild populations and produce super-organisms. It also raises the issue of who owns these new organisms. Another concern is that GMOs might pose a risk to humans who eat them. Some GMOs contain genes from another species. For example, some pigs have been genetically modified with human genes. The meat of these pigs contains less fat, which is healthier for humans. Some countries have banned GMOs, while other countries have regulations that require food companies to indicate clearly on the label if a product has been genetically modified. Currently, Canada has no regulations regarding labelling.

3.5

CHECK YOUR Understanding

1. Name two organisms that have been improved by selective breeding.
2. (a) Identify the process that is being used in Figure 6.
   (b) Name some plants that are artificially reproduced by this process.
   (c) What is the advantage of this process?

Figure 6

3. In general, what type of plants are artificially reproduced using grafting?
4. Describe the process of artificial insemination in farm animals.
5. In addition to farm animals, with what other animals is artificial insemination sometimes used?
6. (a) What does *in vitro* mean?
   (b) Where does in vitro fertilization take place?
7. Of what benefit to salmon survival is fertilizing the eggs in a bucket instead of naturally in the wild?
8. (a) Which organism is most frequently used for recombinant DNA technology?
   (b) Describe how recombinant DNA technology works.
9. Name three substances that are produced by recombinant DNA technology.
10. What does "GMO" stand for?
11. Give an example of a crop that is a GMO.
12. What are the concerns about eating foods made from GMOs?
13. Compare and contrast three types of vegetative reproduction techniques that are used in agriculture.
14. In vitro fertilization can be used to produce calves that have the same genetic mother and father, but different birth mothers. Explain how this can happen.
15. Explain how artificial insemination is different from in vitro fertilization.
16. Why might a gardener want to graft branches from different trees onto a single stem?
17. A brand of GM crops is called "Roundup Ready" (Figure 7).

Figure 7

   (a) Explain why the crop is called "Roundup Ready."
   (b) Why might farmers find these plants more desirable that non-GM plants?

3A Investigation

Examining Flowers

As you learned in Section 3.3, many flowering plants are hermaphrodites. They contain both male and female reproductive organs on the same plant.

There are many different types of flowers, with different colours and fragrances. Pollination is most often accomplished by animals, such as insects, birds, and bats. Animals are attracted to flowers by the colour, pattern, or fragrance. They land in the flower to collect nectar and, at the same time, inadvertently pick up pollen. When the animals move on to the next flower in search of more nectar, they deposit some of the pollen onto the female part the flower.

Pollination is also accomplished by the wind. Wind-carried pollen often bothers people with asthma and allergies.

Question

Are the reproductive structures of all flowers the same?

Prediction

Predict any similarities or differences you may observe in the structures of two different flowers.

Experimental Design

In this investigation, you will examine and compare the structures involved in sexual reproduction in several different flowers.

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Materials

- disposable gloves and masks (if needed)
- variety of flowers
- magnifier (lens or loupe) or dissecting microscope
- forceps
- dissecting scissors
- scalpel

Be careful using the scissors and scalpel. Cut on your desk, not in your hand. If you have allergies to pollen, wear a disposable mask and gloves.

Procedure

1. Review the diagram of a flower (Figure 1). Re-read the descriptions of the various structures on page 85. Your flowers may look different than the diagram.

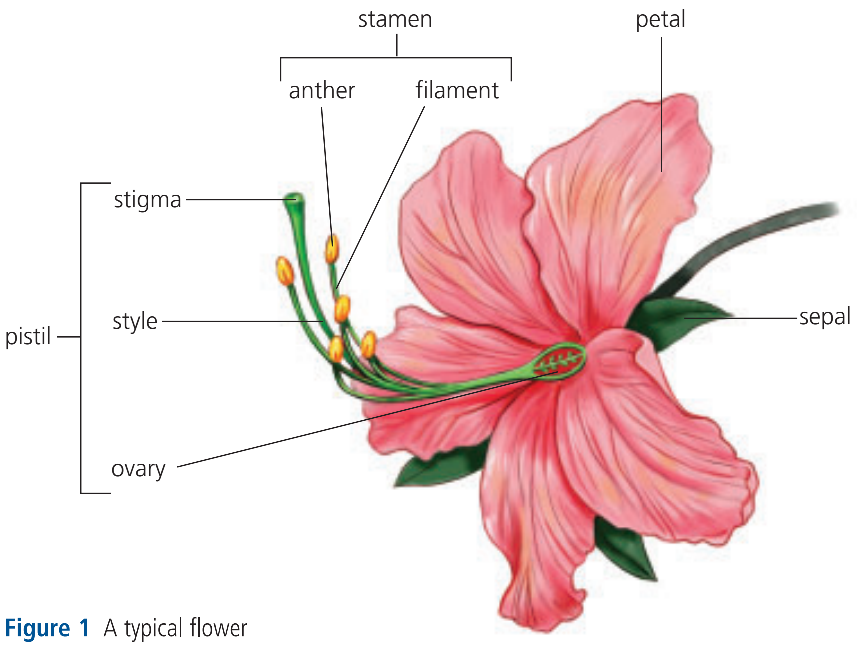


Figure 1 A typical flower

2. Prepare a table similar to Table 1.

Table 1

Characteristic	Flower 1	Flower 2
number of petals		
number of sepals		

3. Choose two flowers from the selection available. Examine both flowers closely with a magnifier or under the dissecting microscope. Count the number of petals, sepals, stamen, and pistils on each flower. Record your observations in your table.
4. Remove a few adjoining petals and sepals, and examine the inside of each flower.
5. Draw a diagram of each flower. Label the structures you can identify. Indicate which structures are male and which structures are female.
6. Using the scalpel, carefully cut through the pistil from top to bottom. Examine the inside with a magnifier and the dissecting microscope.
7. Draw a diagram of the inside of each pistil, and label all the structures.
8. When you are finished the dissections, dispose of the flowers as instructed, and clean your work area carefully.

Analysis

(a) Was your prediction correct? Explain why or why not, based on your observations.

(b) Were there similarities between the two different flowers? List any similarities. Why should there be similarities?

(c) Were there differences between the two flowers? List any differences. How can you explain these differences?

(d) Were there any structures in Figure 1 that were missing on either of your flowers? Describe these structures.

Evaluation

(e) Were you able to make adequate observations using the magnifying glass and dissecting microscope? Explain your answer.

Synthesis

(f) Why are the sepals not coloured the same as the petals?

(g) Based on the structures of your flowers, suggest how each might be pollinated.

(h) Based on where the ovaries are located in your flowers, suggest what the male gamete has to do to reach the egg in each flower.

(i) Observe the structure of the ovary. Explain how this structure is suitable for containing the fertilized egg.

(j) What happens to the fertilized egg(s) in flowers?

(k) What other methods could you use to observe differences among flowers?

3B Investigation

Examining Seeds

Recall, from Grade 8 science, that the chloroplasts in the leaves of a plant produce starch. This starch is used by the plant as a food supply. Where does a seed get the energy to grow the first shoots and leaves?

Seeds are part of the diet of a variety of animals, including humans. Starch is one molecule that is produced by plants that animals eat. Iodine is a chemical that turns a blue-black colour when starch is present.

Question

Does a plant seed contain other components, in addition to the embryo?

Prediction

Write a prediction about what you will find inside plant seeds.

Experimental Design

In this investigation, you will examine bean and corn seeds and identify the structures of the embryo. You will also identify structures that may contain starch, a common plant food molecule. You will test the seeds with iodine to determine the presence of starch.

Materials

- safety goggles
- disposable gloves
- apron
- dry lima-bean seeds
- dissecting needle
- magnifier (lens or loupe) or dissecting microscope
- pipette
- iodine solution
- corn seeds soaked in water for 24 h
- forceps
- scalpel

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Exercise care and caution when using sharp dissecting needles and scalpels.
Wear your safety goggles, gloves, and apron throughout this investigation. Iodine irritates eyes and skin, and may stain clothing.

Procedure

1. Obtain a dry bean seed, and a bean seed that has been soaked in water for 24 h. Use Figure 1 to help you identify the various parts of the seed. Compare the appearance of the two seeds. Record your observations.

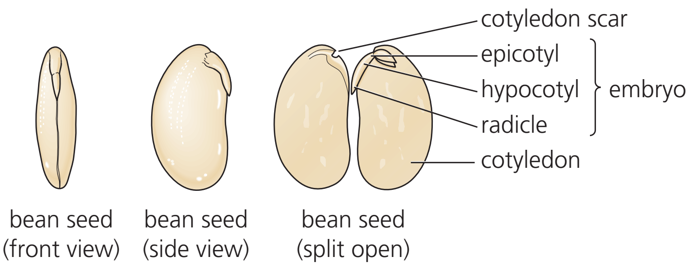


Figure 1 Bean seed anatomy

2. Use your fingers to gently remove the seed coat from the soaked bean seed.
3. Carefully insert the dissecting needle into the joint between the two seed halves.
4. Locate the parts of the embryo, and examine them with a magnifier or the dissecting microscope. Draw and label a diagram of the embryo.
5. Using a pipette, carefully add individual drops of iodine to various parts of the embryo. On your diagram, use a coloured pencil to indicate where the iodine changed colour.
6. With a magnifier, examine a kernel of corn that has been soaked in water. Look for the embryo (Figure 2). On one of the flat sides, you should see a pale oval area with a narrow ridge along

the centre. The oval area is the cotyledon, and the ridge is the embryo containing the radicle and the epicotyl. The radicle is toward the point of attachment to the cob, and the epicotyl is near the silk scar.

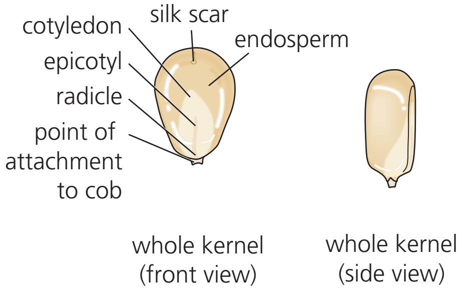


Figure 2 Corn seed anatomy

7. Draw and label a diagram of your corn seed. How does the corn seed differ from the bean seed?
8. Hold the seed with your forceps. Using the scalpel, carefully cut the corn seed in half lengthwise to expose the interior of the seed (Figure 3).

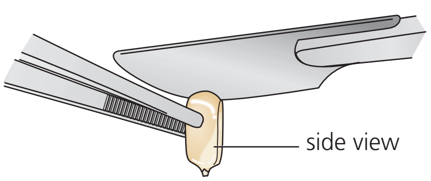


Figure 3 Step 8

9. Repeat step 5 with the corn seed.

Analysis

(a) Did you find structures that contained starch? Explain why or why not, based on your observations.

(b) Were there similarities between the two different seeds? List any similarities. Why should there be similarities?

(c) Were there differences between the two seeds? List any differences. How can you explain these differences?

Evaluation

(d) Bean seeds are classified as dicotyledons, and corn seeds are classified as as monocotyledons. On the basis of your observations, explain the meaning of the prefixes "mono" and "di."

(e) Examine Figures 4 and 5, which show bean and corn seeds developing, or germinating. Describe what is happening to the cotyledons in the bean and the endosperm in the corn as the two seedlings grow. Using your results in step 5, explain what is happening.

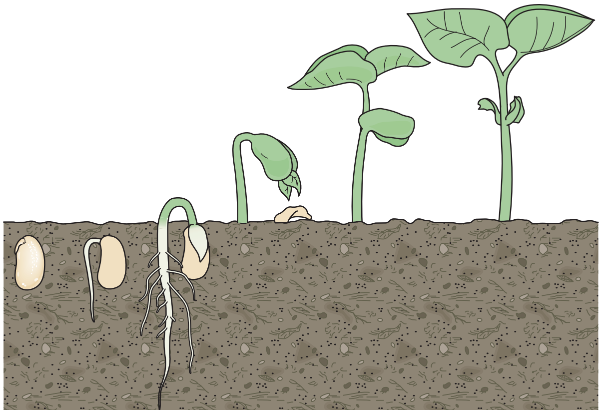


Figure 4 A germinating bean seed

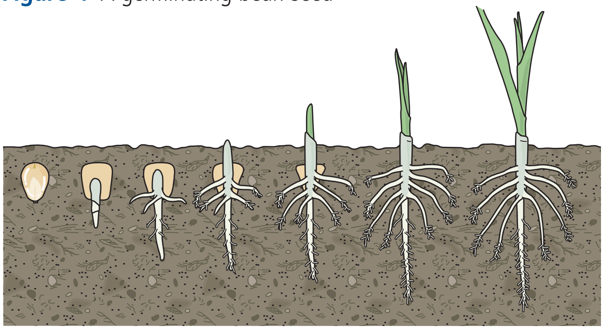


Figure 5 A germinating corn seed

Synthesis

(f) Based on your observations, write a hypothesis that explains where an embryo gets the energy it needs to grow the first shoots and leaves.

(g) Both the cotyledons of the bean seed and the endosperm of the corn seed get smaller as germination progresses. Suggest a reason for this. Does your reason support your prediction?

CHAPTER 3

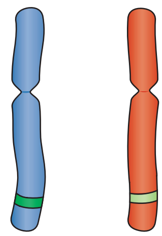
Review

Sexual Reproduction

Key Ideas

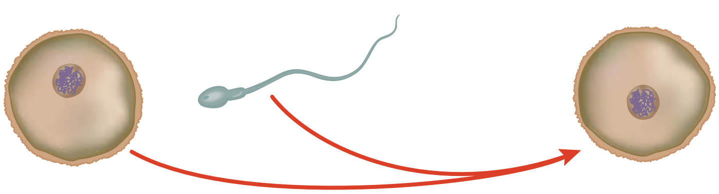
Meiosis is the process that produces sex cells.

- Meiosis reduces the number of chromosomes in the gametes by half.
- Diploid (2*n*) cells are called somatic cells and have a complete set of chromosomes. Haploid cells (*n*) are called gametes and have half the parent cell's chromosomes.
- Male sex cells are called sperm. Female sex cells are called eggs or ova.
- Corresponding chromosomes, with genes for the same traits, are called homologous chromosomes.
- Meiosis produces four haploid gametes. Mitosis produces two diploid cells.



Sexual reproduction involves the joining of genetic material from two parents.

- During fertilization, the sperm and the egg fuse to produce a diploid zygote.
- The zygote has a complete set of chromosomes, half from each parent.



Sexual reproduction creates the incredible diversity among members of the same species.

- The offspring are genetically different from the parents and siblings.
- Alleles are different forms of the same gene and, when combined, can produce a variety of different traits.
- Diversity among offspring allows species to survive in a changing environment.

Vocabulary

somatic cells, p. 74
gametes, p. 74
sperm, p. 74
eggs (ova), p. 74
meiosis, p. 74
haploid, p. 74
diploid, p. 74
homologous chromosomes, p. 75
meiosis I, p. 75
meiosis II, p. 76
fertilization, p. 79
diversity, p. 79
alleles, p. 80
dominant allele, p. 80
recessive allele, p. 80
conjugation, p. 83
hermaphrodite, p. 83
stamen, p. 85
filament, p. 85
anther, p. 85
pollen, p. 85
pistil, p. 85
stigma, p. 85
style, p. 85
ovary, p. 85
petals, p. 85
sepals, p. 85
pollination, p. 85
external fertilization, p. 86
internal fertilization, p. 86

There are advantages and disadvantages to both asexual and sexual reproduction.

- Individuals produced sexually are different from each other and may be able to adapt to a changing environment.
- Identical offspring produced asexually can reproduce rapidly to take advantage of ideal conditions, but cannot adapt to a changing environment.
- One parent is required for asexual reproduction, while two parents are required for sexual reproduction.
- Asexually reproducing organisms tend to produce many offspring more quickly. Sexually reproducing organisms tend to produce fewer offspring more slowly.

Organisms use a variety of strategies to ensure the success of sexual reproduction.

- Some unicellular organisms use conjugation to exchange genetic material.
- Hermaphrodites have both male and female reproductive organs on one individual. Many aquatic animals and flowering plants are hermaphrodites.
- Most animals have separate sexes.
- External fertilization usually occurs in aquatic environments.
- Land animals have specialized organs for internal fertilization.

Scientists have used their knowledge of sexual and asexual reproduction to develop reproductive technologies.

- Selective breeding is used to produce desirable traits in plants and animals.
- Vegetative reproduction techniques are used to produce more plants faster.
- Artificial insemination and in vitro fertilization are used for domestic animals.
- Fish hatcheries increase the number of fertilized eggs.
- Recombinant DNA technology is used to produce some human drugs.
- Genetically modified organisms have desirable traits, but contain DNA from other organisms, which raises concerns.

embryo, p. 88
seed, p. 88
cotyledons, p. 89
germinate, p. 89
radicle, p. 89
epicotyl, p. 89
hypocotyl, p. 89
placenta, p. 91
fetus, p. 91
umbilical cord, p. 91
selective breeding, p. 93
artificial insemination, p. 94
in vitro fertilization, p. 94
recombinant DNA technology, p. 95
genetically modified organisms (GMOs), p. 96

Review Key Ideas and Vocabulary

1. An animal cell that contains two of each type of chromosome is called
   (a) a sperm cell
   (b) an egg cell
   (c) diploid
   (d) haploid
2. Which of the following is required for asexual reproduction?
   (a) meiosis
   (b) fertilization
   (c) gametes
   (d) one parent
3. A chimpanzee's somatic cells have 48 chromosomes. Which of the following statements is correct?
   (a) A zygote would have 96 chromosomes.
   (b) Muscle cells have 24 chromosomes.
   (c) A cell would have 24 chromosomes following meiosis I.
   (d) A cell would have 48 chromosomes following meiosis I.
4. Where would the process shown in Figure 1 occur?
   (a) brain cells
   (b) liver cells
   (c) reproductive cells
   (d) heart cells

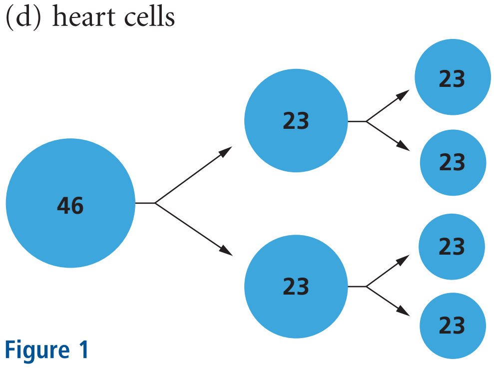


Figure 1

5. Where are the eggs of a flower located?
   (a) pistil
   (b) stamen
   (c) ovary
   (d) style
6. Which of the following is demonstrated by a roan-coloured animal?
   (a) dominance
   (b) recessiveness
   (c) incomplete dominance
   (d) codominance
7. Which location in the bean seed in Figure 2 contains the highest level of starch?
   (a) 1
   (b) 2
   (c) 3
   (d) 4

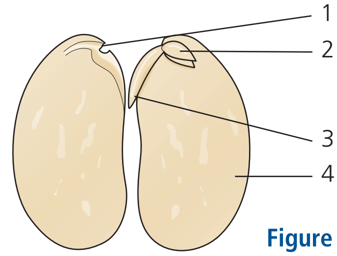


Figure 2

8. Name the part of the seed you identified in question 7.
9. Meiosis is divided into two main phases. Name and describe these phases.
10. What is the main purpose of meiosis?
11. Complete the following sentences with the correct vocabulary word.
    (a) Animals that contain both male and female sex organs are called ___?___.
    (b) Some bacteria exchange genetic material in the form of plasmids. This process is called ___?___.
    (c) The two types of gametes are called ___?___ and ___?___.
    (d) The fusion of two ___?___ is called fertilization.
    (e) Gametes are haploid, while body cells are ___?___.
    (f) The name given to a complete set of chromosomes is ___?___.
    (g) Haploid is to *n* as ___?___ is to 2*n*.
    (h) Stamen is to male as ___?___ is to female.
12. Use a labelled diagram to describe homologous chromosomes.
13. Use a Venn diagram to compare the three types of mammals.
14. Describe the process of selective breeding.
15. What are GMOs? Give one example of a GMO.

Use What You've Learned

16. (a) What happens to the sister chromatids during meiosis?
    (b) How is this different than what happens during mitosis?
17. Figure 3 compares mitosis and meiosis in a cell that contains 32 chromosomes.
    (a) How many chromosomes would be found in cell A?
    (b) How many chromosomes would be found in cell C?
    (c) How many chromosomes would be found in cell D?
    (d) Which cells would be haploid?

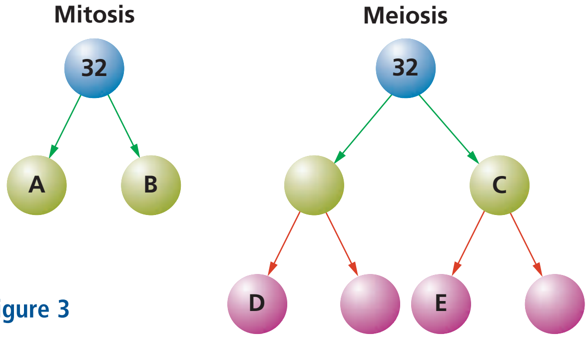


Figure 3

18. Compare the end products of mitosis and meiosis.
19. Describe what happens to the end products of mitosis and meiosis.
20. Describe the types of alleles that are found in the cells of a human with a straight hairline.
21. What advantages does the asexual reproduction of plants have for a farmer? Could this ever be a disadvantage? Explain.

Think Critically

22. Bacteria and humans both reproduce sexually. Explain how the outcomes are different.
23. Hermaphrodites contain both male and female reproductive organs, and both parents produce offspring. Why is this considered to be sexual reproduction?
24. Using your knowledge of gametes and chromosome numbers and types, explain why sexual reproduction can produce a variety of traits in individuals of the same species.
25. Choose one form of vegetative reproduction, and explain how it is used in agriculture.
26. Scientists use the process of recombinant DNA to produce useful drugs for humans. Identify the organism that is most commonly used. Explain how the ability to reproduce both asexually and sexually is important for recombinant DNA technology.
27. Choose three organisms that use internal fertilization. Research their method of reproduction, and compare them in terms of the following:
    - how sperm reaches the egg
    - the approximate number of offspring produced
    - the environmental conditions of the offspring following birth

    www.science.nelson.com GO

28. Many fruits that we eat are seedless. How do these plants reproduce without seeds?
29. Some countries ban the use of GMOs in human food. Research three examples of GMOs in food in Canada, and what the risks and benefits of each are.

    www.science.nelson.com GO

30. Growing canola that is genetically modified to resist a herbicide, such as Roundup, is controversial. Use the Internet and other sources to research the pros and cons of herbicide-resistant crops.

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Reflect on Your Learning

31. How could you improve the way that you conduct investigations? How would these changes affect that data you collect?
32. In this chapter, you learned about sexual reproduction from a biological perspective. Has this information changed your ideas about what sexual reproduction is? Explain your answer.

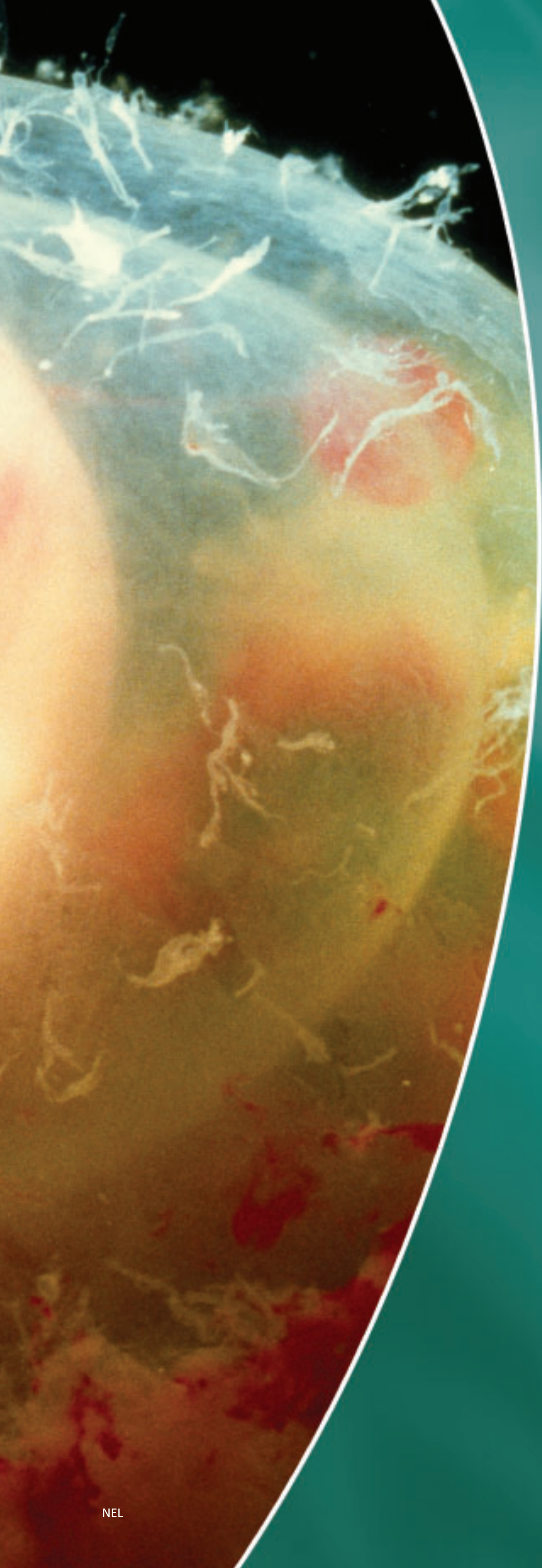
Visit the Quiz Centre at
www.science.nelson.com GO

CHAPTER 4

Human Reproduction

KEY IDEAS

- Male and female humans have specialized organs to produce gametes and to ensure fertilization.
- It takes nine months for a human to develop from a zygote into a baby.
- Sex chromosomes determine the gender of the offspring.
- Errors in meiosis can result in changes to both the gametes and the offspring.
- Scientists have developed technologies that can identify potential problems and allow humans to produce offspring successfully.



Chapter Preview

What is the ratio of males to females in the class? Is it the same as the ratio for the entire human population? How are human males and females different? What changes occur in humans between fertilization and birth? What determines the gender of a baby? Does reproduction always produce a healthy baby? From the production of gametes to fertilization to birth, complicated processes are involved. What if something goes wrong? Can science and technology correct errors?

Scientists have always been interested in how life continues from generation to generation. Technologies exist to improve the success of reproduction in agricultural plants and animals. Are there similar technologies available to humans? In this chapter, you will learn about the specialized structures that are used in sexual reproduction in humans, the development of the embryo from zygote to birth, the mechanisms that determine gender in humans, and the technologies that are available to improve the success of human reproduction.

TRY THIS: Boy or Girl?

Skills Focus: predicting, conducting, recording

Toss a coin to explore the probability of having a boy or a girl.

Materials: 1 coin

1. Record the number of boys and girls in your class.
2. Create a data table similar to Table 1. Use it to record your observations.

Table 1

Number of tosses	Prediction	Heads (H)	Tails (T)	Ratio of H to total	Ratio of T to total
10					

3. Predict how many heads and tails will occur if you toss a coin 10 times. Record your prediction.
4. Toss a coin 10 times. Record the results of each toss by putting tally marks in the "Heads" or "Tails" column of your table.

A. Calculate the ratio of heads to total tosses and the ratio of tails to total tosses. Are they the same?
B. Compare your ratios with your classmates' ratios.
C. Record your ratios in a class data table.
D. Calculate the class ratios for both heads and tails.
E. How do your ratios compare with the class ratios?
F. Calculate the ratio of boys to girls in your class.
G. How does the coin-toss ratio compare with the boys-to-girls ratio?

4.1 The Male Reproductive System

LEARNING TIP

Examine the title, headings, and graphics in Chapter 4. Review the Key Ideas and Chapter Preview. What connections can you make to your prior knowledge? What information will be new to you? What topics do you need to focus your attention on?

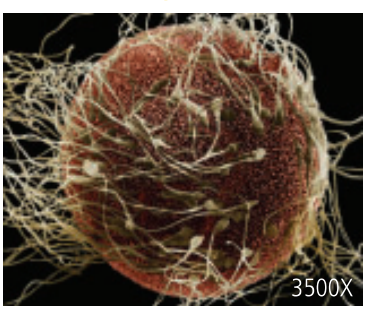
You have learned that the male sex cell is the sperm cell. You have also learned that human eggs are fertilized inside the female's body. Where do human sperm come from, and how do they get to the egg? The male reproductive system is designed for two purposes: to produce sperm and to deliver the sperm to the egg. Humans have primary and secondary sexual characteristics. Primary sexual characteristics include all the structures that produce sperm cells and deliver them to the female. Secondary sexual characteristics are not necessary for sexual reproduction.

Secondary Sexual Characteristics

Whereas the primary sexual characteristics of males are present at birth, the secondary sexual characteristics do not develop until puberty. **Puberty** is the period in the development of a human during which he or she becomes sexually mature and able to reproduce. In males, puberty usually begins between ages 11 and 13 and continues until about age 18. Puberty begins when hormones released from the pituitary gland in the brain stimulate the testes to produce more of the male sex hormone **testosterone**. The secondary characteristics in males include a growth spurt; emergence of facial, underarm, and pubic hair; and the deepening of the voice. These secondary characteristics distinguish males from females, but do not have a direct role in reproduction. It is the primary sexual characteristics that have a direct role in reproduction. The primary sexual characteristics in males include the reproductive organs that produce sperm and allow the sperm to reach the female. GO

If you would like to learn more about puberty in males, go to **www.science.nelson.com** GO

Did You KNOW?



Not Equal

The human sperm cell is dwarfed by the much larger egg cell. In humans, the egg cell is approximately 100 000 times larger than the sperm cell. It would take over 300 sperm cells to cover the outer surface of the egg if laid side by side.

Structure of a Human Sperm Cell

The design of the human sperm cell, shown in Figure 1, tells you about its function. The sperm cell is very streamlined and built to move. It consists of a head, a middle piece, and a tail. The head contains the haploid nucleus with 23 chromosomes. At the front of the head is an entry capsule. It is packed with chemicals that allow the sperm cell to enter the egg. The middle piece is directly behind the head and is packed with mitochondria, which provide the sperm with energy. The whip-like tail is called the flagellum and propels the sperm.

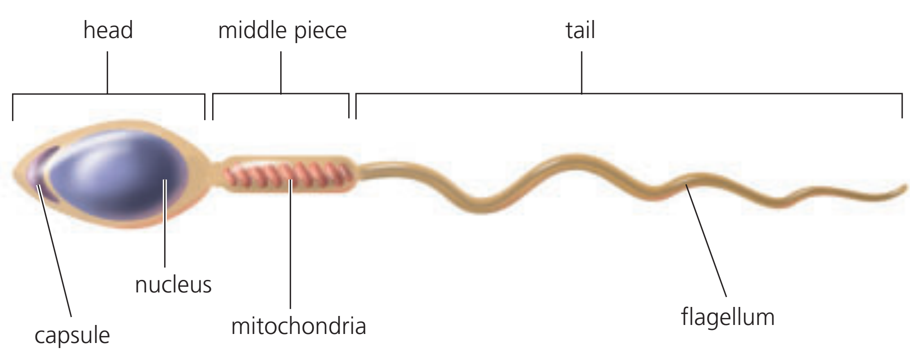


Figure 1 Human sperm cell

Male Reproductive Structures

The male reproductive system is shown in Figure 2. During puberty, these primary sexual characteristics mature and enable males to reproduce. There are two testes that hang outside the abdominal cavity. The testes are enclosed in a protective sac, called the **scrotum**. The **testes** produce and nourish the developing sperm, and also produce testosterone. Each testis contains a mass of coiled tubes called **seminiferous tubules**, which contain diploid cells that undergo meiosis to produce haploid sperm cells. Sitting above each of the testes is the **epididymis**, where mature sperm are stored.

Did You KNOW?

Cool Sperm

Most mammalian sperm cells, including human sperm cells, cannot be produced at normal body temperature. Therefore, the testes in the scrotum hang outside the abdominal cavity, where the temperature is about two degrees cooler. Whales and bats are the only mammals that permanently retain the testes in the abdominal cavity.

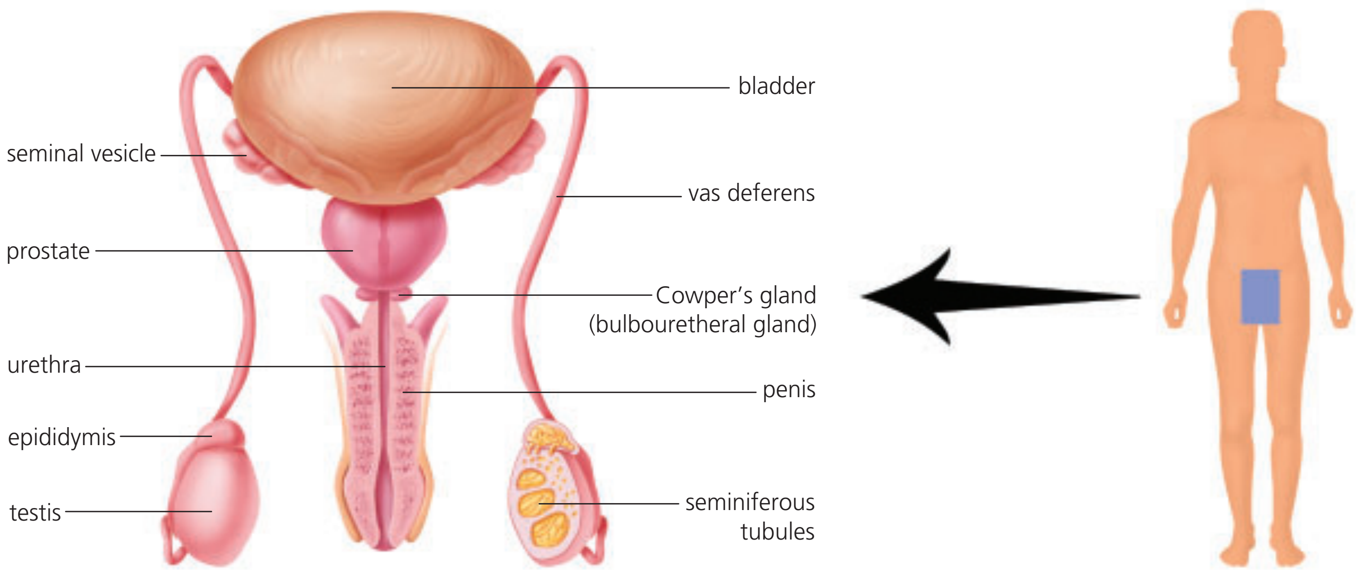


Figure 2 The male reproductive system

The Path of the Sperm Cell

Mature sperm travel to the outside through two tubes. Attached to the epididymis is the **vas deferens**, a tube that carries the sperm to the urethra. The **urethra**, which is part of both the excretory and reproductive systems, transports both sperm and urine outside the body. Note that urine from the bladder cannot travel through the urethra at the same time as sperm. The **penis** is the organ that contains the urethra. It enters the female during sexual intercourse. Muscular contractions propel the sperm cells along. The sperm cells, together with other fluids, are ejaculated out of the erect penis when it is inside the female.

LEARNING TIP

Diagrams help you clarify information visually. As you study Figures 2 and 3, look back and forth between the figures and the boldface words in the text.

LEARNING TIP

Did you notice that Section 4.1 includes many new terms? To help you with your studying, try using index cards. On one side of a card, write a term. On the other side, write a brief definition.

Male Accessory Glands

Sperm cells need a fluid in which to swim, as well as nutrients to provide energy for the journey. The seminal vesicles, prostate gland, and Cowper's glands (also called bulbourethral glands) (Figure 2) are accessory glands that secrete seminal fluid. Seminal fluid provides sugar for energy, protects the sperm from the acidic female reproductive tract, and provides the fluid for swimming. The sperm and the seminal fluid together make up **semen**.

Sperm Production and Development

Sperm cells start out as diploid cells on the inside surface of a seminiferous tubule (Figure 3). They increase in numbers by undergoing mitosis several times. These cells are gradually pushed closer to the centre of the tubule. They then undergo meiosis to become haploid cells. Even though they are haploid, they don't yet look like mature sperm. In order to develop into sperm, they need lots of nutrients. Special support cells provide nourishment to the developing sperm. When the sperm cells are almost mature, they have reached the centre of the tubule. The sperm cells then move to the epididymis, where they finish maturing.

Sperm cells have a short life cycle. It takes from 65 to 75 days for a sperm cell to mature. Males with a healthy reproductive system can produce 200 to 300 million sperm each day. Even though only one sperm cell fertilizes an egg, millions of sperm are needed because many die on the way. Sperm that are not released die within a few days and are broken down by white blood cells. New sperm cells continually replace the old sperm cells. Males can produce sperm even into old age, but the number of mature sperm decreases with age. Only mature sperm can reach and fertilize an egg.

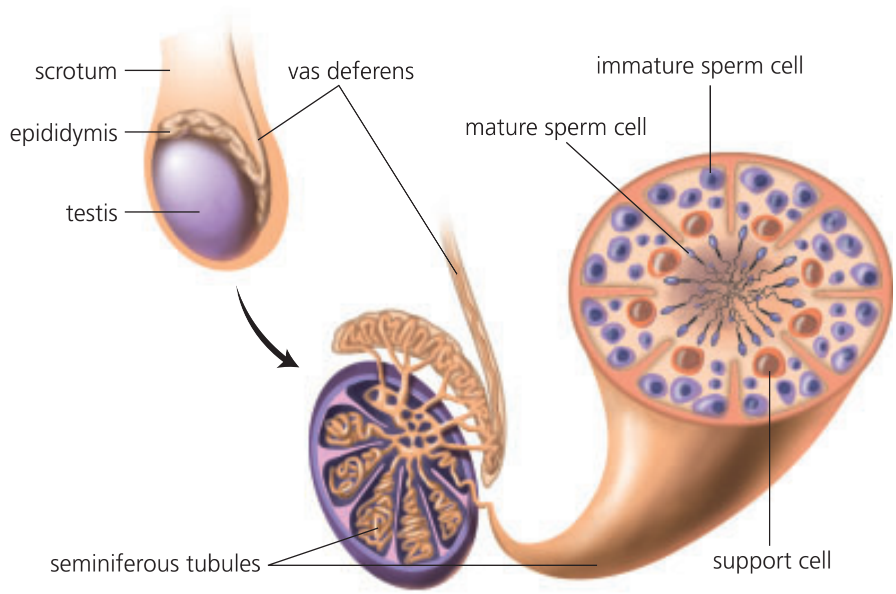


Figure 3 Sperm cells are produced in the testes, stored in the epididymis, and travel through the vas deferens.

4.1

CHECK YOUR Understanding

1. (a) Identify the parts of the sperm, labelled A to D, in Figure 4.

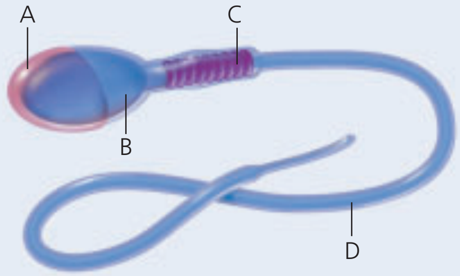


Figure 4

   (b) How is a sperm cell designed for its function?

2. What is the purpose of the numerous mitochondria in the middle section of the sperm?
3. Which structure produces sperm?
4. (a) How many sperm are produced in a single day?
   (b) What happens to sperm cells that are not used?
5. What are the two functions of the testes?
6. Name the structure that stores sperm.
7. (a) Name the structures of the male reproductive system that sperm do not travel through.
   (b) What is the name given to these structures?
8. Describe the composition and importance of semen.
9. What two functions does the penis have?
10. Name the other body system that the penis is part of.
11. Name the structures labelled A to D on Figure 5.

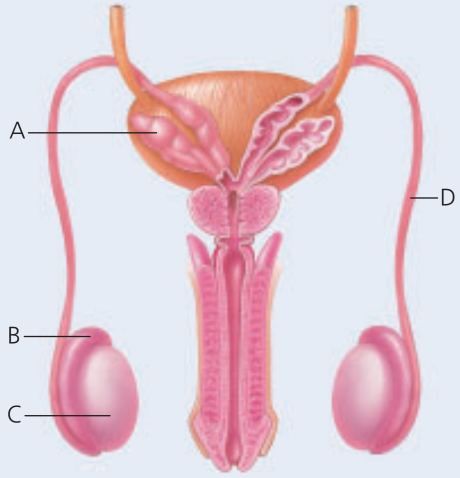


Figure 5

12. (a) Describe the secondary sexual characteristics of males.
    (b) Why are these characteristics called secondary?
    (c) What event is responsible for causing them?
    (d) What purpose do you think they serve? (Hint: Think about the early humans.)
13. Which parts of the male reproductive system are outside the body? Why do you think they are outside the body?
14. Propose an explanation for why males have two testes.
15. Using a flow chart, trace the path of the sperm from its formation in a male until it dies or fertilizes an egg in a female. Label all the structures. Include accessory organs and their functions.
16. What are the differences between an immature sperm cell and a mature sperm cell?

4.2 The Female Reproductive System

Both males and females contribute gametes to the reproductive process. As you learned in Chapter 3, however, mammalian females have another vital role. Because fertilization is internal, they must nurture the fertilized egg from conception to birth. They give birth to the next generation.

Secondary Sexual Characteristics

In females, puberty usually begins between ages 10 and 12 with a growth spurt that includes the development of mammary glands, or breasts. If a woman gives birth, the **mammary glands** produce milk to nourish the baby. Other changes during puberty include the growth of underarm and pubic hair and a widening of the hips (pelvic girdle). As well, the primary sexual organs mature at this time. GO

If you would like to learn more about puberty in females, go to **www.science.nelson.com** GO

Egg Production and Development

The human egg, also called the ovum, is well designed for its functions. It is much larger than the sperm because it contains many nutrients that will be used in cell division once the egg is fertilized. The egg also has an outer barrier that prevents more than one sperm from entering.

Unlike the male, the female has all her sex cells at birth. She may be born with as many as two million eggs, but most will degenerate, leaving approximately 400 000 at puberty. Once sexual maturity is reached during puberty, a single egg matures and is released each month.

The primary female reproductive organ is the **ovary**, where egg cells mature and are released (Figure 1). Females have two ovaries located in the lower portion of the abdominal cavity. The ovaries have many **follicles**, each containing a single immature egg. The follicles also contain cells that nourish and protect the developing egg. The ovaries produce the female sex hormones, **estrogen** and **progesterone**.

LEARNING TIP

As you study Figure 1, ask yourself, "What does this show?" Relate the information in Figure 1 to the information in the text.

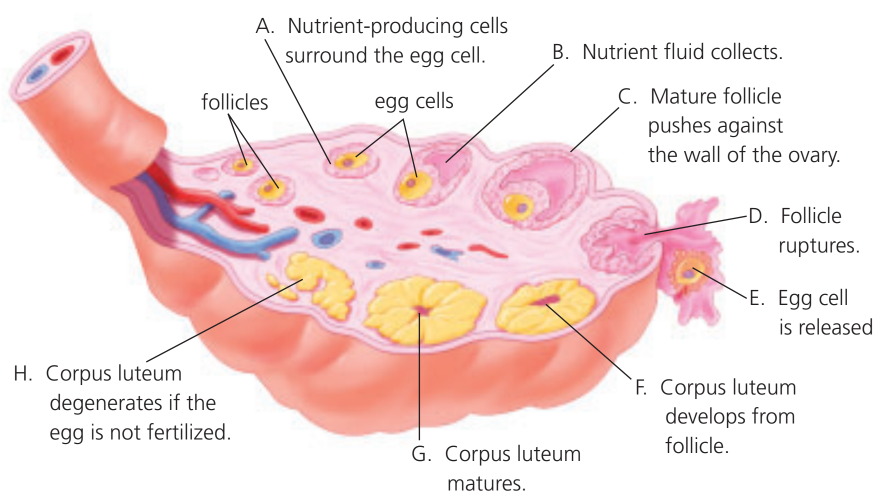


Figure 1 The ovary contains follicles, which contain eggs. Once the eggs mature, they are released from the ovary.

The Menstrual Cycle

The **menstrual cycle** is the female reproductive cycle. It begins at the onset of puberty. The menstrual cycle lasts approximately 28 days, although it can vary in length from 20 to 40 days in different women. The length of the cycle can change throughout a woman's reproductive life. In each cycle, usually a single egg matures and is released. The menstrual cycle keeps repeating until **menopause**, when it stops. Menopause most often occurs in women between 40 and 50 years of age.

Several follicles develop during each reproductive cycle, but usually only a single follicle and egg reach maturity in either ovary. Occasionally, both ovaries release an egg, which can result in twins if both eggs are fertilized. As the follicle matures, nutrient-producing cells develop around the egg cell (Figure 1). The cells will divide and form a nutrient-rich cavity. Once the egg matures, it will burst through the wall of the ovary. This release from the ovary is called **ovulation**. The empty follicle is called the **corpus luteum**. The corpus luteum matures and produces the hormones estrogen and progesterone.

LEARNING TIP

Make connections to your prior knowledge. Ask yourself, "What do I already know about the menstrual cycle?" Consider the information you have read, observed, and/or experienced.

The Path of the Egg

After ovulation, the egg is propelled by finger-like projections that surround the opening to the oviduct. The **oviduct** (also called the **fallopian tube**) is a tube that transports the egg to the uterus (Figure 2). Peristalsis, which is wave-like muscular contractions, and tiny cilia move the egg through the oviduct. Figure 2 shows the two ovaries and the two oviducts. The **uterus**, also called the **womb**, is the organ that will receive the embryo if the egg is fertilized. The lining of the uterus is called the **endometrium**. It is rich in nutrients, blood vessels, and mucus, and provides the nourishment for the embryo. The **cervix** is the muscular opening between the uterus and the vagina. The **vagina** receives the male penis and sperm during sexual intercourse, and it is the birth canal through which a baby comes out. The opening to the vagina is directly behind the opening to the urethra. Unlike males, whose urethra transports both urine and semen, the female urethra only transports urine.

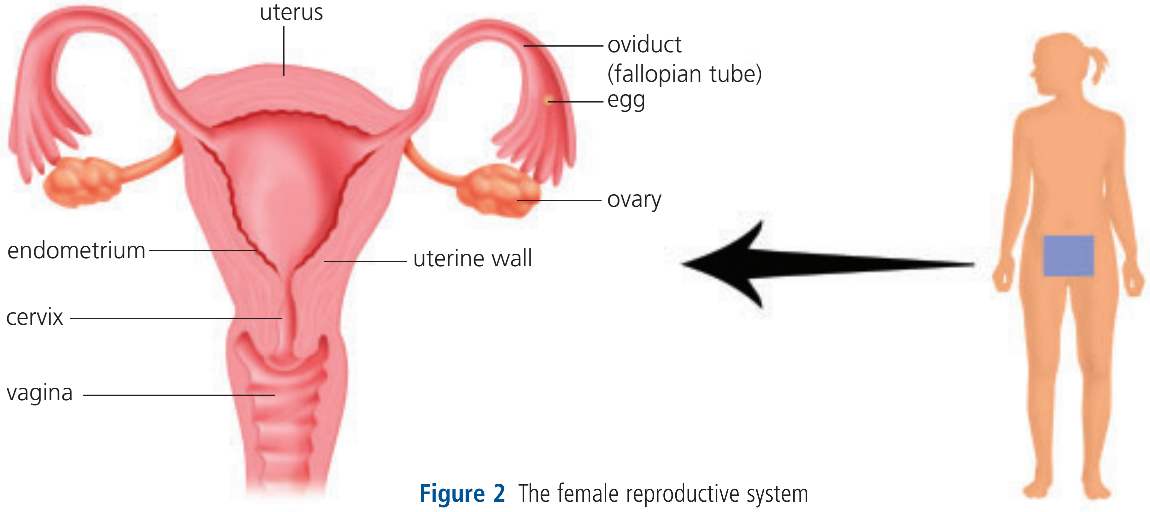


Figure 2 The female reproductive system

Depending on whether the egg is fertilized, one of two events will happen: menstruation or pregnancy.

Menstruation

If no sperm are present in the oviduct, then the egg continues to the uterus and is discharged out of the vagina. Since no zygote has implanted in the uterus, the endometrium stops developing and is shed. **Menstruation** is the shedding of the endometrium. This marks the first stage of each menstrual cycle (Figure 3), the **flow phase**. Because the endometrium is so rich in blood vessels, menstruation looks like blood is being released. Since no zygote has implanted, a new follicle starts to develop in the second phase, the **follicular phase**. Once the follicle has developed, the third phase, ovulation, occurs. In ovulation, the egg leaves the ovary and travels toward the uterus. Once the egg is released, the final stage, the **luteal phase**, begins, and the empty follicle develops into the corpus luteum. The corpus luteum releases the hormone progesterone, which stimulates the endometrium to develop in preparation for the fertilized egg. During pregnancy, progesterone will also prevent any other eggs from maturing. Table 1 summarizes the events in the menstrual cycle.

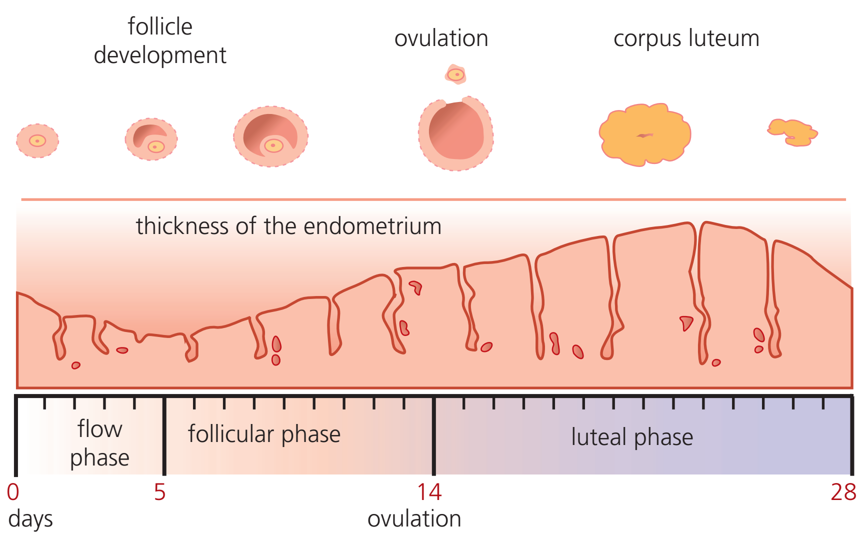


Figure 3 This graph summarizes the events of the menstrual cycle in the ovary and the uterus.

Table 1 A summary of the female menstrual cycle

Phase	Description of events	Hormones produced	Day (approximate)
flow phase	Endometrium is shed (menstruation).	none	1–5
follicular phase	Follicles in ovaries develop. Endometrium re-forms.	Estrogen is produced by follicles.	6–13
ovulation	Egg is released from ovary.		14
luteal phase	Corpus luteum forms. Endometrium thickens.	Estrogen and progesterone are produced by the corpus luteum.	15–28

LEARNING TIP

Tables help you identify specific information quickly. As you study Table 1, look at the headings. The headings will help you focus on what is important in the table.

Pregnancy

If the egg is in the oviduct and sperm are present, then fertilization can occur. One sperm penetrates the outer membrane of the egg while it is in the oviduct. The two haploid nuclei fuse to produce the zygote with 23 pairs of chromosomes. The zygote begins dividing as it continues its journey through the oviduct. About one week after fertilization, the mass of cells, now called an embryo, reaches the uterus, where it will implant into the endometrium. Pregnancy begins when the egg is fertilized and continues until the baby is born, approximately nine months later. Embryonic development happens during pregnancy. **Embryonic development** is an orderly series of changes that an embryo undergoes to become a fully formed baby. You will learn more about pregnancy and embryonic development in the next section.

TRY THIS: Determining the Number of Eggs Released in a Lifetime

Skills Focus: predicting, recording

Materials: calculator

1. A female has approximately 400 000 eggs available at puberty.
2. Predict the number of eggs that you think a human female will release in her lifetime. Record your prediction.
3. If one egg is released approximately every 28 days, calculate how many eggs would be released in one year. Record your answer.
4. Using the approximate age of 12 for when puberty begins, and the approximate age of 50 for when menopause occurs, calculate the number of eggs released. Record your answer.

A. What event would reduce the number of eggs released from puberty to menopause?

B. Approximately how many eggs have been released in a woman aged 40, who has given birth to four children?

C. Why do you think there is such a difference between the number of available eggs and the number of eggs released?

Female Accessory Glands

Another conspicuous feature that characterizes female mammals is the presence of mammary glands. Humans and other primates have two glands, while other mammals may have multiple glands. The number of mammary glands is related to the number of offspring that are produced in one pregnancy. During pregnancy, high levels of estrogen and progesterone stimulate the mammary glands to develop more milk ducts. Shortly after birth, progesterone decreases and another hormone, called prolactin, causes milk to be produced to feed the baby. Each breast contains many milk-producing lobes, each with a duct that leads to the nipple. In most mammals, milk is the sole source of nutrition for some time after birth.

LEARNING TIP

Did you notice that Section 4.2 includes many new terms? Check the Glossary at the back of this textbook to find the meanings of terms that you are unsure of.

4.2 CHECK YOUR Understanding

1. List the secondary sexual characteristics of females.
2. (a) What is the function of mammary glands?
   (b) Why are mammary glands considered secondary sexual characteristics in humans?
3. Identify structures A, B, and C in Figure 4.

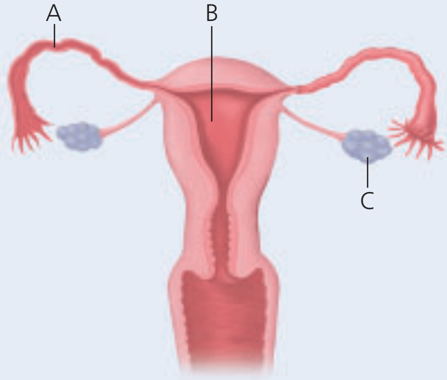


Figure 4

4. The endometrium is important in the female menstrual cycle. Describe its structure, location, and function.
5. Where does the endometrium fit into the menstrual cycle?
6. Name the two female sex hormones, and describe their roles.
7. Name the hormone that causes the production of milk shortly after birth.
8. (a) What event happens during menstruation?
   (b) What event or events will stop menstruation?
   (c) What event happens approximately two weeks before menstruation?
9. Identify structures A, B, and C in Figure 5.

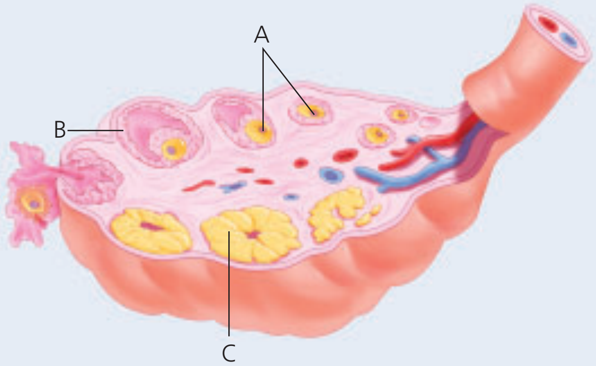


Figure 5

10. How does the corpus luteum develop?
11. What name is given to the process that releases an egg from the ovary?
12. List the four phases of the menstrual cycle, and describe what is happening during each phase.
13. List, in order, the parts of the female reproductive system that are involved in the sequence of events from ovulation to fertilization to the birth of an offspring. Indicate where fertilization takes place.
14. On average, how many eggs does a woman release in her reproductive life?
15. (a) When describing the menstrual cycle, the convention is to begin with the flow phase. Suggest why this is so.
    (b) What is another name for the flow phase?
16. If the ovaries of a woman are removed, can she still give birth to a baby? Support your answer.

4.3 Pregnancy: Fertilization to Birth

You have learned that the role of the female reproductive system is to produce eggs and to carry the fertilized egg from fertilization (also called conception) to birth. How exactly does fertilization occur? What changes take place in the embryo during the nine months of pregnancy? You began life as a single cell, a zygote, about 0.1 mm in diameter. One single cell divided into the trillions of very different cells that make up your body.

LEARNING TIP

You can use a table to help you organize information for studying. Make a three-column table with the following headings: First trimester, Second trimester, Third trimester. Under the appropriate heading, record important information in point-form notes. Include the words in bold in your notes.

Fertilization

Millions of sperm are released into the vagina during sexual intercourse. Most die on the way, and only about 100 make it as far as the oviduct. These 100 or so sperm surround the egg and try to penetrate the egg's outer coating. As soon as one sperm penetrates the egg (Figure 1), the egg releases a protein that prevents other sperm from penetrating. The cell membranes of the sperm and the egg fuse. The sperm's nucleus enters the egg, where it will fuse with the egg's nucleus to produce the zygote.

Fertilization is the beginning of a nine-month (38-week) period of pregnancy, which ends with the birth of the offspring. The nine months of pregnancy are divided into three trimesters (three-month periods) for convenience.

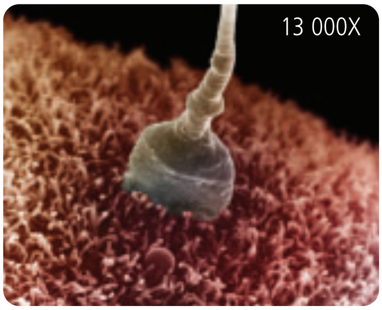


Figure 1 A single sperm cell fusing with an egg cell

First Trimester

The first trimester starts at fertilization and ends after the third month. The zygote begins dividing in the oviduct and is called an embryo when it implants into the uterus by the end of the first week. Hormones are secreted that prevent menstruation from happening.

Soon after implanting, a sac forms around the embryo and is filled with **amniotic fluid**, which supports, protects, and maintains a warm environment for the embryo until birth. When a mother's water breaks during birth, it is this amniotic fluid that is released.

By the fourth week, the brain and nervous system are developing, and the heart is beating. The embryo is now 500 times bigger than the zygote, although it is still only about 5 mm long. The beginnings of eyes, ears, and nose are noticeable at the end of week five (Figure 2). All the cells of the embryo follow the instructions in their DNA and develop different structures and functions. Limb buds and a tail are visible. The tail will reduce, and all that will be left at birth is the tail bone.

Figure 2 In the late first trimester, rudimentary limbs and eyes are visible. This fetus is about 4 cm long and has a mass of less than 10 g.

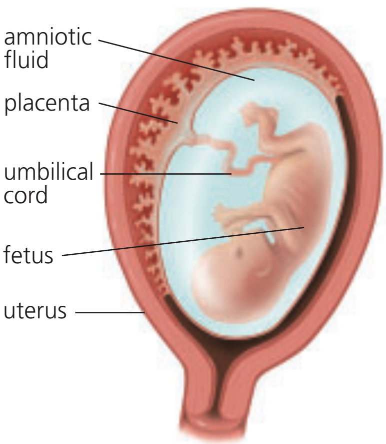


Figure 3 The fetus receives nutrition from the mother via the placenta and the umbilical cord.

By the end of the eighth week, the embryo now has the beginnings of all the organs and is called a fetus. The fetus looks human, but it is only the size of a lima bean. It is now receiving nutrition from the mother through the placenta (Figure 3). The placenta is shaped like a disk and grows to 20 to 30 cm in diameter. It contains blood vessels from the mother and blood vessels from the fetus. Nutrients and oxygen diffuse from the mother's blood into the fetus's blood. Wastes from the fetus diffuse into the mother's blood. Because the mother's and fetus's blood vessels are so close to each other, diffusion is possible. The mother's blood does not enter the circulatory system of the fetus. The fetus's circulatory system is connected to the placenta through the umbilical cord.

By the end of the third month, muscles and bones are forming. The fetus can flex arm and leg muscles, and may hiccup. The heart is beating and blood is circulating. Sex organs are forming, and gender can be determined. The head is almost half the size of the body. The fetus is about 12 cm long, with a mass of around 50 g.

Since the mother's gain in mass is about 1 kg, she may not look different. There are usually signs of pregnancy, however, such as no menstruation, enlarged breasts, and sometimes nausea. A blood test done by a health-care provider can confirm a pregnancy. The fetus is most susceptible to birth defects during the first trimester. A birth defect is a structural or physiological problem in the fetus that develops before birth.

The Second Trimester

Months four, five, and six are a time of intense growth for the fetus. The fetus grows from 8 to 30 cm long by the end of the sixth month. The heartbeat can be detected with a stethoscope. The fetus is sucking and swallowing amniotic fluid, which will be excreted in urine. The mother now looks pregnant, as her abdomen swells. Movement of the fetus can be felt by the mother, first as a flutter but soon as pokes and kicks as the legs and arms develop.

At 24 weeks, the fetus resembles a tiny infant (Figure 4). Fingers and toes have elongated. Facial features are more developed, and eyelashes are visible. The fetus is now covered with a fine hair. Practice breathing also occurs, although no gas exchange occurs. Oxygen reaches the fetus through the blood vessels in the umbilical cord.

Figure 4 By the end of the second trimester, facial features are present and internal systems are maturing.

The Third Trimester

During the last three months (Figure 5), the fetus puts on most of its mass as it continues to develop in preparation for birth. The organ systems are functioning properly. The fetus has sleeping and waking patterns and reacts to stimuli from the outside world. The brain is developing rapidly. The bones are developed but still soft. The eyelids are open. The fetus fills the uterus and the mother's belly may undulate as the baby changes position. During the last month, the fetal hair disappears. The fetus turns so that the head is pointing down in preparation for birth. The lungs continue to mature right up to birth. At 37 weeks, the fetus is considered full term. The size of the fetus ranges from 45 to 55 cm and can be up to 4.5 kg in mass, although the average size is 53 cm and 3.4 kg at birth.

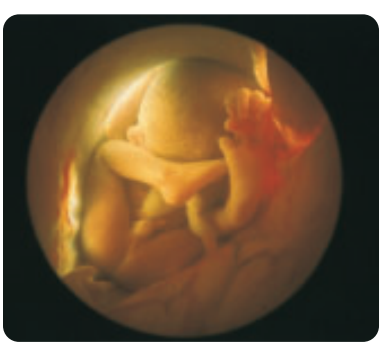
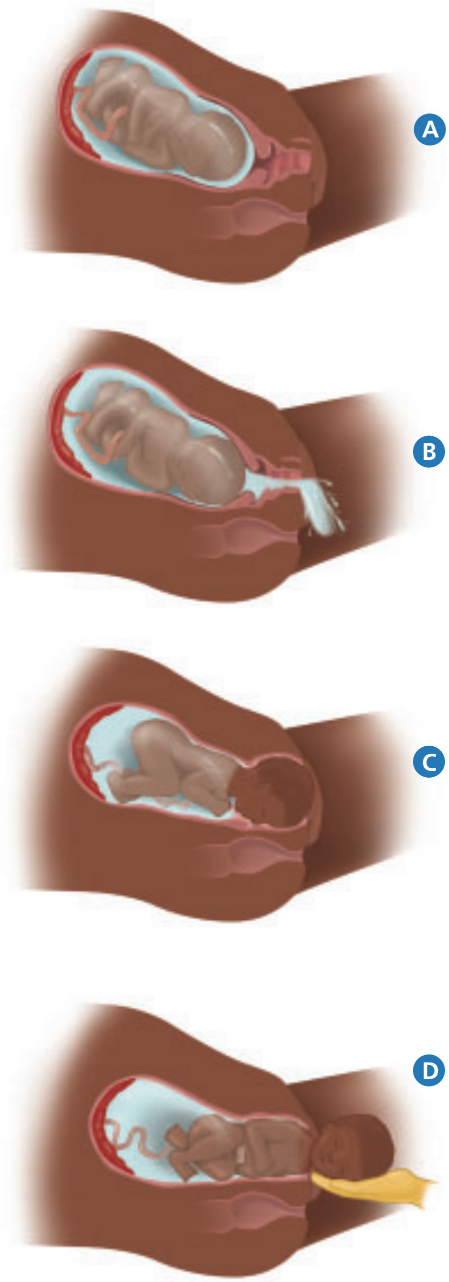


Figure 5 In the third trimester, the fetus fills the uterus. With so little space, the fetus no longer moves around as much.

Birth

About nine months or 266 days after fertilization, the muscles of the mother's uterus contract regularly (every 15 to 20 minutes, and lasting at least 40 seconds). The birth process, called **labour**, has begun. Hormones control the process, which is described in Figure 6.



A The cervix begins to dilate, or open up. The membrane surrounding the baby is forced into the vagina (now called the birth canal).

B The amniotic membrane breaks, and amniotic fluid lubricates the canal. This is called the "breaking of the water."

C Once the cervix has widened to 10 cm, uterine contractions push the baby's head into the birth canal. The baby's head is followed by the rest of the body.

D When the head and shoulders are free of the birth canal, the rest of the baby slips out easily. The baby is born. A short while later, the placenta, often called the "afterbirth," is pushed out of the uterus. Once the baby is breathing on his or her own, the umbilical cord is cut and tied off to prevent bleeding. The "belly button" is the scar from the umbilical cord.

Figure 6 The birth process

Did You KNOW?

All Pregnancies Are Not Equal

Pregnancy is also called gestation. The gestation period is often related to the size of the mammal. Here are some mammals and their gestation periods in weeks:

- elephant—88
- horse—48
- grizzly bear—30
- lion—17
- wolf—9
- squirrel—3.5

LEARNING TIP

Imagine the birth process (Figure 6) and the explanations (A to D) happening visually. Share your mental images with a partner.

Stem Cells and Differentiation

The one-celled zygote has the instructions in its DNA to produce the more than 200 specialized types of cells in your body. **Differentiation** is the process of growing from unspecialized cells into many different specialized cells. After the zygote divides several times, it is a ball of roughly 150 unspecialized cells (Figure 7). This ball has stem cells in it. **Stem cells** are unspecialized cells that have the ability to reproduce themselves. When stem cells undergo cell division, the daughter cells will either remain stem cells or begin differentiating into one of many different types of specialized cells. As the embryo grows and develops into a fetus, and these stem cells divide, they lose their ability to grow into *all* the different types of cells. These can then only differentiate into certain families of tissues. As the fetus develops further, stem cells are found in only certain tissues. Stem cells in these tissues can only form into the types of cells found in these tissues. For example, the stem cells found in the bone marrow can differentiate into the more than a dozen types of blood cells.

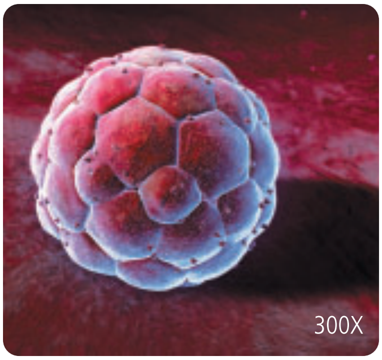


Figure 7 The zygote has divided several times. This ball of cells contains stem cells, which are unspecialized. As these cells divide, they can differentiate into all the different types of cells in the body.

Stem cells are of great interest to scientists because of their ability to differentiate into different types of cells. Scientists might be able to use this property of stem cells to develop new technologies. For example, scientists might be able to grow new heart muscle cells to replace cells that have been damaged in heart attacks. In order to do research, however, scientists need a source of stem cells. Stem cells can be found in certain adult tissues, such as bone marrow, and in the blood in the umbilical cord of a newborn. Another possible source is the extra embryos produced after in vitro fertilization (You will learn about in vitro fertilization in humans in Section 4.7.) Many eggs are fertilized, but only a few embryos are implanted. The extra embryos are frozen for future use. There is much controversy around stem cell research, and legislation in Canada controls the use of extra embryos for research. GO

If you would like to learn more about stem cells, go to **www.science.nelson.com** GO

Twins

Occasionally, more than one fetus develops inside the uterus. There are two types of twins: identical twins and fraternal twins. Fraternal twins occur when two eggs are released at the same time, usually one from each ovary. Since there are plenty of sperm cells in the oviducts, both eggs are fertilized. Each zygote develops its own placenta. Fraternal twins have the same birth date, but they are as similar or different as any brothers and sisters. They have different genetic material.

Identical twins (Figure 8) result from one fertilized egg that splits at the zygote or early embryo stage. Normally, the zygote undergoes mitosis to become a ball of cells, which stay together and become an embryo. Occasionally, when the zygote undergoes cell division, the daughter cells separate from each other and each daughter cell develops into an embryo. However, they share the same placenta. These twins contain identical genetic material because they came from the same egg and sperm. Identical twins are the same gender because they contain identical DNA.

Figure 8 About one in 250 births produce identical twins.

4.3

CHECK YOUR Understanding

1. How large is a fertilized egg?
2. (a) How many sperm cells fertilize an egg?
   (b) How many sperm cells actually reach an egg?
   (c) What happens to the sperm that do not reach an egg?
3. Describe what happens in the egg after sperm penetration.
4. What is another name for the fertilized egg?
5. Where in the female reproductive system does fertilization take place?
6. What event happens that changes a zygote into an embryo?
7. Identify structures A to E in Figure 9.

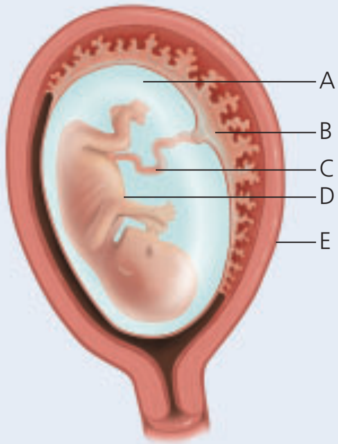


Figure 9

8. What are the functions of the amniotic fluid?
9. Where does the embryo get its nutrition before the umbilical cord forms?
10. Women do not menstruate once the embryo has implanted. What controls this?
11. How are the nine months of pregnancy divided?
12. During which trimester does each of the following events occur?
    (a) Eyelids have lashes.
    (b) Heart begins beating.
    (c) Activity decreases.
    (d) Size of the head is almost half of the fetus.
    (e) Embryo becomes a fetus.
    (f) Placenta develops.
    (g) Fetus responds to stimulus.
    (h) All organs are formed.
    (i) All organ systems are working.
    (j) Fetus swallows amniotic fluid.
    (k) Arm and leg buds form.
    (l) Mother can feel fetal movement.
13. What functions do the placenta and the umbilical cord serve?
14. Is the zygote a stem cell? Explain.
15. About how many different types of cells are found in your body?
16. What two signs signal the beginning of birth?
17. Which part of the baby normally leaves the birth canal first?
18. What happens to the umbilical cord and the placenta once the baby is born?
19. Copy Table 1 into your notebook and use it to compare the two types of twins.

Table 1

Characteristic	Fraternal twins	Identical twins
Number of eggs fertilized		
Placenta		
Genetic material		

Science
WORKS

CORD BLOOD: BIOLOGICAL INSURANCE

Scientists have discovered biologically valuable cells in the umbilical cord.

In the past, when a baby was born, the umbilical cord was cut and discarded (Figure 1). Scientists have now discovered that stem cells are present in a newborn's umbilical cord. In a biological sense, these cells are potentially very valuable. Cord blood stem cells can turn into any type of blood cells: red blood cells, white blood cells, or platelets. Therefore, stem cells collected from cord blood could potentially be transplanted into people who have diseased blood cells that cannot be repaired or replaced. Once inside the body, the stem cells could replace the diseased blood cells by turning into healthy blood cells.

Currently, people can receive stem cells found in bone marrow through bone marrow transplants. However, bone marrow cells from other individuals can be rejected. If the recipient's immune system identifies the donor stem cells as foreign, the immune system destroys the cells. One potential advantage of cord blood stem cells is that when they are transplanted, they are not recognized as being foreign. This eliminates the problem of rejection. Cord blood transplants have been successful in treating some blood diseases, such as leukemia.

Across North America, private clinics offer to bank a newborn's cord blood, as a supply of stem cells that could be used if the child developed a life-threatening blood illness or disease in the future. This technique is being marketed to worried parents as a unique opportunity to do something now that could possibly save their child's life in the future. Banking blood at public cord-blood banks is encouraged by the medical community because the stem cells would be available to any needy patient, but banking at private clinics is discouraged. Some European countries have actually outlawed private cord-blood banking. Canada has both public and private cord-blood banks.

What do you think? Should parents be able to bank their child's cord blood and keep it at a private clinic for use only by their family? This is just one of the many interesting issues your generation will decide upon in the future.

Figure 1 The umbilical cord is still attached to this newborn.

4.4 Gender Determination in Humans

In Chapter 2, you observed both onion root tip cells and whitefish cells during cell division. You were able to identify the stages of mitosis because chromosomes are easier to see during cell division. They are condensed and look shorter and thicker than they look during the rest of the cell cycle. Scientists have taken advantage of this by developing a technique to examine a cell's chromosomes.

The Human Karyotype

Scientists use a microscope to take pictures of the condensed chromosomes during metaphase, magnify the pictures, and cut out the individual chromosomes. They can then match up the homologous pairs by shape and size. This arrangement of an organism's chromosomes from one body cell is called a **karyotype**. The human karyotype shown in Figure 1 has 23 pairs or 46 chromosomes.

LEARNING TIP
To help you understand the human karyotype, read the paragraph about sex chromosomes, and then refer to Figures 1 and 2.

Figure 1 This human karyotype was made by cutting up a photograph of chromosomes from one somatic cell and arranging them into pairs.

Sex Chromosomes

When you look closely at the pairs of chromosomes in Figure 1, you will notice that one of the pairs has chromosomes that are different sizes. These two chromosomes are called the sex chromosomes because they determine the sex, or gender, of the individual. Both the primary and secondary sexual characteristics in humans are controlled by the two sex chromosomes, the X chromosome and the Y chromosome (Figure 2). The larger chromosome is the X chromosome, and the smaller chromosome is the Y chromosome.

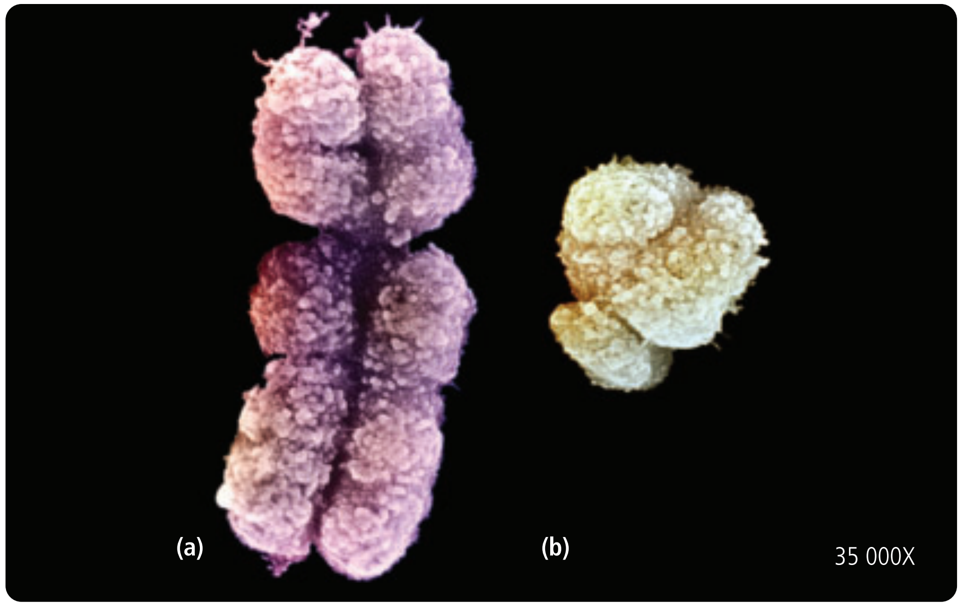


Figure 2 The X chromosome (a) is far bigger than the Y chromosome (b)

Females have two X chromosomes and males have one X chromosome and one Y chromosome. During meiosis, the gametes that are produced have only half of the parent's chromosomes. Since the female parent cell has two copies of the X chromosome, all the eggs produced will have a single X chromosome. Since the male parent cell has a single X chromosome and a single Y chromosome, half the sperm produced will contain an X chromosome and half will contain a Y chromosome (Figure 3).

Meiosis in males produces four haploid sperm cells. However, meiosis doesn't always produce four equal haploid cells. In females, meiosis produces only one large haploid egg cell containing 23 chromosomes and most of the cytoplasm from the parent cell. The other three tiny cells, each composed of mainly a haploid nucleus, eventually disintegrate.

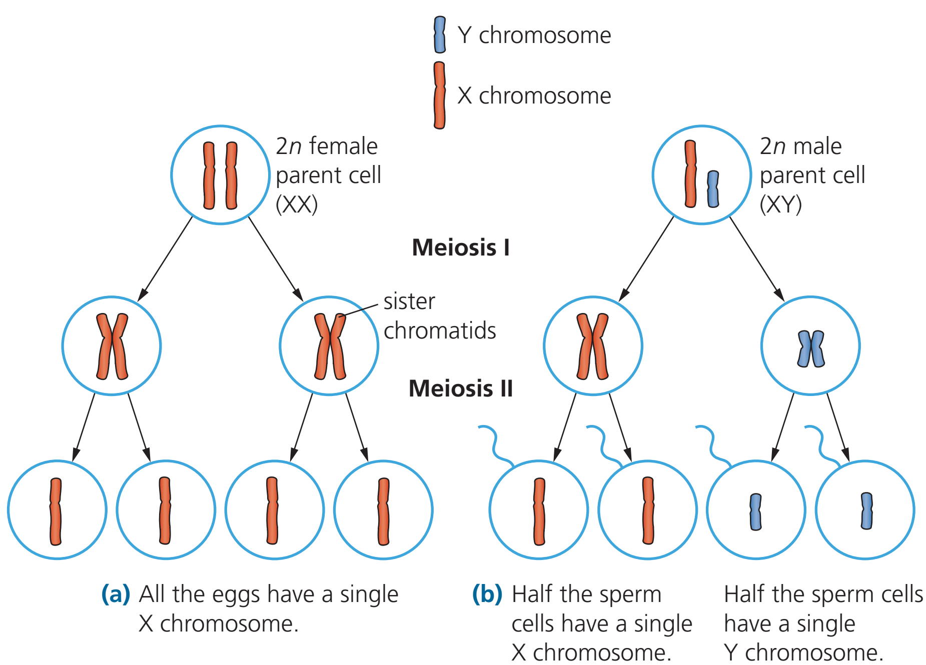


Figure 3 Meiosis of a female reproductive cell produces four haploid cells, each with one X chromosome (a). Meiosis of a male reproductive cell produces two haploid cells with one X chromosome and two haploid cells with one Y chromosome (b).

Male Zygotes or Female Zygotes

How do females get two X chromosomes and males get one X and one Y chromosome? It all depends on which sperm fertilizes the egg. Figure 3 shows that all the eggs have a single X chromosome, while the sperm can have either one X or one Y chromosome. Figure 4 shows all the possible outcomes of fertilization.

LEARNING TIP

Are you able to explain how gender is determined? If not, ask yourself, "What do I need to figure out?" Then reread the explanation, and re-examine Figure 4.

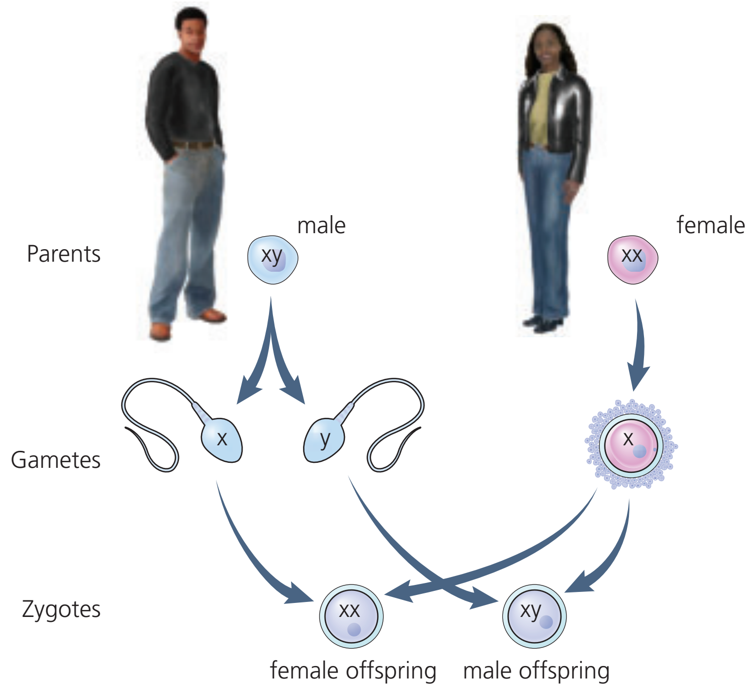


Figure 4 The sex chromosome in the sperm determines the gender of the offspring. A sperm with an X chromosome will produce a female offspring, and a sperm with a Y chromosome will produce a male offspring.

As you can see in Figure 4, because half the sperm produce male offspring and half produce female offspring, there is a 50 percent chance that the child will be male and a 50 percent chance that the child will be female. Gender is determined by the father. GO

If you would like to learn more about how the different genders develop, go to **www.science.nelson.com** GO

Sex-Linked Characteristics

Have you ever wondered why there are more bald men than bald women? This imbalance occurs because the X and Y chromosomes are not homologous (Figure 2). Unlike the other 22 pairs of chromosomes, the X chromosome and the Y chromosome do not carry matching genes. Female offspring have 23 pairs of homologous chromosomes with corresponding genes. Males, however, have one X chromosome and one Y chromosome. The smaller Y chromosome is missing some of the genetic material that is present in the X chromosome. As a result, certain traits are controlled by the genes on the X chromosome. These are known as **sex-linked characteristics** and they occur more frequently in males than in females. As well as baldness, red-green colour blindness (Figure 5) is more common in males than in females. Hemophilia is a disease that is more common in males. The symptoms of hemophilia include excessive bleeding due to the absence of some important clotting proteins normally found in blood. Hemophilia is treated with medication that contains the missing clotting factors.

Figure 5 Test for red-green colour blindness. More females than males will be able to see the word in the test.

4.4

CHECK YOUR Understanding

1. What is a karyotype?
2. During which phase of mitosis are the chromosomes photographed for a karyotype?
3. Describe the steps that are used to produce a karyotype.
4. Explain why karyotypes are important for biologists.
5. How many sex chromosomes do humans have? Name them.
6. Make a drawing of the X and Y chromosomes to show the difference in size.
7. Examine the karyotype in Figure 5. What is the gender of the individual whose karyotype is shown?

Figure 5

8. (a) Describe the sex chromosomes of a female human.
   (b) Describe the sex chromosomes of a male human.
9. Describe the difference between an egg cell and a sperm cell in terms of the sex chromosomes that may be present.
10. Make a drawing to show the possible zygotes formed after fertilization. Indicate whether each zygote will grow into a female child or a male child.
11. (a) A family has one male child. What is the probability that the next child will be a girl?
    (b) A family has two female children. What is the probability the next child will be a boy?
12. Name two sex-linked characteristics.
13. Explain why sex-linked characteristics are expressed more often in males than females.
14. Figure 6 shows human fertilization.
    (a) Indicate the number of chromosomes in each cell.
    (b) Indicate the sex of cells D and E.
    (c) Explain how you know the sex of cells D and E.

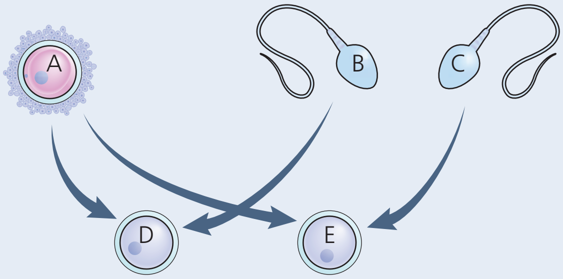


Figure 6

4.5

Atypical Meiosis

Although meiosis occurs correctly in every male and female thousands of times throughout adult life, this mechanism, which separates homologous chromosomes into gametes, can occasionally go wrong. Once in a while, errors do occur. The most common error is known as nondisjunction. **Nondisjunction** occurs when the homologous chromosomes do not separate during meiosis. This produces gametes with the wrong number of chromosomes.

If one of the gametes that come together during fertilization has the wrong number of chromosomes, the resulting zygote can either have too much genetic material or too little. For example, in humans, a gamete with 22 chromosomes that fuses with a normal gamete with 23 chromosomes will produce a zygote with only 45 chromosomes (Figure 1). In most cases, the zygote does not divide and dies.

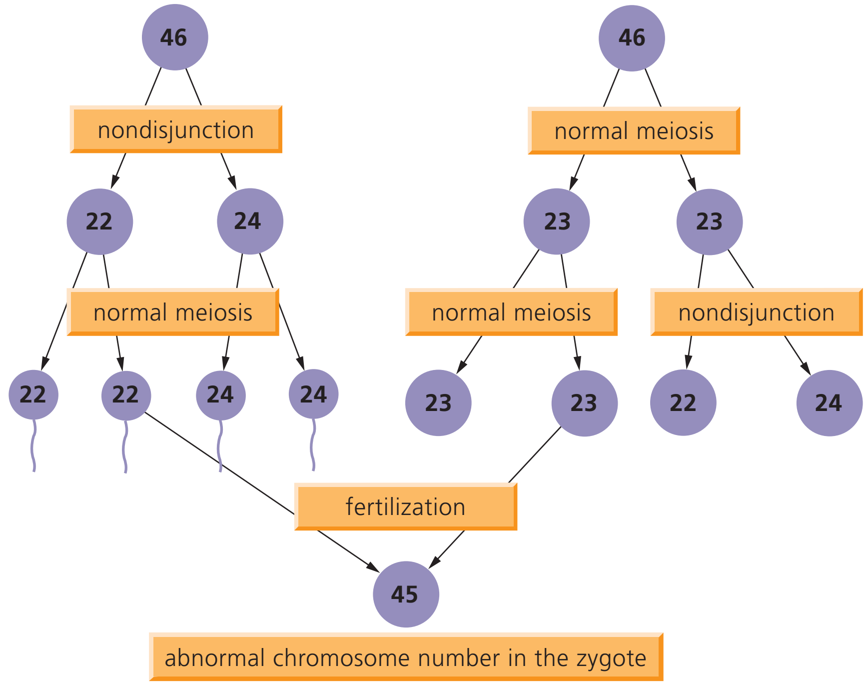


Figure 1 Nondisjunction can occur either during meiosis I or meiosis II.

LEARNING TIP

To read Figure 1, begin with the number at the top of the diagram. What does this tell you? Now read the label. What does this tell you? Next, look at the arrows and numbers. What do they tell you? Do the same for the rest of the labels, numbers, and arrows.

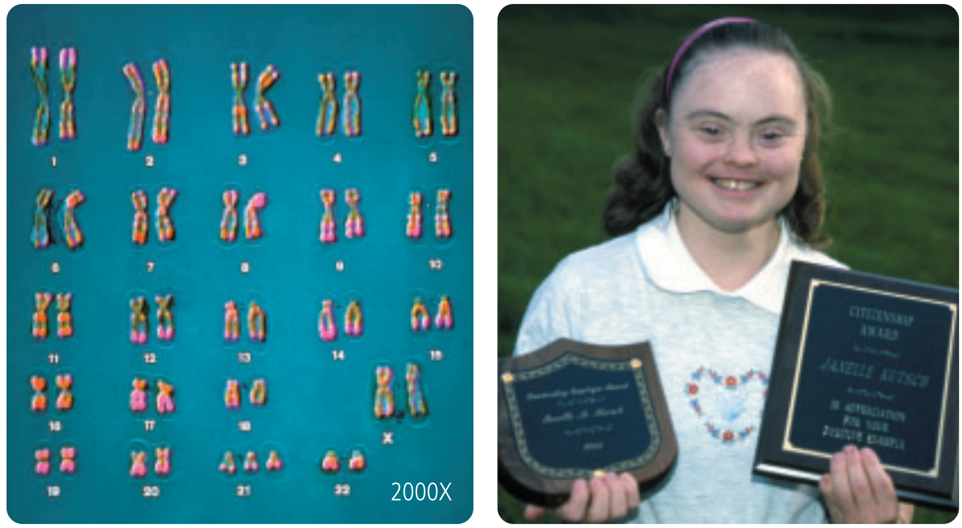
Down Syndrome

Sometimes a zygote with the wrong number of chromosomes continues to divide into an embryo, becomes a fetus, and develops into a baby. **Down syndrome** is a common disorder that results from a zygote with 47 chromosomes. The zygote undergoes cell division with each new daughter cell, also containing 47 chromosomes. People with Down syndrome have three copies of chromosome 21, instead of the normal pair (Figure 2(a)). They have similar facial features (Figure 2(b)), mild to severe mental disabilities, as well as a variety of physical disorders.

Did You KNOW?

Down Syndrome Facts

Down syndrome occurs in one of approximately 600 births. It often occurs in babies born to women over age 40 and is thought to be caused by nondisjunction during egg production. People with Down syndrome tend to be smaller and have a shorter lifespan.



(a) **(b)**

Figure 2 The karyotype of Down syndrome shows three copies of chromosome 21 (a). People with Down syndrome may lead active, productive lives (b).

Sex Chromosome Disorders

Nondisjunction can also occur with the X and Y chromosomes. When this happens, gametes can be produced with either an extra sex chromosome or none at all. **Turner syndrome** occurs when a female is born with only one X chromosome (Figure 3). One of the gametes is missing the sex chromosome. The reproductive organs of females with Turner syndrome do not develop at puberty. Therefore, females with Turner syndrome do not menstruate and cannot reproduce. Trisomic females have an extra X chromosome. Unlike Turner syndrome females, trisomic females' reproductive organs develop at puberty and they can reproduce. They may, however, be taller and thinner than average.

A nondisjunction disorder that occurs in males is Klinefelter syndrome. In **Klinefelter syndrome**, males are born with two X chromosomes and a Y chromosome. One of the gametes had an extra X chromosome (Figure 3). Males with Klinefelter syndrome produce less of the sex hormone testosterone than normal, and they cannot father children.

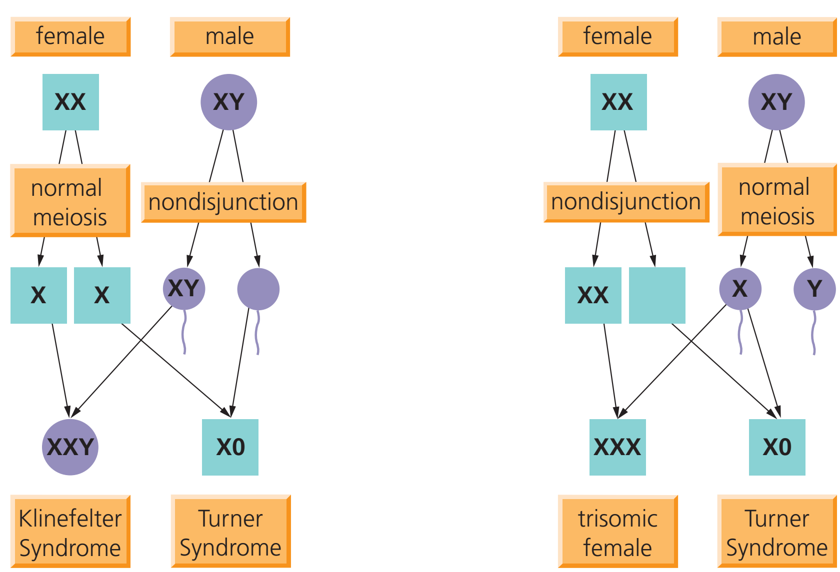


Figure 3 Turner and Klinefelter syndromes result from nondisjunction of the sex chromosomes.

4.5 CHECK YOUR Understanding

1. How many pairs of homologous chromosomes are in a single human body cell?
2. What is nondisjunction?
3. Explain how a human somatic cell could have 47 chromosomes.
4. A zygote contains 45 chromosomes. How many chromosomes would be found in the muscle cells of the baby?
5. Use Figure 4 to answer the following questions.
   (a) Which cells in the diagram have the normal diploid chromosome number?
   (b) How many chromosomes would be found in cell A?
   (c) How many chromosomes would be found in cell B?

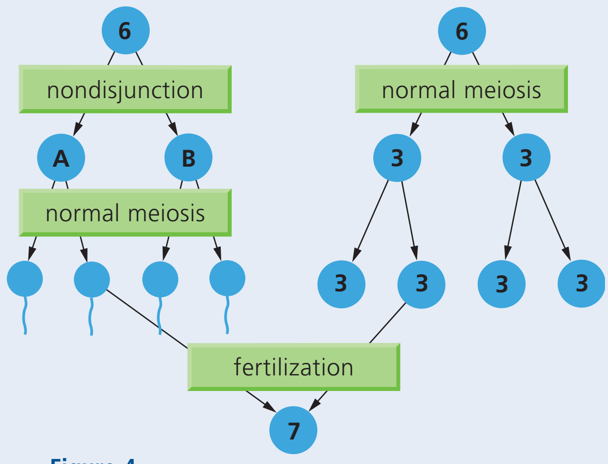


Figure 4

6. (a) How many chromosomes are in the body cells of a person with Down syndrome?
   (b) Describe the chromosome makeup of the gametes of a person with Down syndrome.
7. Name two disorders that result from nondisjunction of the sex chromosomes.
8. (a) Which gender are people with Turner syndrome?
   (b) Describe the sex chromosomes of someone with Turner syndrome.
9. Match the individuals in Table 1 to the correct chromosome makeup. (The number represents the number of non-sex chromosomes.)

Table 1

Individual	Chromosome makeup
a) normal male	44XX
b) normal female	45XX
c) Klinefelter syndrome male	45XY
d) Down syndrome female	44XY
e) Turner syndrome female	44X
f) Down syndrome male	44XXY

10. Both Down syndrome and Klinefelter syndrome somatic cells contain 47 chromosomes. Describe the difference in the chromosomes of each.
11. Do chromosomes come in homlogous pairs in all humans? Give examples to support your answer.
12. Which syndrome is represented by the karyotype in Figure 5?

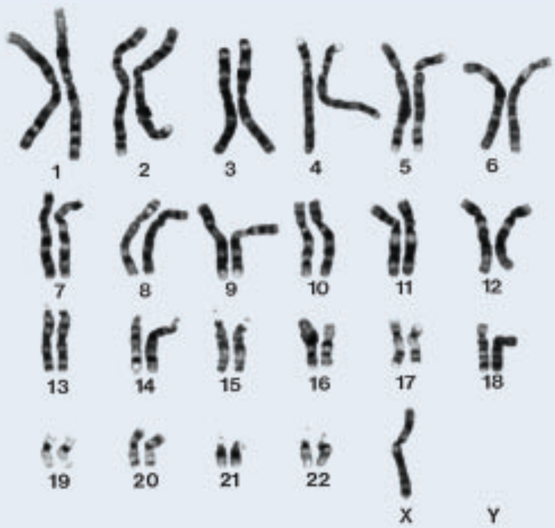


Figure 5 2000X

4.6 Prenatal Procedures

(a)

(b)

Figure 1 An ultrasound involves using sound waves to produce an image of the fetus (a). The image is called a sonogram (b).

Certain diseases are caused by mutated genes. For some diseases, scientists have identified which gene has the mutation. For example, scientists have identified the genes that, when mutated, cause cystic fibrosis and Huntington's disease. The main symptom of cystic fibrosis, a buildup of mucus in the lungs, develops in childhood. Breathing is difficult, and most people do not live beyond their twenties. The symptoms of Huntington's disease usually do not develop until people reach their mid-thirties or forties. Symptoms include personality changes and progressive loss of memory and muscle control.

Scientists have been able to diagnose genetic disorders since the 1950s. Many disorders, such as Down syndrome and Turner syndrome, can be detected before a baby is born. Prenatal (before birth) tests most often confirm that fetuses are normal.

Testing for genetic disorders prior to birth raises some ethical issues. Parents could decide to terminate the pregnancy. Knowing the gender of the fetus early on in the pregnancy may also be used as a reason to terminate the pregnancy. In most cases, however, the information helps parents make decisions that will better prepare them to raise their offspring.

Ultrasound

The technology that is most commonly used to detect abnormalities in the developing fetus is ultrasound. **Ultrasound** (Figure 1(a)) uses high-frequency sound waves to create a 3-D image, called a sonogram (Figure 1(b)), of the developing fetus. It is used to view the developmental progress of the fetus and to detect any physical abnormalities. It can also be used to determine the gender of the fetus.

LEARNING TIP

The photographs and diagrams in this section will help you understand prenatal procedures. First, read the explanation of each procedure. Then look carefully at the related figure.

Amniocentesis

In a procedure called **amniocentesis** (Figure 2), the doctor uses a syringe to remove amniotic fluid from the sac that surrounds the fetus. The amniotic fluid contains cells from the fetus, and these cells contain the chromosomes of the developing fetus. These cells are treated, allowed to reproduce, and then stained and placed on a microscope slide. A photo of the genetic material is used to produce a karyotype of the fetus. The test is done around the 20th week of pregnancy. 4A *Investigation*

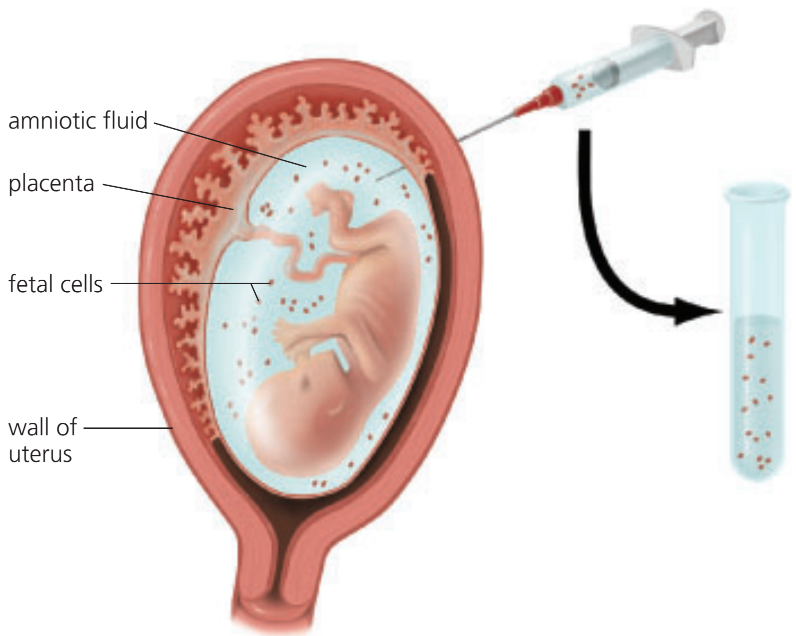
Since the 1970s, amniocentesis has been a common procedure used to view the chromosomes of fetuses in high-risk pregnancies. A pregnancy is considered to be high-risk when the mother is over the age of 35, the mother has already had a child with Down syndrome or a child with a defective spinal cord or brain, the mother or father has a genetic disease in the family, or the mother has had previous miscarriages. A **miscarriage** occurs when a fetus is involuntarily expelled from the womb before it has developed enough to survive on its own. Miscarriages can be caused by birth defects in the fetus, accidents, or illnesses.

4A *Investigation*

The Human Karyotype

To perform this investigation, turn to page 139.

In this investigation, you will create a karyotype of human chromosomes.



LEARNING TIP

Use questions to check your understanding of amniocentesis. Ask yourself, "What is involved in this procedure? What are the advantages and disadvantages of this procedure? What else is it used for?"

Figure 2 Amniocentesis removes amniotic fluid, which contains fetal cells. These cells are karyotyped.

Other information, such as whether the fetus has a spinal cord defect, can also be obtained from amniotic fluid. As well, in the third trimester, the amniotic fluid can be analyzed to determine how well the fetus's lungs have developed. The levels of certain chemicals in the fluid indicate whether the lungs of the fetus are mature enough to function well outside the womb. GO

If you would like to learn more about amniocentesis, go to **www.science.nelson.com** GO

Chorionic Villus Sampling

Chorionic villus sampling involves inserting a catheter through the vagina into the uterus to sample cells of the placenta. The chorionic villi are extensions of the chorion, the layer of the placenta that connects to the uterus (Figure 3). The chorionic villi contain many more fetal cells than the amniotic fluid. The sample is taken between 8 and 12 weeks of pregnancy. The karyotype of the fetus can be determined much earlier in the pregnancy than with amniocentesis. However, the test does not provide information about possible spinal cord defects or lung maturity.

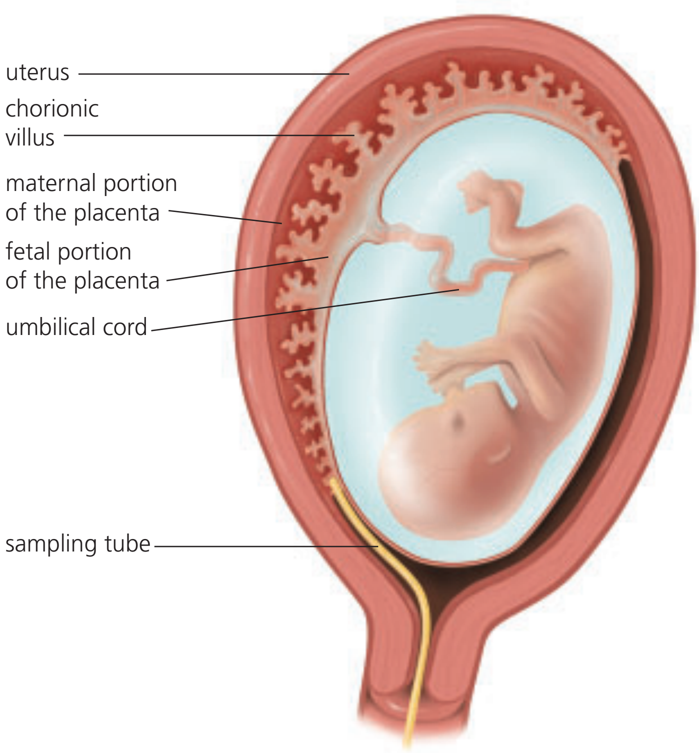


Figure 3 Chorionic villus sampling provides fetal cells, from which a karyotype is made.

Egg Collection

Women who choose in vitro fertilization have some eggs collected and tested for genetic disorders. An optical device called laparoscope is inserted into the abdominal cavity to view the ovary. A suction device is inserted to collect some eggs, which are then tested in a laboratory. If they are healthy, the eggs will undergo in vitro fertilization. Examining eggs will only detect disorders from the mother's genes.

4.6

CHECK YOUR Understanding

1. Name two diseases or disorders that can be detected by prenatal tests.
2. (a) Name the prenatal procedure used to produce the image in Figure 4.

Figure 4

   (b) What is the image in Figure 4 called?
   (c) Name one condition that this procedure can detect.
3. Identify four situations that cause a pregnancy to be considered a high-risk pregnancy.
4. Name the prenatal procedures that are used to produce a karyotype of the fetus.
5. Which sample contains more fetal cells, the amniotic fluid or the chorionic villus?
6. In Figure 5, which label (A, B, or C) shows where the fluid is taken from in amniocentesis?

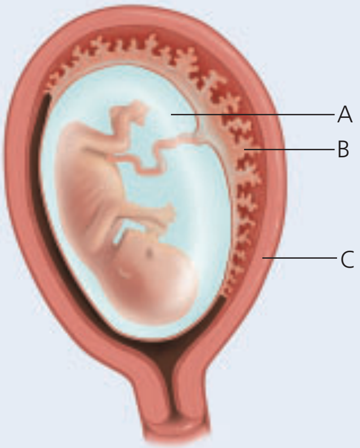


Figure 5

7. Which test(s) could be used to determine each of the following?
   (a) Down syndrome
   (b) gender
   (c) genetic disorder from the mother only
   (d) condition of the fetal lungs
8. Which test can produce a karyotype earlier in pregnancy, amniocentesis or chorionic villus sampling?
9. Would chorionic villus samples be useful for indicating the maturity of the lungs? Explain your answer.
10. Which of the prenatal diagnoses is the least invasive way to produce a karyotype? Explain your answer.
11. (a) Describe how eggs are collected.
    (b) What is the purpose of egg collection?

FIGHTING HUNTINGTON'S DISEASE

Genetically modified mice are helping Vancouver scientists learn more about this deadly genetic disease.

Would you want to know right away if you carried the gene? Would you rather wait and see if you developed the symptoms? Children of people with Huntington's disease must ask themselves these questions. Huntington's disease is a disease of the nervous system that is characterized by loss of memory, reasoning, and judgment, as well as involuntary jerky movements of the limbs, head, and neck. The onset of Huntington's disease is usually between 30 and 50 years of age, and because there is currently no cure, death occurs from complications 10 to 15 years after the onset of the disease. People with Huntington's disease usually die from falls or choking.

Huntington's disease is the result of a mutation in the gene that codes for huntingtin protein, a protein that is essential for proper nerve cell functioning. Amino acids are the building blocks of proteins. Normally, the huntingtin protein has many molecules of the amino acid glutamine, usually between 10 and 35 in a row. In people with Huntington's disease, the mutated gene creates a protein that has over 40 glutamine molecules in a row. The extra glutamines change the shape of the protein, which in turn causes nerve cell death. The death of nerve cells is the cause of the symptoms and progression of Huntington's disease (Figure 1).

Scientists, such as Dr. Michael Hayden at the Centre for Molecular Medicine and Therapeutics in Vancouver, have developed special mice that serve as models to study this disease. These mice were developed by transferring new genes into the nuclei of fertilized mouse embryos. The genetically modified mice have symptoms that resemble Huntington's disease. As the mice mature and develop symptoms, scientists learn about the disease mechanisms and potential treatments for Huntington's disease.

There is a test to determine the base sequence of the gene on chromosome 4, which codes for huntingtin protein. It is the only reliable way to determine if an individual will develop Huntington's disease. Interestingly, many people who have a parent with Huntington's disease do not want to get tested. It is an individual choice.

Think of what it would be like to wonder, every time you tripped or dropped a glass, if you were getting the disease. Without a cure, however, would wondering be better than facing the certainty of the disease?

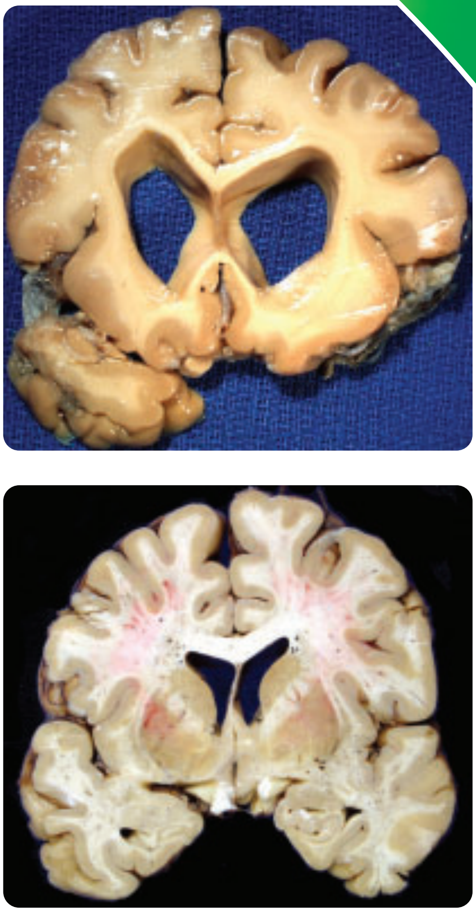


Figure 1 Cross sections of a brain from a person who died from Huntington's disease (top) and a normal brain (bottom). In the Huntington's brain, notice the large spaces created by the death of cells in these areas of the brain.

4.7

Reproductive Technologies

LEARNING TIP

Preview Section 4.7, and read the headings. What types of reproductive technologies will you be reading about in this section?

Although reproduction is a normal part of human life, complications can arise at all stages of the human reproductive cycle. Reproductive technologies are changing the ways that babies are conceived and born, and are shaping the laws that determine parenthood and responsibility. What are some of the ways that humans have overcome barriers to reproduction? Are there new technologies on the horizon?

There are many reasons why couples are infertile and are unable to have babies. The man may not be able to produce enough healthy sperm. The oviducts of the woman may be blocked, or the ovaries may not be functioning properly. There may not be enough of the proper hormone at the correct time in the woman's cycle. Whatever the reason, couples can get advice and treatment from doctors who specialize in fertility problems. There are a number of reproductive technologies that doctors can use to treat infertility.

Fertility Drugs

Fertility drugs stimulate the production of hormones that affect the action of the female's follicles. When a woman takes these drugs, more eggs mature and are released from the ovary. This increases the chances of conception. In fact, taking fertility drugs often results in multiple births (twins, triplets). People who undergo any of the following procedures are often prescribed fertility drugs as well.

Artificial Insemination

Artificial insemination involves introducing sperm into the reproductive tract of the female by a method other than sexual intercourse. In humans, several million sperm are needed to ensure successful fertilization. One cause of infertility can be a low sperm count. If the male has a low sperm count, his sperm can be collected over time and then artificially inserted into the female by a doctor. If the male produces no living sperm at all, couples can use sperm from an anonymous donor, obtained from a sperm bank.

Intrauterine Insemination

In intrauterine insemination, sperm is collected from the male and placed directly into the female's uterus (Figure 1), rather than into the vagina, as in artificial insemination. The sperm is placed high up in the uterus at the time of ovulation. Normally, many sperm cells die as they travel from the vagina to the oviducts. This technology ensures that as many sperm as possible reach the egg.

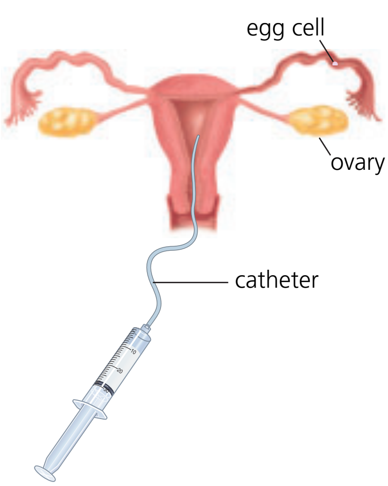


Figure 1 In intrauterine insemination, the sperm are collected and placed in a syringe. They are then injected into the uterus using a catheter. The sperm move into the oviduct to fertilize the egg.

Gamete Intrafallopian Transfer

In gamete intrafallopian transfer (GIFT) the female's eggs are removed from the ovary and reinserted into the oviduct (fallopian tube) along with the male's sperm. This increases the chances of fertilization by bringing the egg and the sperm together in the oviduct, where fertilization normally occurs, thus increasing the chances of fertilization.

In Vitro Fertilization

In vitro fertilization (IVF) means that fertilization takes place outside the female's body in a Petri dish in a laboratory (Figure 2). Children conceived in this way are often called "test-tube babies." Follicles containing immature eggs are removed from the female's ovaries. Once the eggs have matured, sperm cells from the father are added. After a few days, the embryos are inserted into the uterus at the right time of the menstrual cycle. Usually, several embryos are inserted, and often multiple births occur. The embryos may also be implanted in a female who is not the biological mother if there is some reason why the mother's uterus cannot accept the embryos. The female who carries the embryos is called the **surrogate mother**. This will be discussed in Section 4.8.

LEARNING TIP

The process of in vitro fertilization is described in two ways—in text, and in a sequential diagram (Figure 2). Check to see that you understand how the text and the diagram match.

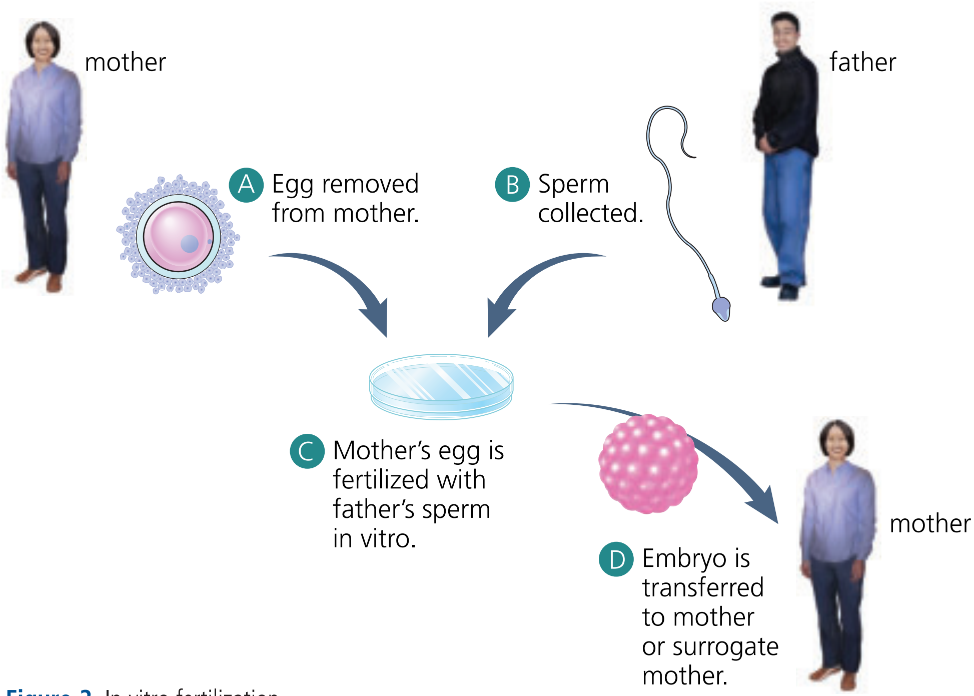


Figure 2 In vitro fertilization

Intracytoplasmic Sperm Injection

Intracytoplasmic sperm injection (ICSI) involves injecting a single sperm into the cytoplasm of a mature healthy egg. This technology is used when normal IVF has not been successful. The sperm count may be extremely low, or the sperm may be structurally unable to swim properly to reach the egg. The sperm can be collected in the normal way or retrieved from the testes.

4.7 CHECK YOUR Understanding

1. At what point in the menstrual cycle would artificial insemination be done?
2. What is a disadvantage of taking fertility drugs?
3. (a) What is gamete intrafallopian transfer?
   (b) Where does fertilization take place?
4. Compare artificial insemination and intrafallopian transfer.
5. Give two reasons why couples might use in vitro fertilization.
6. Babies produced by in vitro fertilization have been called "test-tube babies." Why is this inaccurate?
7. Identify the technology shown in Figure 3.

Figure 3

8. In your notebook, list the following steps of in vitro fertilization in the correct order:
   (a) Eggs are placed in a Petri dish.
   (b) Embryo is transferred to the uterus.
   (c) Eggs are extracted from the ovary.
   (d) Fertility drugs are given to the woman.
   (e) Eggs are fertilized by sperm.
   (f) Embryos are incubated.
9. Which technology usually precedes most other artificial reproduction technologies?
10. (a) Describe the process of intracycloplasmic sperm injection (ICSI).
    (b) Under what circumstances is ICSI used?
11. List the reproductive technologies that use embryo transfer.
12. Which reproductive technologies are used when the woman's reproductive system is functioning properly but the man is not producing enough sperm?
13. Which reproductive technologies require the female's eggs to be collected?
14. Explain why fertility drugs are usually taken by the female before any artificial reproduction technology is used.
15. Using your knowledge of the male reproductive system, explain why males usually do not take fertility drugs.
16. A couple is unable to conceive. The male produces sperm cells like the one in Figure 4. They contain healthy DNA but cannot swim properly. Which reproductive technology is most likely to help the couple conceive?

Figure 4

4.8 Explore an Issue

DECISION MAKING SKILLS

- ○ Defining the Issue
- ● Researching
- ○ Identifying Alternatives
- ● Analyzing the Issue
- ○ Defending a Decision
- ● Communicating
- ○ Evaluating

Surrogate Mothers

All the technologies described in Section 4.7 involve the mother becoming pregnant and delivering the baby nine months later. Sometimes, the mother can conceive but is unable to maintain a pregnancy, and so cannot produce a baby. In this situation, artificial reproductive technologies do not help. In the past, the only opportunity for these couples to become parents was to adopt a child.

The Issue: Surrogate Mothers

Because of advances in reproductive technologies, it is possible to remove an egg from a woman, fertilize the egg with sperm in vitro, and then transfer the embryo into the uterus of another woman—a surrogate mother. The surrogate mother is pregnant with the fetus for nine months, and then returns the newborn to the genetic mother. Surrogacy made headlines in 2004, when U.S. television personality Joan Lunden announced that she had hired a surrogate mother. The surrogate mother gave birth to twins (Figure 1).

Figure 1 Surrogate mother Deborah Bolig (left) and Joan Lunden (right) hold the twins.

Statement

The law should allow couples who cannot have children naturally to hire a surrogate mother.

Background to the Issue

In some cases, the genetic mother cannot physically carry a baby to term or does not want to be pregnant. A healthy woman acts as surrogate mother by becoming pregnant with an embryo that is conceived through IVF and contains the DNA of the genetic mother and father. Often a female friend or relative volunteers to be the surrogate. Commercial surrogacy occurs when the surrogate mother carries the developing baby for a fee. A contract is entered into by both parties: the surrogate mother and the genetic parents.

Make a Decision

A series of meetings have been organized by the federal and provincial governments to address the concerns related to the hiring of surrogates. Many of the stakeholders have been asked to make presentations at these meetings. The stakeholders have very different perspectives about surrogacy.

Sample Stakeholder Perspectives

- An infertile couple has tried several times to conceive a baby using artificial reproductive technologies. These attempts have been expensive and unsuccessful. The couple's eggs and sperm are healthy, but the woman cannot maintain a pregnancy. Being able to use a surrogate mother to give birth to a baby with the couple's DNA would allow them to raise their own child.
- A young woman would like to be a surrogate mother. She wants to use the money to fund her university studies.
- A fertility specialist has performed several embryo transfers and thinks the procedure is generally safe for both the embryo and the surrogate mother.
- The ministry of health is concerned that if either the baby or the mother developed complications during the pregnancy, difficult decisions would have to be made. These decisions could have unexpected consequences. Who would make these decisions?
- The ministry of social services thinks that there are many young children who are in need of loving homes, and there are young women with unwanted pregnancies who plan to put up their babies for adoption. Infertile couples should consider adoption instead of surrogacy.
- A women's rights advocate thinks that surrogacy exploits the female body. Complications during the pregnancy may affect the surrogate mother's ability to have children later on in her life.

1. In your group, read the sample stakeholder perspectives, and evaluate each one.
2. Record the main ideas in a table with the headings "For the statement" and "Against the statement." Add your own ideas under these headings as well.
3. Choose a stakeholder that you will represent.
4. Conduct research, using the Internet and other sources, to find information that supports the perspective of your stakeholder. The stakeholder's perspective should support or refute the statement.

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Communicate Your Decision

5. In your group, prepare to present your stakeholder's perspective to the audience. Present only the opinions of the stakeholder that you represent. Be prepared to answer questions from other stakeholders and audience members. Also be prepared to ask questions of other presenters.
6. After the presentations have been made and the questions have been answered, discuss in your group whether your position has changed. Using your position, prepare your recommendations to the government. Make sure that your recommendations are supported.

4A Investigation

The Human Karyotype

The genetic material in human cells is contained in 46 chromosomes, arranged in 23 pairs. A karyotype is used to organize and analyze the genetic material of individuals.

Question

What information can you obtain from a human karyotype?

Experimental Design

In this investigation, you will use an image of human chromosomes to construct a karyotype.

Materials

- image of human chromosomes
- scissors
- glue
- paper
- marker

Procedure

1. Cut out all the individual chromosomes.
2. Arrange the chromosomes in homologous pairs. What features can you use to arrange them into pairs?
3. Once you have matched the chromosomes, arrange them in ordered pairs, as shown in Figure 1.

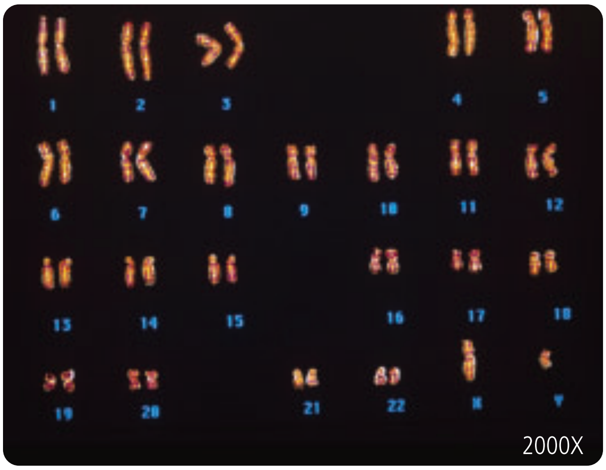


Figure 1 A human karyotype. The homologous pairs are numbered.

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	● Synthesizing
○ Predicting	● Analyzing	● Communicating
● Planning		

4. Paste your chromosome pairs, in order, on a blank sheet of paper.
5. Number your chromosome pairs from 1 to 23.
6. Compare your karyotype with your classmates' karyotypes. Indicate the gender of each of your classmates' karyotypes.

Analysis

(a) How many pairs of chromosomes have you matched?

(b) Did all the chromosomes have a matching partner? If not, explain why.

(c) Is your karyotype male or female? Explain how you know.

Evaluation

(d) What features of the chromosomes did you use to match them?

(e) Are there other features you could have used?

(f) Were there any chromosomes that were difficult to match?

Synthesis

(g) What type of information can be gained from a karyotype?

(h) Would karyotypes from the same family look the same? Explain.

(i) Why would it be useful to compare karyotypes of family members?

CHAPTER 4

Review

Human Reproduction

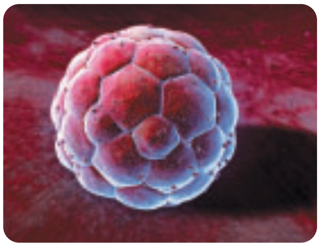
Key Ideas

Male and female humans have specialized organs to produce gametes and to ensure fertilization.

- Males produce sperm, the male gametes, in the testes. Females produce eggs, the female gametes, in the ovaries.
- Fertilization of an egg by a sperm cell happens in the female's oviduct. The zygote develops in the uterus.

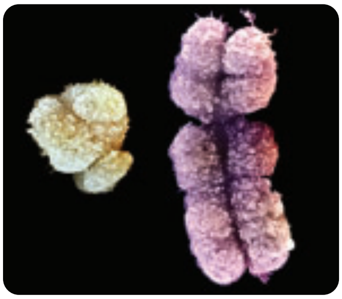
It takes nine months for a human zygote to develop into a baby.

- In the first trimester, the embryo becomes a fetus and the placenta forms. In the second trimester, limbs and facial features develop. In the third trimester, all the organ systems continue developing and the fetus continues to gain mass.
- During birth, rhythmic contractions of the uterus push the baby out of the mother. The placenta is pushed out shortly after.
- The zygote and the cells created from the first few cell divisions are unspecialized stem cells. Stem cells can form into any type of specialized cell.



Sex chromosomes determine the gender of the offspring.

- The X and Y chromosomes control whether an individual is male or female: an XX combination produces a female and an XY combination produces a male.
- The X and Y chromosomes also control sex-linked characteristics such as red-green colour blindness and having hemophilia.

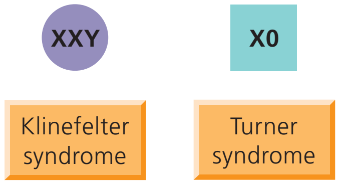


Vocabulary

puberty, p. 108
testosterone, p. 108
scrotum, p. 109
testes, p. 109
seminiferous tubules, p. 109
epididymis, p. 109
vas deferens, p. 109
urethra, p. 109
penis, p. 109
semen, p. 110
mammary glands, p. 112
ovary, p. 112
follicles, p. 112
estrogen, p. 112
progesterone, p. 112
menstrual cycle, p. 113
menopause, p. 113
ovulation, p. 113
corpus luteum, p. 113
oviduct (fallopian tube), p. 113

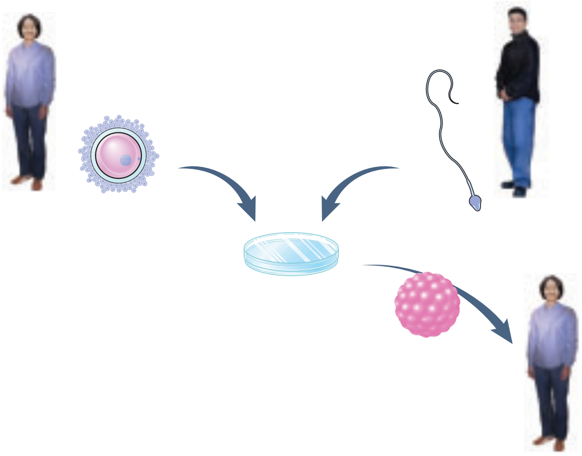
Errors in meiosis can result in changes to both the gametes and the offspring.

- When homologous chromosomes do not separate in meiosis, gametes have either too many or too few chromosomes. Having an extra copy of chromosome 21 causes Down syndrome.
- When sex chromosomes fail to separate during meiosis, gametes have either an extra sex chromosome or are missing one. Having only one X chromosome causes Turner syndrome. Having an extra X chromosome causes Klinefelter syndrome.



Scientists have developed technologies that can identify potential problems and allow humans to produce offspring successfully.

- Ultrasound uses sound waves to create an image of the fetus. The image is used to check that the fetus is developing properly.
- Amniocentesis tests for chromosomal disorders by karyotyping fetal cells found in the amniotic fluid.
- Chorionic villus sampling takes cells from the fetal part of the placenta and uses them to create a karyotype of the fetus.
- Fertility drugs are used to help a woman produce more eggs, which increases the chance of conception.
- In artificial insemination, sperm from the father is inserted into the vagina.
- In in vitro fertilization, the egg is fertilized by the sperm outside the mother's body and the resulting embryo is placed in the mother's womb.



uterus (womb), p. 113
endometrium, p. 113
cervix, p. 113
vagina, p. 113
menstruation, p. 114
flow phase, p. 114
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embryonic development, p. 115
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Down syndrome, p. 127
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Klinefelter syndrome, p. 128
ultrasound, p. 130
amniocentesis, p. 130
miscarriage, p. 130
surrogate mother, p.135

Review Key Ideas and Vocabulary

1. Which of the following is a primary male sexual characteristic?
   (a) facial hair
   (b) testes
   (c) deeper voice
   (d) muscle development
2. Which of the following is an accessory sexual organ in males?
   (a) epididymis
   (b) vas deferens
   (c) urethra
   (d) prostate
3. Approximately how many sperm reach an egg?
   (a) 1
   (b) 100
   (c) 400 000
   (d) 2 000 000
4. Which of the following refers to the release of an egg?
   (a) menstruation
   (b) implantation
   (c) lactation
   (d) ovulation
5. Which of the following is the male sex hormone?
   (a) progesterone
   (b) estrogen
   (c) testosterone
   (d) cortisone
6. Which of the following is the most important change during puberty in females?
   (a) growth of mammary glands
   (b) widening of hips
   (c) releasing of eggs
   (d) growth of underarm and pubic hair
7. Which list gives the correct order of the menstrual cycle?
   (a) ovulation, follicular phase, menstruation, luteal phase
   (b) menstruation, ovulation, follicular phase, luteal phase
   (c) menstruation, follicular phase, ovulation, luteal phase
   (d) ovulation, follicular phase, luteal phase, menstruation
8. Which type of cells has the ability to differentiate into all different types of cells?
   (a) reproductive cells
   (b) gametes
   (c) stem cells
   (d) somatic cells
9. Sperm is to testes as an egg is to ___?___.
10. (a) Name the chromosomes that determine gender in humans.
    (b) Name the sex chromosomes in a male and in a female.
    (c) Why aren't the sex chromosome always considered homologous chromosomes?
11. Give two functions of the urethra in males.
12. Identify the parts of the male reproductive system, labelled A to D, in Figure 1.

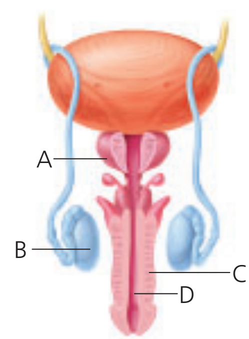

Figure 1

13. What event prevents the occurrence of a menstrual cycle? How does it do this?
14. (a) What is the placenta?
    (b) Why is the placenta so important to the developing fetus?
15. (a) What is a sex-linked characteristic?
    (b) Why are sex-linked characteristic expressed more frequently in males?
16. Describe the two procedures that are used when a man's sperm count is extremely low.
17. Identify the parts of the female reproductive system, labelled A to C, in Figure 2.

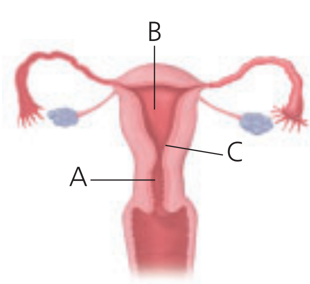

Figure 2

Use What You've Learned

18. List at least three differences between the male and female reproductive systems.
19. Explain the difference between ovulation and implantation.
20. The endometrium is important during the menstrual cycle and pregnancy. Explain the role and fate of the endometrium.
21. Why do you think the circulatory system is the first to function in a developing human embryo?
22. Why are scientists interested in stem cell research?
23. Draw diagrams to show the difference between identical twins and fraternal twins.
24. (a) Does the karytoype in Figure 3 belong to a female or a male?
    (b) Explain how you can tell the gender.

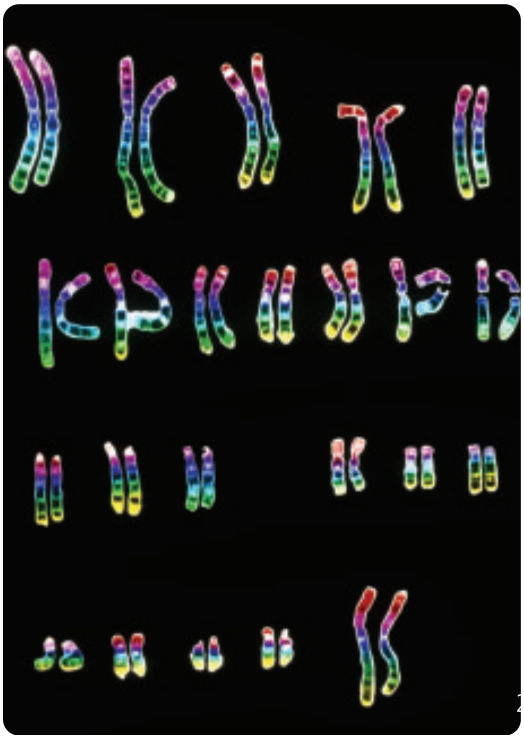

Figure 3

25. Explain how nondisjunction can cause disorders. Use examples.
26. List three prenatal diagnostic procedures and the disorder or condition that the procedure can diagnose.

Think Critically

27. The human embryo develops inside a sac filled with amniotic fluid. What is the purpose of this fluid?
28. Human males produce millions of sperm each day and release millions of sperm into the female vagina during ejaculation. Females only release one egg at a time. Explain this difference in the number of gametes released.
29. During the second trimester, the fetus swallows amniotic fluid and urinates. If the fetus is getting its nutrition from the mother through the umbilical cord, what is the purpose of swallowing the fluid?
30. Some references list 280 days as the length of a human pregnancy, while others list 266 days. Both are considered to be correct. How might this difference be explained?
31. Many multiple births result from using artificial reproductive technologies. Explain why these multiple births occur.
32. Home pregnancy test kits are very common. Use the Internet and other sources to research how they work and how reliable they are.

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Reflect on Your Learning

33. Reproductive technologies often involve complicated procedures that are expensive and may not be successful. Why do you think many parents choose these invasive methods instead of adopting a baby?
34. Did the discussion about hiring surrogate mothers change your opinion about the use of surrogate mothers? Explain why or why not.

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Reproduction

Unit Summary

In this unit, you have learned about the growth and reproduction of cells and complete organisms. The molecule that allows identical daughter cells to be produced by cell division is DNA. The information contained in DNA is unique to each individual of a species. Asexual reproduction passes on the identical DNA to each new organism. In sexual reproduction, parents contribute a copy of half of their DNA to their offspring through meiosis. The variety of traits produced through sexual reproduction allows organisms to adapt to changing environments. DNA contains the genetic code for all the instructions for life. Thus, DNA controls the growth and development of all living things. Changes in DNA can be harmful, causing diseases such as cancer.

Beginning with DNA at the cellular level, add words and arrows to make a concept map that shows your understanding of the relationships between the following terms:

- chromosomes
- nuclear membrane
- proteins
- replication of chromosomes
- ribosomes
- sister chromatids

Using one or more of these terms, expand your concept map to include other key ideas and vocabulary in this unit. Use diagrams, symbols, and text to illustrate the relationships.

Review Key Ideas and Vocabulary

1. Approximately how many cells are in the human body?
   (a) 1 million
   (b) 100 million
   (c) 1 billion
   (d) 100 trillion
2. Which of the following is a function of cell division?
   (a) growth and repair
   (b) production of energy
   (c) reproduction
   (d) both (a) and (c)
3. Which statement explains why cells divide?
   (a) The nucleus gets too big.
   (b) The volume is too large.
   (c) The size is too small.
   (d) There is not enough cytoplasm.
4. Which organism reproduces using cell division?
   (a) humans
   (b) multicellular plants
   (c) Paramecium
   (d) blue whales

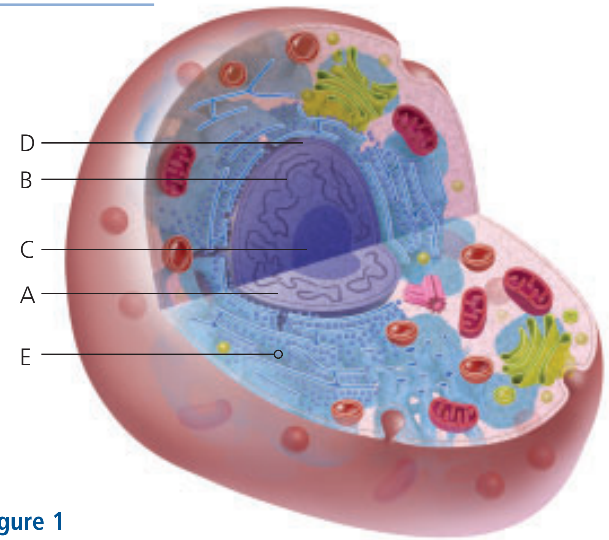

Figure 1

Use Figure 1 to answer questions 5 to 8.

5. Which structure produces the ribosomes?
   (a) A (b) B (c) C (d) D
6. Which structure contains DNA?
   (a) A (b) B (c) C (d) E

7. Which structure breaks down in preparation for cell division?
   (a) A (b) B (c) C (d) D
8. Humans have 46 of these.
   (a) A (b) B (c) D (d) E
9. A human egg cell has __?__ chromosomes.
   (a) 46 (b) 24 (c) 48 (d) 23
10. Which hormones are the female sex hormones?
    (a) testosterone and estrogen
    (b) estrogen and progesterone
    (c) progesterone and cortisone
    (d) cortisone and estrogen
11. Use Figure 2 to answer the following questions.

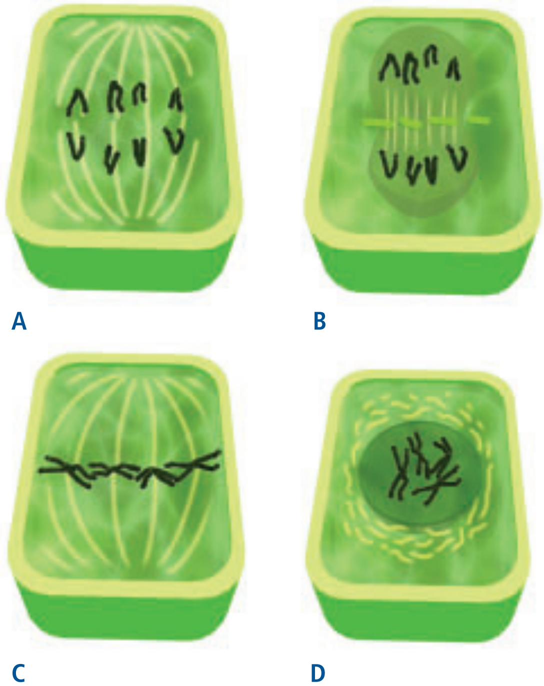

Figure 2

    (a) Name the stages and put them in the correct order.
    (b) Does the illustration show plant or animal mitosis? Explain.
    (c) Identify the stages that have sister chromatids attached.
    (d) Which stage of the cell cycle is missing?
12. Match the term on the left with the description on the right.

Table 1

Term	Description
a) allele	process that does not occur during meiosis
b) meiosis I	diploid
c) chromosome number	process in which the sister chromatids stay together during metaphase
d) meiosis II	one form of a gene
e) interphase	process that creates four daughter cells

13. Give two examples of organisms that reproduce by each of the following methods.
    (a) seeds
    (b) spores
    (c) binary fission
    (d) vegetatively
    (e) fragmentation
    (f) embryo developing in a uterus
14. Indicate whether each statement is true or false. If you think that a statement is false, rewrite it to make it true.
    (a) DNA is composed of sugars, phosphates, and nitrogenous bases.
    (b) Humans have 23 chromosomes in each somatic cell.
    (c) Zygotes are diploid.
    (d) Chromosomes replicate during metaphase.
    (e) Gametes are diploid.
    (f) DNA and RNA are only found in the nucleus.
    (g) If the fertilized egg of a fruit fly has eight chromosomes then the cells of the fruit fly's wings have four chromosomes.
    (h) When plants such as potatoes reproduce by creating tubers, they reproduce without sex cells.
    (i) Cancer cells divide at the same rate as normal cells.
    (j) Human egg cells have half as many chromosomes as human sperm cells.

15. Complete the following table to compare mitosis and meiosis.

Type of cell division		
Number of chromosomes in parent cell	2n	
Number of daughter cells		4
Number of chromosomes in daughter cells		n

16. (a) What are cancer-causing agents called?
(b) Name three known causes of cancer.

17. (a) What special ability do the stem cells in an embryo have?
(b) Where else are stem cells found?

18. List the following events of pregnancy in the correct order.
(a) The umbilical cord connects to the placenta.
(b) The head of the fetus is down.
(c) The heart begins to beat in the embryo.
(d) The gender of the fetus is obvious.
(e) The fetus has a wake and sleep cycle.

Use What You've Learned

19. Use your knowledge of the cell cycle to answer the following questions.
(a) In which phase does growth occur?
(b) When do cells replicate their genetic material?
(c) When do chromosomes line up at the equator?
(d) When does cytokinesis begin?
(e) When do chromosomes shorten, thicken, and become visible under the microscope?
(f) When do sister chromatids separate and move to the poles of the cell?
(g) When does the cell plate begin to form?

20. How does DNA carry the genetic code?

21. Identify the following characteristics as belonging to normal cells or cancer cells.
(a) The cells stay attached after cell division.
(b) The nucleus is enlarged.
(c) The cells stop dividing when they touch another cell.
(d) The cells travel through the blood vessels.

22. Explain the relationship between a carcinogen and a mutation.

23. Fruit flies normally have eight chromosomes. Figure 4 shows the stages of meiosis.
(a) In which parent did nondisjunction take place?
(b) What is happening during process X?
(c) How many chromosomes would be found in zygotes D, E, and F?
(d) Which zygote would most likely be normal?

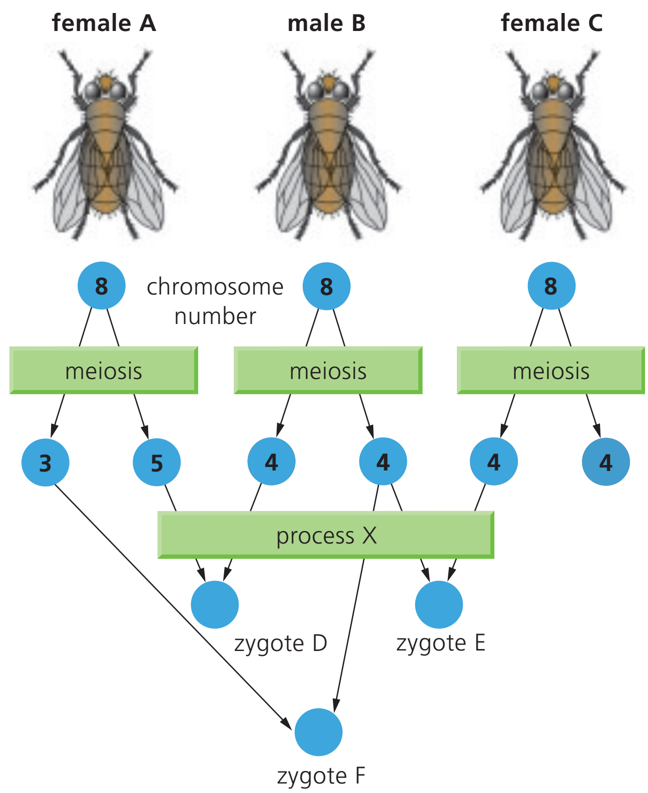

Figure 4

24. Use your knowledge of reproduction to answer the following questions.
(a) How many chromosomes are in the egg cell?
(b) Explain how the egg cell could be produced from a cell that has 46 chromosomes.
(c) How many chromosomes are in each cell of the embryo?
(d) What process causes growth of the embryo and an increase in the number of cells?
(e) What role do stem cells play in the development of the embryo?

25. Compare in vitro fertilization with the normal events of fertilization in humans.

26. People with Down syndrome have 47 chromosomes. They have three copies of chromosome 21. Is it possible for two people, both with Down syndrome, to have a child who does not have Down syndrome? Use a diagram to explain your answer.
27. Explain the difference between genetically modified organisms (GMOs) and organisms produced through selective breeding.
28. A man has testicular cancer and needs to have a testis removed. Can this man still produce children? Explain.
29. The DNA molecule is sometimes called a double helix.
    (a) Explain how the structure of DNA allows it to replicate.
    (b) Explain how DNA provides the instructions for the production of proteins.
    (c) Summarize the steps involved in building a protein from DNA.
30. Amniotic fluid plays several roles both in the development of the fetus and in providing clues to the health of the fetus. Explain these roles.

Think Critically

31. Insulin used to be extracted from the pancreas of pigs and cows. Now it is produced by recombinant DNA technology. Why is this technology better than using pigs and cows?
32. Describe the advantages of each of the following reproductive strategies.
    (a) A fern plant produces and releases many thousands of spores.
    (b) An opossum produces eight embryos, but only six are able to find the mother's pouch and attach to a nipple.
    (c) A parasitic worm produces thousands of eggs that are released in the solid waste of the host animal.
    (d) A flower is cross-pollinated with pollen from a flower in a distant field.
    (e) Individual earthworms have both male and female reproductive systems.
33. Compare the seed of a plant with the embryo of a mammal using the following headings: Source of nutrition, Protection, Role of the female parent.
34. One of the concerns about nuclear energy is that people could be exposed to excess radiation, which might lead to the development of cancerous tumours. Often, the chromosomes are damaged by excess radiation and broken apart in the nucleus.
    (a) How might the fragmentation of chromosomes affect cell division?
    (b) Suggest a method that could be used to detect these changes in chromosomes.
35. Your genetic material codes for many different amino acids. Explain how this can cause the unique traits that you have.
36. Recent medical research in Canada suggests that problems with cell division in stem cells may be a primary cause of cancer. Stem cells may act as cancer "seeds." The research also shows that while most cancerous cells respond to treatments such as radiation and chemotherapy, cancerous stem cells do not. Not all researchers agree with the stem-cell hypothesis, but they all agree that further research is needed immediately. Write five questions that could be the basis of further research in this area. Each question should contain two of the following phrases: cancer, stem cells, and treatment.
37. Infertility affects both males and females. Use the Internet to find possible causes and risk factors of infertility.

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Reflect on Your Learning

38. In this unit, you have learned a lot about how cells and organisms reproduce. Make a list of interesting facts about reproduction that you have learned. Did your understanding of reproduction change as a result of studying this unit? Explain how.

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UNIT

B

ATOMS, ELEMENTS, AND COMPOUNDS

Unit Preview

What makes fireworks so spectacular? Is it the noise, the light, or the colours? How do they travel so high and spread across the sky? Fireworks, like everything else that surrounds you, are made of matter. To answer questions about fireworks and the nature of matter you need to understand how matter behaves and how it is constructed.

As you investigate the nature of matter you will learn how matter can be classified according to properties and behaviours. You will also learn how matter is constructed and why the internal structure of matter gives substances their unique properties.

CHAPTER 5

Properties and Changes

KEY IDEAS

- Matter can be classified as pure substances or mixtures.
- Pure substances can be identified by their physical and chemical properties.
- A physical change alters a substance's state or form, but not its composition.
- A chemical change alters a substance's composition to create new substances.
- The kinetic molecular theory explains the nature and behaviour of matter.

Chapter Preview

Have you ever wondered how something works or why a material behaves as it does? Why do balloonists burn propane with oxygen to get airborne? What makes heating ice and burning wood so different? Why do certain candies pop in your mouth, while others do not?

With the discovery of fire, humans have been determined to use and understand the matter found around them. All cultures, including those of British Columbia's Aboriginal peoples, have applied the chemistry of the materials in their environment to improve their living conditions. Aborignal peoples discovered many uses for local materials. For example, they preserved food with salt, built homes with wood and bark from trees, created art with wood and metals, and used plants as medicine. They used the properties of matter to make materials useful to them.

In this chapter you will learn about the properties of matter and the changes that matter can undergo. This is an important first step in developing an understanding of modern chemistry.

TRY THIS: Popping Candy

Skills Focus: conducting, observing, analyzing

Materials: safety goggles, popping candy, bowl, spoon, water

1. Wearing your safety goggles, put a piece of popping candy in a bowl. Using a spoon, crush the candy with moderate pressure. Did you hear it pop?
2. Put another piece of candy in a bowl, add water, and stir. Was there any popping?

A. Do you know the names of the materials inside the candy? How do these materials make the candy pop?

B. How do you think this type of candy is manufactured?

5.1 The Classification of Matter

Chemistry is the study of matter. **Matter** is anything that has mass and volume. **Mass** is the amount of matter that an object has. **Volume** is the amount of space that an object fills. How many different examples of matter can you count in the classroom? Did you include the air and the glass in the windows? Air and glass both have mass and volume. Matter is not limited to your immediate surroundings. It is the material that makes up the whole universe (Figure 1).

Figure 1 Matter is anything that has mass and volume, whether or not you can see it. The air and clouds (a), a paramecium (b), desks (c), and the trees, rocks, and water (d) in Cayoosh Creek, B.C. are all matter.

Is there anything that is not matter? What do you think? What about sound or light or heat? These are not matter—they are forms of energy, and although they do not take up space or have mass, they are present in your environment.

All matter can be classified according to the diagram in Figure 2:

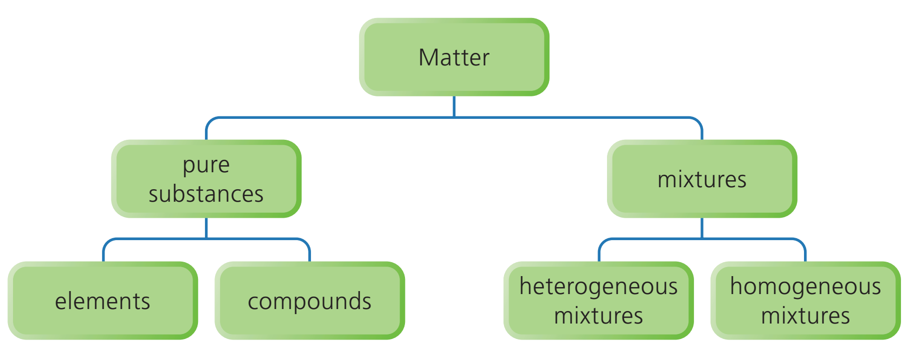


Figure 2 A tree diagram showing the classification of matter

Pure Substances

All matter can be classified as pure substances or mixtures. A **pure substance** is matter that contains only one type of particle. For example, copper wire is made from only copper particles. Water is a pure substance that contains only water particles. A **mixture** contains two or more pure substances, such as table salt dissolved in water, or iron mixed with sulfur.

Pure substances can be further classified as elements or compounds. Elements are the basic building blocks of matter. An **element** is a pure substance that cannot be changed into anything simpler. An element contains only one kind of particle. By 1000 BCE, the physical properties of some of the metal elements (such as copper, zinc, silver, and gold) were understood, but none of these were recognized yet as elements (Figure 3). Today, we know that there are at least 116 elements.

LEARNING TIP
Active readers ask questions to check their understanding of new terms. Ask yourself, "Can I tell the meaning of the words in bold on pages 153 and 154 from the sentences in which they are found?"

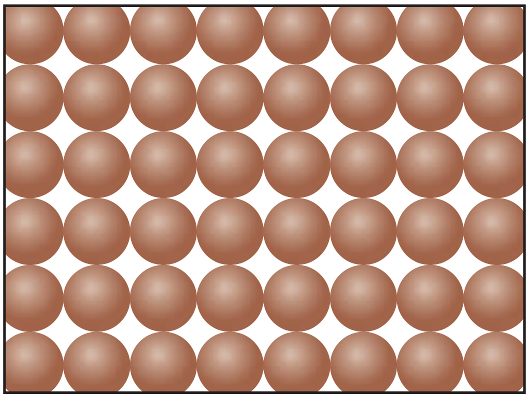


Figure 3 Copper is an element with only one kind of particle.

A **compound** is a pure substance that consists of two or more elements. The elements are in definite proportions and cannot be separated by physical means. For example, water always has two parts hydrogen to one part oxygen. Compounds have only one kind of particle, but each particle consists of two or more elements that are chemically joined (Figure 4).

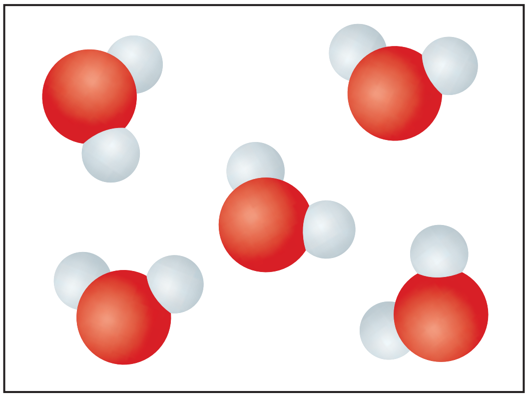


Figure 4 Water is a compound that has only one kind of particle. Compound particles are made from elements that are chemically joined.

Remember that elements and compounds are considered to be pure substances because they both contain only one kind of particle. For convenience, the term "substance" is often used by chemists to mean the proper term "pure substance."

Mixtures

Mixtures are formed when two or more pure substances are put together but their particles are not chemically joined. Also, the pure substances may be present in any proportions. Different fertilizers, for example, may just be mixtures of the same pure substances in different proportions (Figure 5).

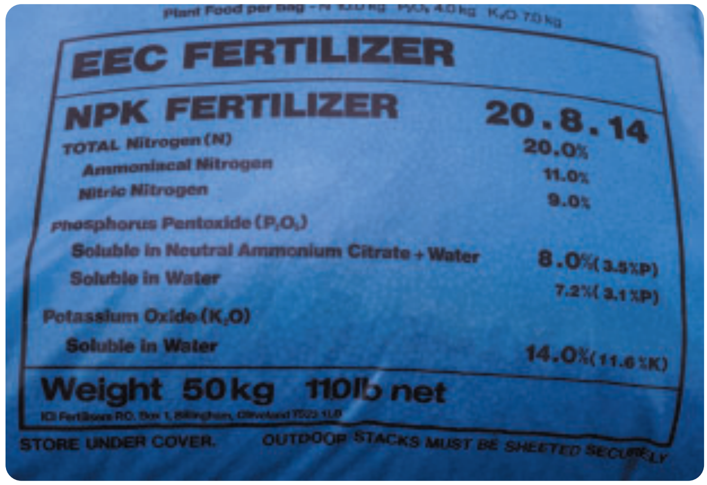


Figure 5 The numbers on a bag of fertilizer show the percentage by weight of each substance in the bag. This bag is 20 % nitrogen, 8 % phosphate (phosphorous pentoxide), and 14 % potash (potassium oxide). Other bags of fertilizer can have the same substances but in different percentages, such as 12-6-6, 24-5-11, or 30-10-10. The remaining percentage is filler.

LEARNING TIP

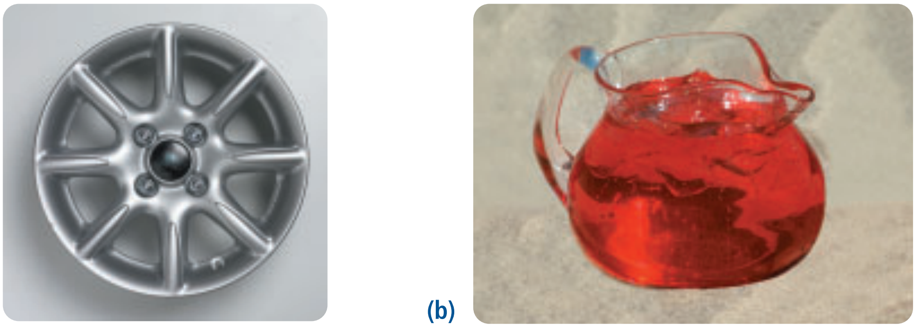
The prefix *hetero* indicates "difference." The prefix *homo* indicates "sameness." How will this help you understand the differences between heterogeneous and homogeneous mixtures?

A **heterogeneous mixture** is a mixture that is not uniform in its composition. The particles of the substances exist in large, visible clumps. This means that the components of heterogeneous mixtures can be visibly distinguished (Figure 6). For example, oil and water is a heterogeneous mixture, as is sulfur and iron.

(a) (b)

Figure 6 In a heterogeneous mixture, you can see the different substances that make up the mixture. In (a), you can see rocks of different sizes embedded in the cement. In (b), you can see the different layers of the salad dressing. One layer is oil and the other is vinegar based.

A **homogeneous mixture** is made of substances that are evenly and microscopically mixed together. The particles of the pure substances in a homogeneous mixture are separate but indistinguishable from each other. Solutions are examples of homogeneous mixtures of liquids and/or gases. For example, soda pop is a solution of sugar, corn syrup, and carbon dioxide gas in water. The air you breathe is a solution of oxygen, nitrogen, and small amounts of other gases. Alloys are homogeneous mixtures of solids. Alloys of metals are often stronger or harder than either of the component metals (Figure 7).



(a) (b)

Figure 7 You cannot see the different substances that make up a homogenous mixture. For example, you cannot see the different metals that make up the car wheel in (a) or the substances that make up the drink in (b).

Did You KNOW?

Mixtures in Electronics

The circuits in a music player or cell phone are highly dependent on mixtures of pure substances. Many electronic circuits consist of 99.999 % pure silicon, which does not conduct electricity. The electrical properties of the circuits are made possible by adding tiny amounts of impurities which make controlled conduction possible.

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TRY THIS: *Comparing Mixtures and Compounds*

Skills Focus: conducting, observing, recording, analyzing, inferring

Materials: letter-size blank sheet of paper, thin cardboard slightly bigger than paper, spoon or spatula, powdered sulfur, coarse powdered iron, 2 medium test tubes, 2 stoppers, 1 test tube rack, magnet, safety goggles, apron, 5 mol/L dilute hydrochloric acid, sample of heated sulfur and iron

Use caution when working with hydrochloric acid. Even dilute acid is corrosive. Wash all surfaces that come in contact with this substance.

1. Draw four large circles, one in each quarter of a piece of blank paper, and label them A, B, C, and D. Place the paper on the cardboard. Measure approximately 2 mL of sulfur onto circle A, and measure another 2 mL into a test tube. Measure approximately 2 mL of coarse powdered iron onto circle B, and 2 mL into the test tube with the sulfur. Put a stopper in the test tube and shake well.
2. Pour half of the mixture from the test tube onto circle C. Lift the cardboard a little and place the end of the magnet under the sulfur, and then under the iron (Figure 8). Move the magnet under each circle. What happens?
3. Place the magnet under the mixture and move it. What happens?
4. Put on your safety goggles and apron. Carefully add two or three drops of hydrochloric acid to the mixture left in the test tube. What do you observe?

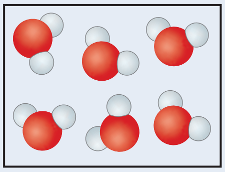
Figure 8

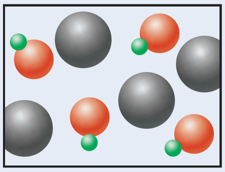
5. Your teacher will give you a sample of a mixture of iron and sulfur that has been heated and then ground into a fine powder. Put part of this sample on circle D and the rest into a second test tube.
6. Place the magnet under the sample in circle D and move it. What happens?
7. Carefully add two or three drops of hydrochloric acid to the sample in the second test tube. What do you observe?
8. Clean up your work area as instructed by your teacher. Wash your hands and all glassware carefully.

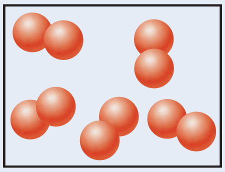
A. Which substance—the substance in circle C or the substance in circle D—is a mixture? Which one is a compound? How do you know?

5.1 CHECK YOUR Understanding

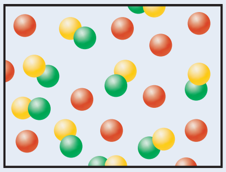
1. What are the characteristics of matter?
2. What are the two classifications of pure substances? How are they similar? How are they different?
3. Give two examples of each of the following:
   (a) an element
   (b) a compound
   (c) a homogeneous mixture
   (d) a heterogeneous mixture
4. Use the terms "element," "compound," "homogenous mixture," or "heterogenous mixture" to classify the following substances:
   (a) iron
   (b) the air you breathe
   (c) soda pop
   (d) distilled water
5. If all the particles in a material are made up of several smaller particles, and every larger particle is identical, is the material a pure substance or not? Explain your reasoning.
6. In the Middle Ages, most scientists believed that the world was made from four simple elements and that almost everything was a mixture. Which type of pure substance had they not yet discovered?
7. What does each of the following diagrams represent: an element, mixture, or compound? Explain your choice.

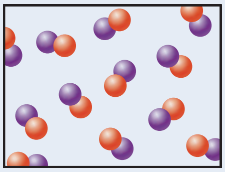
   (a)
   

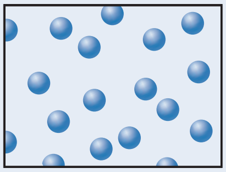
   (b)
   

   (c)
   

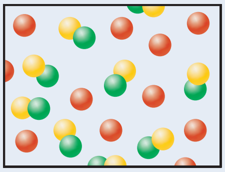
8. Which of the following diagrams might represent a mixture? Why?

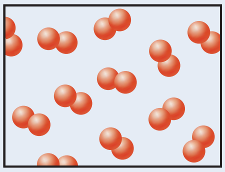
   (a)
   

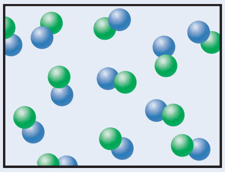
   (b)
   

   (c)
   

9. Which of the following diagrams might represent an element? Why?

   (a)
   

   (b)
   

   (c)
   

10. Identify each of the following as an element, mixture, or compound.
    (a) salt
    (b) silver
    (c) seawater
    (d) hydrogen
    (e) gasoline
    (f) water
11. Is blood a mixture? Explain your reasoning.
12. An unknown, clear liquid is given to you in a beaker. You transfer some of the liquid from the beaker to a clean, empty test tube, and begin to heat it. Soon, you observe a vapour leaving the top of the test tube. With further analysis you discover that the vapour is water vapour. Eventually, all that's left are a few crystals stuck to the sides of the test tube. Was the original liquid an element, a compound, or a mixture? Explain your reasoning.
13. A shiny magnesium ribbon is burned in air, to form a greyish powder called magnesium oxide. Is this oxide an element, a compound, or a mixture? Explain your thinking.

5.2 Properties of Matter

The special characteristics of pure substances that make each one unique are called properties. The properties of the element or compound are true for any amount of the material anywhere. So the properties of Canadian gold are identical to South American gold. The differences in properties help to identify pure substances and make the substances useful for different applications. All matter exhibits two types of properties. One type is physical.

Physical Properties

The **physical properties** of matter are those you can observe with your senses, measure, or calculate. Although many physical properties (such as colour and hardness) of substances are directly observable, many are detected through an extension of the senses, for example with microscopes, X-rays, or magnetic resonance imaging (MRI) machines (Figure 1). Other properties, such as density or solubility, must be measured or calculated.

Did You KNOW?

Cornstarch Footsteps

A physical property of cornstarch is the sound it makes when compressed. You may have heard it in the movies. Sound engineers use this property to imitate the sound of footsteps in snow!

(a) (b)

Figure 1 (a) Using the magnetic properties of the body's tissues and radio waves, MRI machines produce the best possible images of the inside of the human body, without surgery. (b) This image shows the top of the spine and some of the nerves and muscles around the spine.

Examples of physical properties are the colour of a substance, the temperature at which it melts, and the amount that will dissolve in a litre of water. Table 1 lists only a few of the possible physical properties.

LEARNING TIP

Make connections to your prior knowledge. Ask yourself what you already know about the words in Table 1 from information you have learned in school, from your own reading, or by direct observation and experience.

Table 1 Physical Properties

colour	ductility	malleability	density	boiling point
melting point	conductivity	crystalline structure	brittleness	magnetism
solubility	viscosity	hardness	state	lustre

Important physical properties are those that help to identify an unknown pure substance or provide an application of it. The physical properties that are commonly used to identify substances are described below and on the next two pages.

States of Matter

Most substances can exist in more than one physical state. When a substance changes its state, it does not change into another substance. For example, ice, water, and water vapour are all the same compound. The state of a substance at a certain temperature (usually room temperature) is considered a physical property that can be used to identify it. The three **states** in which matter can usually be found are solid, liquid, and gas (Table 2).

LEARNING TIP

As you study Table 2, ask yourself, "What does this show? How does it relate to what I already know about the three states of matter?"

Table 2 Examples of a Solid, a Liquid, and a Gas

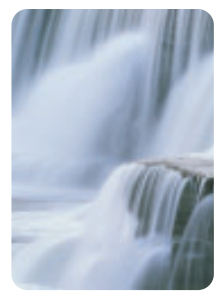
Rock is a solid at room temperature. Solid matter can be picked up and carried around without being in a special container.	
Water is a liquid at room temperature. Liquids flow to the lowest level and can be poured. They must be in containers to be moved or stored. Liquids take the shape of the container they are in.	
Helium is a gas at room temperature. Gases take both the volume and shape of any container they are placed in. If a gas is not in a container, it will spread out indefinitely.	

Figure 2 Nichrome is an alloy that has a melting point of 2550 °C. This melting point makes it useful for heating elements in toasters and ovens.

Melting Point and Boiling Point

The temperature at which a substance changes from one state to another is a property unique to that substance. The **melting point** of a substance is the temperature at which the substance changes from a solid to a liquid (Figure 2). The change of state from liquid to solid occurs at the same temperature as the melting point. The **boiling point** of a substance is the temperature at which a liquid rapidly changes to a gas. The change of state from gas to liquid occurs at the same temperature as the boiling point. Table 3 gives the melting and boiling points of some common substances.

Table 3 Melting and Boiling Points of Some Common Substances

Pure substance	Melting point (°C)	Boiling point (°C)
carbon (diamond)	3550	4830
chlorine	−101	−34
copper	1085	2580
gold	1065	2710
iron	1540	2890
magnesium	650	1120
mercury	−39	357
oxygen	−218	−183
sodium	98	890
sodium chloride (table salt)	808	1465
water	0	100

LEARNING TIP

Headings are visible organizers. Try turning these headings into questions, and read with the goal of answering your questions. Clarify the meanings of words in bold by examining Figures 3 to 7.

Malleability

Since their early discovery, metals have been important because they can be physically changed in shape. Metals that can be beaten into thin sheets are considered to be **malleable** (Figure 3).

Figure 3 Most metals are malleable and can be hammered into different shapes. Some Aboriginal peoples of British Columbia have been using metal to make items like this mask for more than 2000 years.

Ductility

The softness of certain metals provides them with special properties. Some metals are **ductile**, meaning they can be "drawn" into wires. In other words, if you pull at opposite ends of some metal rods, they will become thinner and thinner until they form a wire (Figure 4).

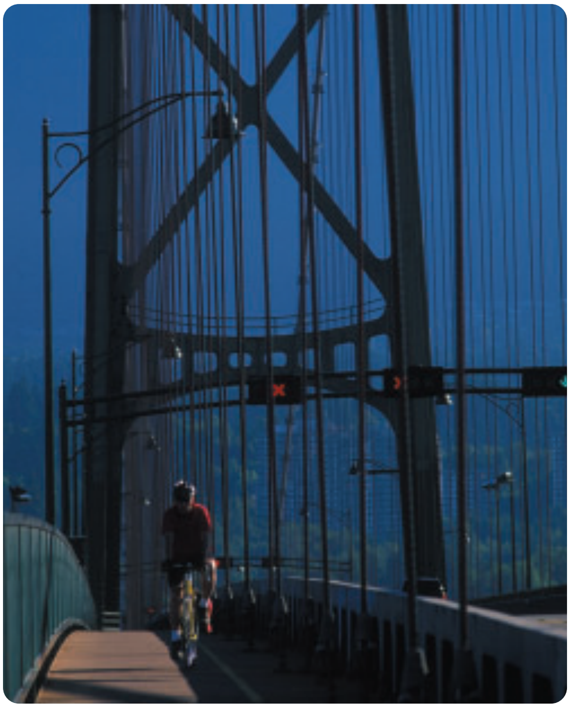


Figure 4 The ductility of some metals and the development of technology that can draw steel into wires make suspension bridges, like the Lions Gate Bridge in Vancouver, possible.

Figure 5 Some substances can be separated from mixtures because of differences in solubility. The brown substance in the photo can be filtered out of the water because the substance is not soluble in water.

Solubility

The degree to which a substance will dissolve in a given amount of another substance, usually water, is called **solubility** (Figure 5). The ability to dissolve or not dissolve in other liquids is a physical property. Salt, for example, is quite soluble in water, but not in gasoline.

Conductivity

The ability of a material to conduct electricity or heat is called **conductivity**. Electrical conductivity is a necessary property for wiring in our very electrical world (Figure 6). Non-conductivity is an important property for materials that are used to contain and protect against electrical flow.

Figure 6 Electrical conductivity makes our electrical world possible.

Density

What we often describe as the "heaviness" of a substance is really the density of the substance. **Density** is the mass per unit volume of a substance. It is a constant property of a substance no matter how much of the substance is present (Figure 7). There is no device to measure density—it can only be calculated. The following formula can be used: density $= \frac{\text{mass}}{\text{volume}}$. Density is usually expressed in g/cm^3.

Figure 7 Why might the density of a diet pop be less than the density of a regular pop?

For example, if a piece of aluminum with a mass of 20 g has a volume of 7.4 cm^3, its density can be calculated as follows:

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{20\text{ g}}{7.4\text{ cm}^3} = 2.7\text{ g/cm}^3$$

Density can also be expressed in g/mL. The millilitre is defined as the liquid equivalent of a cubic centimetre. For example, if glycerol in a container has a mass of 1500 g and a volume of 1190 mL, its density can be calculated using the same formula:

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{1500\text{ g}}{1190\text{ mL}}$$
$$= 1.26\text{ g/mL or } 1.26\text{ g/cm}^3$$

TRY THIS: *Is It Gold?*

Skill Focus: conducting, measuring, recording, analyzing, interpreting data

Materials: a small piece of gold jewellery, scale, graduated cylinder, water

1. Measure the mass of the piece of jewellery.
2. Add enough water to the graduated cylinder to immerse the jewellery completely. Measure and record the volume of the water alone.
3. Add the jewellery to the graduated cylinder and completely immerse it. Measure and record the new volume.
4. Calculate and record the density of the jewellery and compare it with the data in Table 4.

Table 4

Gold (karat)	Density (g/cm^3)
10K	11.4
14K	13.1
18K	15.5
24K	19.3

A. Does the density of the jewellery match any of the different karats of gold? Which one?

B. What does it mean if the density of the jewellery doesn't match any of densities in Table 4?

C. Some jewellery is gold plated, meaning that it has a layer of gold over a cheaper metal. Would you be able to detect the difference using the density of the jewellery? Explain.

Chemical Properties

The second type of properties that can be used to identify substances are chemical properties. A **chemical property** describes the behaviour of a substance as it changes into a new substance. Chemical properties are often used to group substances based on several common reactions. Chemical properties include whether one substance will react with another substance, the rate of reaction of these substances, the amount of heat produced by the reaction, and in what proportion the substances react. The chemical properties that are commonly used to identify substances are described on the next page.

Did You KNOW?

From Failure to Success

3M Post-It Notes have changed the way many people communicate, yet their invention came about by looking at apparent failure in a different way. The semi-sticky glue used on the notes was developed by a scientist who was trying to improve the adhesives used on tape. It was a failure as a glue, but with a little thought and a change in perception, this "poor" property became the foundation for a new communication device. What may often be perceived as a failure may often be an opportunity to learn something new.

Flammability

One of the first chemical properties ever observed was that some materials burn. **Flammability** is the rapid reaction of some substances with oxygen, resulting in the release of a great deal of energy. (The terms flammable, inflammable, and combustible all mean that a substance will burn.) Flammability can be a very useful property, supplying the heat for our homes and the energy to move our cars, but it can also be dangerous, causing fires and explosions (Figure 8). The chemical property of non-flammability is equally important for keeping our world safe from fire. Water and carbon dioxide are not only non-flammable, but they are also able to cool and smother fires.

Figure 8 Ripple Rock in the Seymour Narrows just north of Campbell River was destroyed in 1958 when 125 000 kg of an ammonium nitrate explosive created one of the greatest non-nuclear explosions.

LEARNING TIP

Check your understanding. Explain, in terms of corrosion, why cars rust.

Corrosion

Another chemical property also involves a reaction with oxygen, but at a much slower rate. **Corrosion** is the slow reaction of certain metals with oxygen to form metal oxides. This process is called oxidation. The iron hull of the *Titanic* is a good example of the change in the properties of iron as it becomes rust (iron oxide). Since the new substance, rust, does not have the same properties as iron, the ship is slowly disintegrating in the deep water (Figure 9).

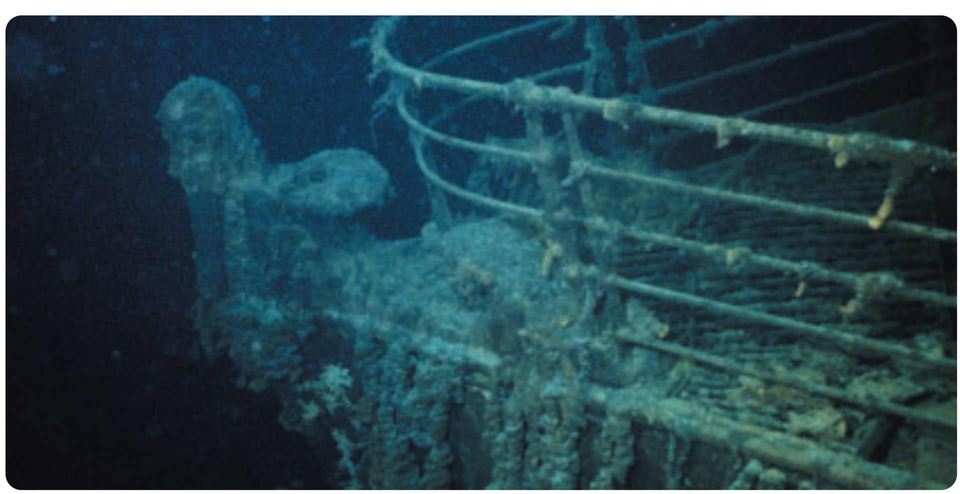


Figure 9 Corrosion is slowly destroying the *Titanic*.

Reactions with Acid

Some metals, such as zinc and magnesium, react with acid (a highly reactive liquid). Some minerals, such as limestone, also react with acid to form carbon dioxide gas. Limestone caves are created when groundwater that is weakly acidic chemically changes the limestone into carbon dioxide and soluble substances (Figure 10).

Figure 10 Beautiful caves are created by only a tiny flow of water and a little dissolved acid. This tour guide in the Home Lakes Caves on Vancouver Island is pointing to the calcium deposits on the cave walls.

TRY THIS: What's The Use?

Skills Focus: analyzing, inferring

We use different substances for different purposes based on their properties. The properties of substances are what make them important for us.

1. Examine Table 5 and identify the properties and possible uses that are missing.

A. The absence of a property is itself a property. For example, the absence of electrical conductivity is a good property for insulation around electrical wire. Choose three properties from the table. For each property, give an example of a situation in which the absence of the property would be an advantage.

B. Name five other substances that you are familiar with, and identify the property that makes them useful. Share your list with a partner.

Table 5

Substance	Property	Use
gasoline	ignites easily at low temperature	
diamond	is extremely hard	
graphite		pencil lead
stomach acid	chemically breaks down substances	
steel		wires of suspension bridges
plastic		covering on electrical wiring
cedar wood		Aboriginal canoe
nitroglycerin	burns extremely rapidly to form a gas	
gold		jewellery

5.2

CHECK YOUR Understanding

1. Which two states of matter require containers? Do the containers have to be different? If so, why?
2. List three products that are manufactured because of the malleability of their materials, and three products that are manufactured because of the ductility of their materials.
3. Oxygen is considered to be a pure substance. The oxygen molecules that you are breathing in at this moment may have come from a tree outside your classroom, pond scum in a nearby drainage ditch, or algae growing on the inside of a school window. Does their origin make any difference in their properties? Explain.
4. Which of the following properties of sulfur are physical properties?
   (a) Its melting point is 112 °C.
   (b) It is a yellow solid.
   (c) It reacts with hydrogen to form a gas.
   (d) Its density is 2.97 g/cm^3.
   (e) It combines with oxygen.
5. Density cannot be measured directly. It is calculated by dividing the mass (in g) of a sample by its volume (in cm^3). What is the density of gasoline if 1 L (1000 cm^3) of gasoline has a mass of 700 g?
6. Suppose that you had two rings of the same size (volume), but one was 10K gold and the other was 18K gold. Which ring would feel heavier? Explain.
7. The ability to conduct heat is a physical property. Metals have a high thermal conductivity while wood and plastic do not. Using this property, explain from a safety point of view which would be better: pots with metal or wooden handles?
8. Which of the following properties of zinc are chemical properties?
   (a) It melts at 419 °C.
   (b) It is a grey metal.
   (c) It corrodes in moist air.
   (d) It conducts electricity.
   (e) Its density is 7.1 g/cm^3.
9. Which property of matter is responsible for each of the following observations?
   (a) A counterfeit diamond has fine scratches and chips on it.
   (b) Small amounts of sugar are each weighed and then added, one at a time, to 100 mL of water until no more can dissolve.
   (c) Silver is flattened with a hammer and shaped into a bracelet.
   (d) A liquid ignites when exposed to a flame.
10. Complete Table 6.

Table 6

Substance	Property	Useful for
helium gas	less dense than air	
	burns quickly	powering vehicles
nitroglycerin	explosive	

11. Erosion is an important geological process. Which state(s) of matter experience(s) erosion? Which state(s) of matter cause(s) erosion? Explain how erosion occurs.
12. In the past, a quick test for pure gold was to bite the coin or nugget. What property do you think this was testing? Explain.
13. Is the X-ray machine at an airport checking the physical or the chemical properties of the substances in your luggage? Explain.
14. What is the property of hairspray that makes it useful?
15. Identify five things you use regularly because their special properties make them useful.

WHAT YOU SEE MAY NOT BE WHAT YOU GET

Diamonds are beautiful to wear and a good investment for your money! But make sure that you know what you are getting.

Advertisements certainly make it clear that diamonds are valuable. However, in today's world, whenever something has great value, there may be unscrupulous people creating counterfeit versions to sell you. Diamonds are no exception.

There are several substances that are used to create counterfeit diamonds. These range from colourless glass to white sapphire, quartz, moissanite, and, commonly, cubic zirconia. Fake diamonds are called *simulants* (Figure 1).

Figure 1 Can you tell which is the diamond?

The majority of diamonds in the world are industrial diamonds, such as those used for drill bits (Figure 2). But when people think of diamonds, they think of sparkle and romance. In jewellers' terms, sparkle is actually composed of "brilliance" and "fire," which both arise from the same physical property, called the index of refraction, (or refractive index). Refraction is the changing of the direction of light as it passes from one substance to another. The index of refraction is an indicator of how much the light changes direction. The index of refraction is very high in diamonds, causing the light to split into colours as it reflects off the inner faces until it reaches your eyes. Counterfeit gems also have high refractive indexes. Since the refraction index is a physical property, however, a gemologist (an expert in the study of gems such as diamonds) can measure it and identify the substance. Table 1 shows the refractive indexes of some clear substances. You can see that diamond has the highest index of those listed.

Table 1 Refractive Indexes of Some Clear Substances

Substance	Refractive index
air	1.00
water	1.33
glass	1.52
dense crystal	1.66
garnet	1.89
cubic zirconia	2.19
diamond	2.42

Figure 2 Many drill bits used by dentists have a diamond coating.

It does not take a gemologist to identify the fakes though. The police use the physical property of hardness to test for fakes. The hardness of diamonds is well known. Although the hardness of some of the fakes is high (cubic zirconia 8.5, moissanite 9.25, and glass 5.5), their hardness cannot compare with diamond's hardness (10) and they can be quickly identified. A softer substance cannot scratch a harder substance.

Gemologists and the police are also able to identify fake diamonds by determining density. For example the density of glass is 2.58 g/cm^3; moissanite 3.21 g/cm^3; and cubic zirconia 5.8 g/cm^3. The density of a pure diamond is 3.52 g/cm^3.

So what does this tell you? Fake diamonds have the appearance of real diamonds, but they do not share the same physical properties. Synthetic cubic zirconia is the most popular imitation diamond in today's market. With the unaided eye, a well-cut and polished cubic zirconia is practically impossible to distinguish from a real diamond. With the use of a few scientific procedures, however, it is not difficult to tell a real diamond from the relatively inexpensive fakes.

5.3 Changes in Matter

LEARNING TIP
Read the first two paragraphs on this page. Write a one sentence summary to remember important information. For the rest of Section 5.3, read each part and pause to think about what you read. Then write a one sentence summary or brief point-form notes to help you remember the important information.

Change is as much a part of your world as the substances that it is made of. You know that erosion is constantly changing the surface of Earth, and that your skin cells are constantly being replaced with new ones. You have seen juice crystals dissolve, condensation appear on a bathroom mirror after a hot shower, wood burn in a fire, and rust appear on metal. Change does not surprise you. Realizing that change happens all the time is the first step to understanding chemistry. Chemistry is the study of matter, so it is also the study of changes of matter (Figure 1).

(a) (b)

Figure 1 Although the processes of change are difficult to see, the changes are not. Some can be as small as a single flame (a), while others can be as large as weather systems on Earth (b).

How is melting an ice cube different from burning a marshmallow? Both involve heating, but somehow the changes are different. Can you identify what the difference is? The ice cube was water before and after heating, while the marshmallow was a marshmallow before and carbon crust after. In order to understand the many changes happening all around us, we must recognize two very different kinds of change. The two kinds of change that are important to chemistry are physical changes and chemical changes. GO

To learn more about physical and chemical changes, go to **www.science.nelson.com** GO

Physical Change

In a physical change, the substance remains the same before and after the change. A **physical change** may cause a change in form or state, but not in substance. For example, cutting a piece of paper into smaller and smaller pieces changes its form, but it is still paper with the same properties.

TRY THIS: Physical Change: A Thought Experiment

Skill Focus: questioning

Some experiments can be done in your head. Great scientists, such as Galileo Galilei and Albert Einstein, used "thought" experiments to help them develop their ideas. Now you can try an interesting thought experiment to demonstrate various examples of physical changes. All you need is your imagination.

1. Imagine an ordinary kitchen appliance, such as a toaster. Now imagine beating it with a hammer. Are the dents you make physical? Is it still a toaster?
2. Imagine taking a bottle of syrup from a cupboard and dropping it on the kitchen floor. The top comes off the bottle, and the syrup runs all over the floor. You leave the syrup where it is. When you come back, it has hardened and stuck to the floor. Is this a physical change? Why?

A. Make up your own thought experiment to show a physical change.

B. Create a rule for physical changes using the words "original substances."

When substances can exist in two or more states, changing from one state to another is a physical change. The substance is the same throughout the changes. Different terms are used to describe the different changes of state (Figure 2). Substances go from solid to liquid or liquid to gas when heat energy is added. They go from gas to liquid or liquid to solid when heat energy is removed. Notice in Figure 2, that some substances can go directly from solid to gas, or vice versa, without passing through the liquid state. Frost and snow, for example, are created through this unique process. Also notice, that the common terms "freezing" and "boiling" are not used because they describe the changes of state of water.

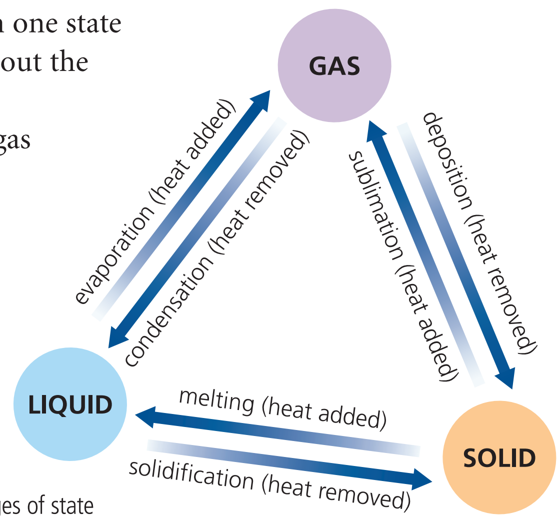


Figure 2 Changes of state

TRY THIS: Recycling Through Physical Change

Skills Focus: conducting, observing, analyzing, inferring

Materials: thermoplastic, safety goggles, hot plate, 400 mL beaker, water, tongs

When glass, paper, or plastic are recycled, what changes do they go through? Part of most recycling processes is the adding of heat. Find out what happens when plastic is heated.

1. Your teacher will provide you with a piece of thermoplastic. Examine it, and note its properties. Bend it slightly. What do you think might happen if it was bent in half?
2. Put on your safety goggles. On a hot plate, boil 200 mL of water in a 400 mL beaker. Using tongs, immerse the thermoplastic in the boiling water, and gently move it in the water. Observe any changes in properties.
3. When the thermoplastic seems quite flexible, carefully remove it from the water, and then roll it into a ball. Allow it to cool for a few minutes. Observe its new characteristics.
4. Unplug the hot plate, and clean up.

A. Do you think the thermoplastic is now a different material, or is it just a different form? Explain your thinking.

B. What would happen if you reheated the thermoplastic?

C. If the thermoplastic was recycled in this form, what would the new manufacturer have to do to use it?

To learn more about the changes of state, go to **www.science.nelson.com** GO

Dissolving is another physical change. When salt is dissolved in water, the crystals disappear but the salty taste of the water confirms that the salt is still present. The salt can be re-crystallized by evaporating the water. For many cultures, including British Columbia's Aboriginal cultures, the ocean was the main source of salt, an important part of their food preservation and nutrition. GO

Chemical Change

A **chemical change** occurs when a substance changes into one or more new substances with different properties. When you burn a candle, what happens to the wax? Scientists in the Middle Ages believed that the wax in the candle changed into energy. Later, however, scientists showed that some of the particles that make up the wax become vapour and react with oxygen in the air to form new substances—carbon dioxide and water. As gases, these new substances escape into the air.

A chemical change is more likely to be a permanent change since many chemical reactions are not reversible. You would not expect your blackened marshmallow to change into a fresh one, or the gases from a burning candle to suddenly form into wax. There are some reactions, however, in which substances change into new substances in one chemical reaction and, in a different chemical reaction, the new substances can change back to the original substances. The chemical reactions that occur in rechargeable batteries during charging and use are good examples of this type of reaction.

Identifying Chemical and Physical Change

The challenge of distinguishing between physical and chemical changes is that you can only observe the large visible changes. What do you look for when trying to decide if a change is physical or chemical? If a new substance is made, you should see a different set of observable properties, such as, a change in colour. In chemical reactions, you may also see bubbles, which indicate that a gas is forming, or you may notice a solid forming from liquids. Although a change in energy is often associated with chemical reactions, it does not provide proof that a chemical reaction has taken place. Some chemical reactions do give off heat and light energy, but others absorb energy. For example, cold packs work because of a chemical reaction that absorbs energy. Physical changes may also involve some change in energy. Changes in state involve a loss or gain in heat.

Table 1 summarizes the characteristics of physical and chemical changes. Table 2 provides examples of what you might observe when specific physical and chemical changes occur. 5A *Investigation*

5A *Investigation*

The Nature of a Burning Candle

To perform this investigation, turn to page 176.

In this investigation, you will observe and identify the physical and chemical changes that happen when a candle burns.

Table 1 Characteristics of Physical and Chemical Change

Physical change	Chemical change
reversible (usually)	irreversible (usually)
no new substance forms	new substance forms (for example, gas or solid)
properties do not change	new set of properties (for example, colour)
energy change may occur, but may not be noticed	energy change may occur (for example, heat or light is given off, or energy is absorbed)

LEARNING TIP

To check your understanding, use Table 1 to explain to a partner the differences between chemical and physical changes. Use examples from Table 2 in your explanation.

Table 2 Examples of Physical and Chemical Changes

Physical change	Chemical change
When cream is whipped, air puffs up the cream. The substances are still cream and air.	Baking powder reacts when heated to create carbon dioxide which makes bread rise. The reaction creates a new gas that takes up more space.
Boiling water creates water vapour that escapes as a gas, but it is still water. The water can condense to become liquid water again.	Gasoline burns explosively to create great heat, carbon dioxide, and water. New gases are created.
Sugar dissolves in tea. The sugar "disappears," but it can still be identified by its sweetness.	Sunlight causes the body to create vitamin D and melanin in the skin.
Tattoo ink is injected under the skin to create graphic tattoos. The properties of the ink are permanent and unchanged.	Hydrogen peroxide is used to bleach hair to a much lighter colour. Darker hair pigments are changed chemically into other substances that have less or no colour.

TRY THIS: Recognizing Chemical Change

Skills Focus: conducting, observing, recording, analyzing.

Sodium hydroxide is corrosive. Clean any spills, especially on skin or clothing, with cold water. Some metal solutions are extremely toxic. Wash your hands after the activity and clean up any spills.

Materials: safety goggles, spot plates, small dropping bottles of the following solutions: 0.5 mol/L sodium hydroxide, 0.2 mol/L copper(II) nitrate, 0.2 mol/L nickel(II) nitrate, 0.2 mol/L magnesium nitrate, 0.2 mol/L iron(III) nitrate, 0.5 mol/L sodium iodide, 0.2 mol/L copper(I) nitrate, 0.2 mol/L lead(II) nitrate, 0.2 mol/L silver nitrate, 0.5 mol/L sodium carbonate, 0.2 mol/L calcium nitrate, disposal container

1. Put on your safety goggles. In one row of your spot plate, add five drops of the sodium hydroxide solution to each of four depressions. Then add two drops of copper(II) nitrate to the first depression, two drops of nickel(II) nitrate to the second depression, two drops of magnesium nitrate to the third, and two drops of iron(III) nitrate to the fourth. Record your observations.
2. In a second row, add five drops of the sodium iodide solution to each of four depressions. Then add two drops of copper(I) nitrate to the first depression, two drops of lead(II) nitrate to the second depression, two drops of copper(II) nitrate to the third, and two drops of silver nitrate to the fourth. Record your observations.
3. In a third row, add five drops of sodium carbonate to each of three depressions. Then add two drops of calcium nitrate to the first depression, two drops of nickel(II) nitrate to the second depression, and two drops of lead(II) nitrate to the third. Record your observations.

A. Identify the combinations of chemicals in which chemical changes occurred.

B. What evidence showed that chemical changes had occurred?

5.3 CHECK YOUR Understanding

1. Describe the difference between a physical change and a chemical change.
2. Which of the following kitchen activities are physical changes, and which are chemical changes?
   (a) cooking bacon
   (b) making icing
   (c) baking a cake
   (d) using oven cleaner
   (e) making whipped cream
3. Which of the following everyday activities are physical changes, and which are chemical changes?
   (a) salting ice on a driveway
   (b) burning leaves
   (c) mixing sand with soil
   (d) composting cut vegetation
   (e) using a glue gun
4. Which of the following geologic changes are physical changes and which are chemical changes?
   (a) formation of a limestone cave
   (b) creation of a canyon by a river
   (c) wearing of rocks by wave action
   (d) destruction of lakes by acid rain
   (e) heaving of the ground by ice formation
5. Which of the following are examples of a physical change?
   (a) change in physical state
   (b) change in size or shape
   (c) change in properties
   (d) change in texture
   (e) change in physical quantities
   (f) change in substances
6. Which of the following are examples of a chemical change?
   (a) corrosion reactions
   (b) combustion reactions
   (c) dissolving of sugar
   (d) evaporation of water
   (e) decaying reactions
   (f) digestion of food
7. What observations indicate that a physical change is occuring?
8. What observations indicate that a chemical change is occuring?
9. Make a list of five physical changes and five chemical changes that you see in your daily life.
10. Give two examples of geological changes that take place over millions of years. Are they physical or chemical changes? Explain.
11. What is the difference between dew and frost? What is different about their formation?
12. Starting with the water in an ocean, use the terms for physical changes of state to trace the path of the water into the atmosphere, to the land, and back to the ocean.
13. All over Europe there is growing concern about the rapid weathering of the statues and architecture over the last 50 years. Some Roman statues have aged more over the last few years than in the previous 2000 years. If most statues are made of calcium carbonate (marble), do you think the process of weathering the statues is physical or chemical? Explain your answer.
14. If you cut a piece of paper in two, do the properties of the paper change? If you cut these two pieces in half, do the properties change? If you repeat this process indefinitely, would there come a time when the properties could change? Explain your thinking.

5.4 The Kinetic Molecular Theory and Changes of State

Chemists know that they will probably never be able to observe exactly what is happening in a chemical reaction. Observation is a powerful tool of science, but it is limited to things that can be detected through the senses. Even with the best microscopes, X-ray machines, and MRI machines, the deepest nature of matter remains invisible. We are able to observe large-scale (macroscopic) changes; for example, when water is left in a glass for a period of time, it disappears through evaporation. But we cannot see the internal behaviour of water that causes the evaporation.

In Chapter 1, you learned how scientists develop theories to explain their observations. Many scientific theories are about changes inside matter, and scientific models are used to show what we cannot see. For example, to understand the evaporation of water, a model could use moving billiard balls or marbles, or even dots on paper, to provide an idea of what might be happening. The idea of tiny, invisible moving particles of water is a model that allows scientists to explain how water can leave a glass as a result of evaporation. A scientific theory, then, is an attempt to explain what is happening in the real world.

TRY THIS: *What's in the Black Box?*

Skills Focus: hypothesizing, predicting, conducting, inferring

"Imagination is more important than knowledge."

Albert Einstein

You may wonder how scientists know so much about the behaviour of matter if what happens inside matter is invisible. Science solves the mysteries of nature through a process that is much like a conversation between what you observe and what you think. What you observe prompts you to think of new ideas, and new ideas allow you to check for new observations. This activity is an opportunity to try the back and forth nature of this scientific conversation.

1. Your teacher will provide your group with a sealed "black box." Make a table like Table 1 to record your tests, observations, and ideas.

Table 1

Experimental test	Observation	Description

2. Examine the box and make some preliminary observations.
3. From these observations, conduct further tests to determine what is inside the box. Record your observations and a description of what you think is inside. For example, if it seems like something is rolling around inside the black box, you might test to see if it rolls on every side (then it could have a spherical shape), or if it only rolls on one side (then it could have a cylindrical shape). (Hint: Slow and gentle movement will likely give more information than rapid and random shaking.)
4. Repeat the process until you think you have completely described the inside of the box.
5. If time permits, try another box.

A. Compare your ideas about what is inside the box with the ideas of others who examined the same box. Do the others agree with you? If they do, does it make you right? If they don't, does this make them right and you wrong? Explain your thinking.

B. Would you like to know what the inside of the box really looks like? Nature never lets us look inside. What does this mean about what we can know?

C. What do you think makes scientists so sure about some models and not so sure about others?

The Kinetic Molecular Theory

The **kinetic molecular theory** is the idea that matter is made from moving invisible particles. This theory is used to explain the behaviour and changes in states of matter that we can observe. It takes ideas from our familiar world to describe the invisible nature of matter. The following principles make up the kinetic molecular theory:

- All matter is made up of tiny particles.
- Different substances have different particles.
- The particles are in constant motion.
- The more energy the particles have, the faster they move.
- The attraction between particles decreases with an increase in distance.

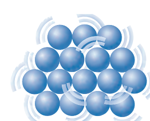
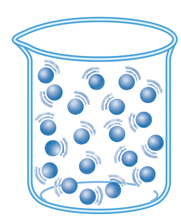
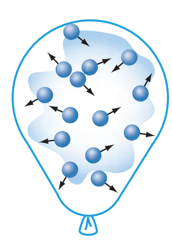
LEARNING TIP

Use Table 2 to explain to a partner the connections between the kinetic molecular theory and the states of matter. What do the visuals in the table show?

Explaining Changes of State

An important challenge for the kinetic molecular theory is to explain the states of matter and their changes in terms of the behaviour of particles. Does a theory of moving particles explain how substances can remain the same substance as they change from solids to liquids and gases, and back again? Table 2 shows the connections between this theory and the states of matter.

Table 2 The States of Matter and the Kinetic Molecular Theory

Solids **Distance:** particles close together **Type of motion:** particles can only vibrate in their place in the structure **Attractive Forces:** high, decreasing as vibrations get larger **Energy:** increasing energy causes an increase in vibration		
Liquids **Distance:** particles close together **Type of motion:** particles still vibrate, but can now move past one another; can bump into each other and the sides of their container **Attractive Forces:** still quite high, but less than solids and decreasing with distance apart **Energy:** increase in energy causes an increase in vibration and movement		
Gases **Distance:** particles very far apart **Type of motion:** particles vibrate, rotate, move past each other, and bump into each other in a very rapid straight line motion **Attractive forces:** no attractive forces; particles are too far apart and are moving too fast **Energy:** increase in energy causes an increase in pressure due to the increase in the speed and number of particles hitting the sides of the container		

Changing from one state to another is made possible by the addition or removal of energy. What we experience as heat, particles experience as motion. Any energy that enters a substance causes an increase in the movement of the particles, resulting in melting or sublimation in solids and evaporation in liquids. Cooling removes energy from a substance causing a reduction in the movement of the particles. This reduction in movement results in the condensation in deposition in gases and solidification in liquids (Figure 1).

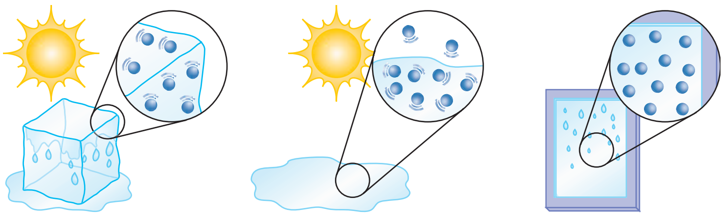


Figure 1 The addition or removal of energy changes the speed of particles and determines the state of the substance. In (a), the addition of energy (heat) causes melting. In (b), the addition of energy causes evaporation. In (c), the removal of energy causes condensation.

Did You KNOW?

Flowing Land

Earthquakes can cause loose solids such as sand and gravel to flow like liquids. This process, called liquefaction, occurs when the sand and gravel particles vibrate enough to begin to move past one another and flow. Buildings can sink in the liquefied ground.

The motion of water molecules changes as heat is added or removed. If you heat solid ice, the water molecules begin to vibrate in place. As you apply more heat, the vibrations become so large that the molecules can now move past each other, resulting in liquid water. Applying more heat allows the water molecules to move even faster, overcoming the attractions between molecules and spreading out in three-dimensional space as fast-moving water molecules. We now have water vapour. If you remove heat from water vapour, the reverse process occurs. The water molecules slow down enough to allow the attraction between molecules to hold them together. Condensation occurs when enough heat is removed to cause molecules of water vapour to come together to form droplets of water. If you continue to remove heat from the liquid water, solidification occurs and the water changes to solid ice.

Explaining Dissolving and Density

The quality of any theory is judged by its ability to explain what we observe and to help us understand what is happening. The kinetic molecular theory can explain a great deal about dissolving. For example, sugar dissolving can be explained by particles of sugar being separated from the solid and entering spaces between particles of water (Figure 2). The kinetic molecular theory also explains the effects of hot water on the rate of dissolving. Since the warmer water particles are moving more quickly, they are capable of separating the sugar particles at a higher rate.

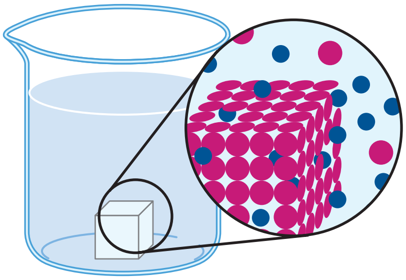


Figure 2 During dissolving, the particles of a solid are separated and distributed among the particles of the water.

Changes in density, too, can be partially explained using the kinetic molecular theory. As substances are heated, the increased motion of the particles causes them to spread apart, resulting in an increase in volume, called expansion. For this reason, sidewalks, bridges, and railway lines are built with gaps to allow the solids to expand without cracking or buckling (Figure 3). Expansion also causes the liquid to rise in a thermometer.

Figure 3 Expansion joints in Lions Gate Bridge, Vancouver

Figure 4 Cloud shapes often show how the air is rising and falling.

Since density equals $\frac{\text{mass}}{\text{volume}}$, when the volume increases and the mass stays the same, the density decreases. This is particularly important in liquids and gases and explains the rising of smoke and steam. Hot air particles are moving faster and have a greater volume (hence lower density) than the same mass of cool air (higher density). This explains why hot air rises or "floats" in cold air, and similarly, why cold water "sinks" in warm water. It is this change in particle motion when heat is added or removed that causes almost all of the weather on Earth (Figure 4).

TRY THIS: Topsy Turvy

Skill Focus: predicting, conducting, analyzing, inferring

Materials: 4 250 mL Erlenmeyer flasks (bottles will work as long as openings are the same size), red and blue food colouring, warm water, cool water, large pan or tray with lip, 2 3 × 5 cm index cards

In this activity, you will use what you know about the kinetic molecular theory to predict what happens when warm and cool water mix. Then, you will test your predictions.

Food colouring will stain clothing and skin.

1. Work with a partner. Add several drops of red food colouring to each of two 250 mL Erlenmeyer flasks. Fill them to the top with warm tap water (approximately 40 to 45 °C). Add several drops of blue food colouring to each of the other two 250 mL Erlenmeyer flasks and fill them to the top with cool tap water.
2. Predict what the outcome will be when one flask of warm water is inverted over one flask of cool water, and the water is allowed to mix. Predict the outcome when one flask of cool water is on top with one flask of warm water on the bottom.
3. Place one of the cool-water flasks in the pan. Place an index card on top of one flask filled with warm water. Invert the flask, holding the card in place. Stack it on top of the cool-water flask. Carefully remove the card (Figure 5) and, holding the flask, observe what happens when the water from both flasks mixes.

Figure 5

4. Repeat the inversion with a flask of cool water on top of a flask of warm water. Carefully remove the card, and observe.

A. Describe what happens when the warm water is on the top. Explain this in terms of the kinetic molecular theory.

B. Describe what happens when the warm water is on the bottom. Why do you think this happens when the warm water is on the bottom, not the top? Do you think the density of warm water is different from the density of cold water? Explain this in terms of the kinetic molecular theory.

5.4

CHECK YOUR Understanding

1. Where do the ideas for models and theories come from?
2. What must a scientific model be able to do?
3. How is a scientific model different from, for example, a model airplane?
4. Draw a table like Table 3 in your notebook. Complete the second column using terms from the following list: melting, evaporation, solidification, condensation, sublimation. Complete the third column by telling whether heat is added or removed to cause the change.

Table 3

State change	Name of change	Is heat added or removed?
solid to liquid		
solid to gas		
liquid to gas		
gas to solid		
gas to liquid		
liquid to solid		

5. Identify all the changes of state that are shown in the diagram in Figure 6. Describe what is happening to the water particles in each change.

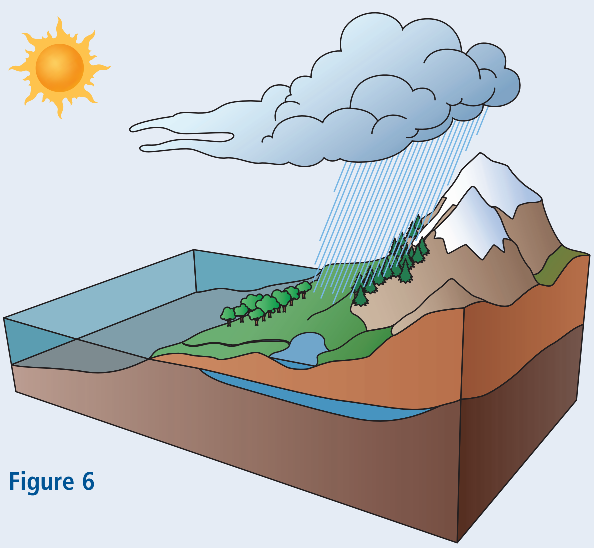


Figure 6

6. Figure 7 represents a beaker of water and a lump of sugar. Draw a sequence of two or three diagrams showing what happens to the particles of both substances as the sugar dissolves.

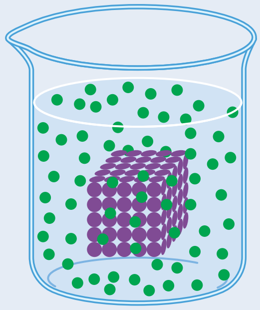


Figure 7

7. Frost forms when particles of water vapour come in contact with a very cold surface. Name this process and draw a representation of it. Give an example of where you might observe it.
8. Use the kinetic molecular theory to explain how stirring increases the rate of dissolving.
9. Which one of the three states of matter do you think can be compressed? What does this tell you about the spaces between particles in the three states?
10. A dented table-tennis ball can sometimes be "repaired" by immersing it in a pan of hot water. Explain how this works using a diagram to show how the change in the motion of the particles inside re-inflates the ball.
11. Explain how a drop of water on your desk can evaporate if the temperature of the room is 23 °C and the boiling point of water is 100 °C.
12. When gases are compressed, they must be placed in thick steel cylinders. Based on your understanding of the kinetic molecular theory, explain why this must be.
13. Roads, bridges, and railway tracks must be built with "expansion joints" to prevent bending and buckling during warm weather. Use the kinetic molecular theory to explain why expansion joints are necessary.

5A Investigation

The Nature of a Burning Candle

Have you ever really observed what happens to a burning candle, both physically and chemically? The scientific process is made of two very different activities that work hand in hand to help us understand the world around us. The first, observation, is the starting point for all scientific learning and is a skill that must be practised. In this activity, you will have an opportunity to refine your observational skill. The second, critical thinking, is questioning what you observe. In this Investigation, you will need to think critically about what you observe.

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Keep all flammable material, including your hair and your clothing, out of the flames. Hot wax and flames can cause severe burns.

Do not allow limewater to make contact with your eyes. If this happens, flush your eyes with water and have someone contact the teacher immediately.

Question

What physical and chemical changes can be observed when a candle burns?

Predictions

Predict what states of matter exist when a candle burns.

Predict the effect of metal on a candle flame.

Predict what new substances may be produced when a candle burns.

Experimental Design

In this Investigation, you will observe and test a burning candle to find out if it undergoes physical and chemical changes.

Materials

- 1 standard candle
- ruler
- scale
- safety goggles
- apron
- matches
- 2 pieces copper wire
- 1 Petri dish or large watch glass
- pencil
- tongs
- cobalt chloride paper
- water
- 100 mL beaker
- 250 mL flask
- limewater
- rubber stopper

Procedure

Part 1

1. Work with a partner. First, read through the Investigation. Look for what you need to record. Make a data table for each part to record your observations.
2. Observe the properties of the unlit candle. What states of matter are present? Measure the mass and length of the candle. Measure the mass of the candle and the Petri dish together. Record your observations in your data table.
3. Put on your safety goggles and apron. Light the candle and melt two or three drops of wax in the centre of the dish. Stick the base of the candle in the wax before it cools so that the candle can stand by itself.
4. Time your observation of the burning candle for exactly 5 min. Make careful observations of the flame noting any different regions in it. Make 10 or more observations, and record them in your data table. Start your observations: How many states of matter do you see? Where does the burning take place? What is actually burning?

5. After 5 min, extinguish the candle and have your partner put a lit match in the smoke above the candle. Record your observations.
6. Determine the length of the candle, and the mass of the candle and Petri dish. Record your measurements.

Part 2

7. Light the candle again. Hold a straight piece of copper wire above, but not in, the flame. What do you observe?
8. Make a coil with a new piece of copper wire by wrapping the copper wire around a pencil. With tongs, lower the coil upright over the tip of the flame without touching the candle wax (Figure 1). Be prepared for the flame to go out. If it does, quickly remove the coil. Record your observations.

Figure 1 Step 8

Part 3

9. Test a strip of cobalt chloride test paper with a drop of water to see what happens. Light the candle. Carefully invert a flask over the candle flame and hold it until the flame is extinguished. Be careful not to let the flask get so hot that you get burned. If necessary, use tongs to hold the flask (Figure 2). Test the inside of the flask with a cobalt chloride test strip. Record your observations.

Figure 2 Step 9

10. Pour tap water to a depth of 1 cm into the Petri dish that is holding the candle. Light the candle. Carefully lower the 250 mL flask over the candle so that the mouth is completely below the surface of the water (the candle may have to be cut to allow it to fit under the flask). Leave it for 1 min, and record your observations.
11. Lift the flask out of the water, turn it upright, add about 25 mL of limewater. Put the rubber stopper in the flask and gently swirl for 1 min. Record your observations.

Analysis

(a) What is the role of the wick in the candle? How does it help to keep the candle lit? Does it burn?

(b) What is the shape of the candle flame?

(c) Where did the wax from the candle go?

(d) Which changes that you noted in step 4 were physical? Which were chemical?

(e) What evidence showed the release of energy? What forms of energy were produced by the burning candle? Where was this energy in the unlit candle?

(f) Based upon your analysis of your observations in Part 3, what are two substances produced by the combustion of the candle?

(g) How does the mass of the candle change during combustion? Explain this change in mass.

(h) Is there any evidence that the candle needs something from the air to help it burn? What do you think this something might be?

(i) What do you think the copper removes from the flame causing it to be extinguished? (Hint: what did the metal transmit to your fingers?)

Evaluation

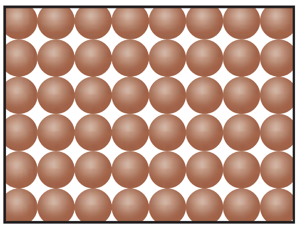
(j) Did the evidence you gathered in this Investigation support your predictions? Explain.

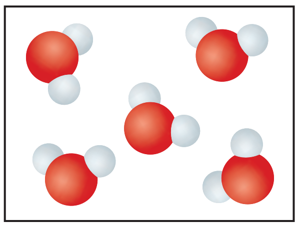
Properties and Changes

Key Ideas

Matter can be classified as pure substances or mixtures.

- Matter has mass and volume.
- Elements and compounds are pure substances.
- Elements have one kind of particle. Compounds have one kind of particle made up of particles of two or more different elements.
- Mixtures have particles from the substances they are made from. In heterogeneous mixtures, you can see the substances. In homogeneous mixtures, the particles are evenly distributed at the microscopic level so the different substances cannot be seen.





Pure substances can be identified by their physical and chemical properties.

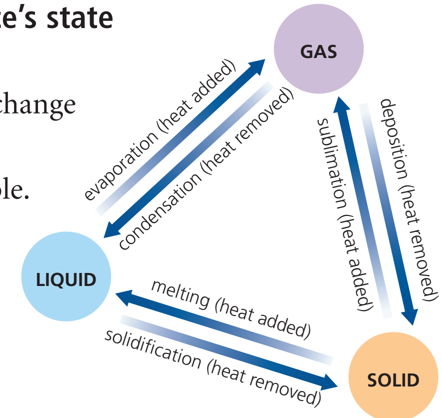
- Different substances have different properties.
- Properties are what make substances useful.
- Physical properties of matter are those that you can observe with your senses, measure, or calculate.
- A chemical property describes the behaviour of a substance as it changes into a new substance.

Vocabulary

matter, p. 152
mass, p. 152
volume, p. 152
pure substance, p. 153
mixture, p. 153
element, p. 153
compound, p. 153
heterogeneous mixture, p. 154
homogeneous mixture, p. 154
physical property, p. 157
state, p. 158
melting point, p. 158
boiling point, p. 158
malleable, p. 159
ductile, p. 159
solubility, p. 160
conductivity, p. 160
density, p. 160
chemical property, p. 161
flammability, p. 162
corrosion, p. 162
physical change, p. 166
chemical change, p. 168
kinetic molecular theory, p. 172

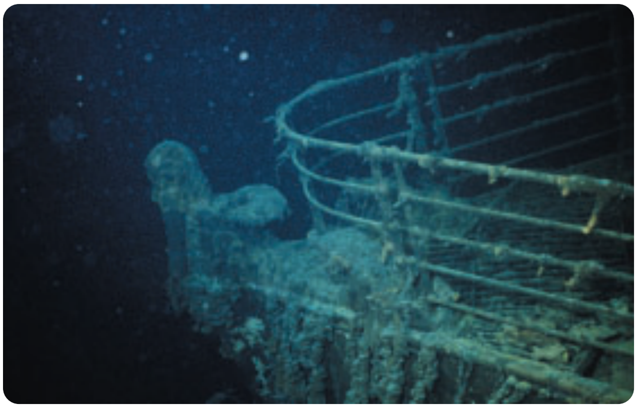
A physical change alters a substance's state or form, but not its composition.

- A change in state or form does not change one substance into another.
- Physical changes are usually reversible.



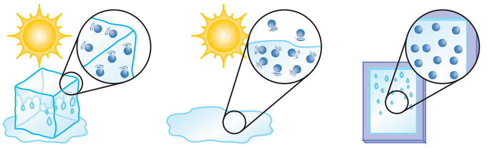
A chemical change alters a substance's composition to create new substances.

- A chemical change results in new substances with new properties.
- Chemical changes are sometimes reversible.



The kinetic molecular theory explains the nature and behaviour of matter.

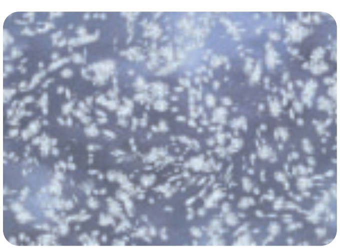
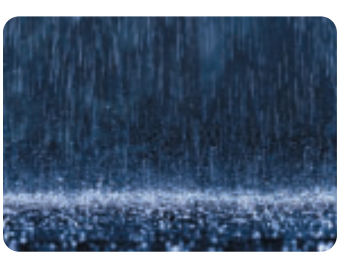
- All matter is made from particles, and each substance has its own unique particles.
- An increase in energy, such as heat, causes the particles to move faster and farther apart. A decrease in energy causes the reverse.
- The theory can explain physical changes, such as changes of state and dissolving.



Review Key Ideas and Vocabulary

1. Match each description with the correct term. Not all terms will be used.

Description	Term
(a) refers to a slow reaction with oxygen	flammable
(b) means the formation of frost	non-flammable
(c) can be made into thin sheets	ductility
(d) freezing of water	melting point
(e) can be found using a formula	corrosion
(f) refers to resistance to burning	density
(g) can be drawn into wires	deposition
	solidification
	malleability

2. What are the two defining properties of matter?
3. Which process does NOT produce a physical change of state?
   (a) melting ice
   (b) heating water vapour
   (c) freezing water
   (d) boiling water
4. Identify the process in each photo as either condensation, deposition, melting, solidification, sublimation, or evaporation.
   (a)
   
   (b)
   
   (c)
   
5. Which statement describes a chemical property?
   (a) The crystals of the substance are a metallic gray.
   (b) It dissolves in alcohol.
   (c) It reacts with acid to produce bubbles of gas.
   (d) It does not conduct electricity.
6. A student investigated the physical and chemical properties of a sample of unknown gas and compared the findings to data from known gases. Which one of the following statements from the report represents a conclusion rather than an experimental observation?
   (a) The gas is colourless.
   (b) When the gas is tested with limewater, the liquid becomes cloudy.
   (c) The gas is carbon dioxide.
   (d) A flaming splint stops burning when placed in the unknown gas.
7. Which statement describing the kinetic molecular theory is incorrect?
   (a) Particles of a gas are moving very quickly in straight-line motion.
   (b) Particles of a liquid vibrate in one position.
   (c) Particles of a gas are not attracted to each other.
   (d) Particles of a gas can overcome gravity.
8. The following box lists some characteristics of solids according to the kinetic molecular theory.

   A. The particles are very closely packed together.
   B. The particles are tightly bound to neighbouring particles.
   C. The particles are arranged in a regular pattern.
   D. The particles can only vibrate in their positions.
   E. Heat causes the vibration of the particles to increase.

   Write the letter(s) of the characteristic(s) that can explain the following observations.
   (a) Solids do not flow or pour.
   (b) Solids cannot easily be compressed.
   (c) As the temperature is increased, many solids melt and become liquids.
   (d) Some solids form crystals.

9. Describe three different examples of chemical changes.
10. To determine the density of an irregularly shaped object, a student immersed the object in 21.2 mL of water in a graduated cylinder, causing the level of the water to rise to 27.8 mL. If the object had a mass of 22.4 g, what was the density of the object? (Remember: 1 mL = 1 cm^3)

Use What You've Learned

11. Carbon fibre bicycles have essentially replaced the aluminum and aluminum alloy bikes in the Tour de France. Carbon fibre has a density of 6.24 g/cm^3. Aluminum has a density of 2.70 g/cm^3. What property of carbon fibre is the most likely reason for the switch? Explain your reasoning.
12. It is possible to represent the particles in solids, liquids, and gases accurately in a diagram. Figure 1 illustrates a solid dissolving in a liquid.

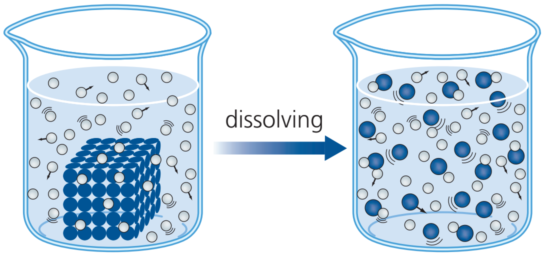


Figure 1

(a) State two ways in which you think the diagram *is a good representation* of a solid dissolving in a liquid.
(b) State two ways in which you think the diagram *is not an accurate representation* of a solid dissolving in a liquid.

13. Solder is a soft shiny alloy with a relatively low melting point. It is used by plumbers to seal the joints in copper pipes. They use a propane torch until the metal flows into the joint, then it is allowed to cool and the metal becomes a solid shiny metal again. Is the change in solder a chemical or a physical change? How do you know?
14. Write a report about the mixture that surrounds us (the atmosphere). Include the major types of particles and the percentages they contribute. Mention the minor types of gas particles and note their importance to Earth. Include a circle graph to show relative proportions in the mixture.

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15. What physical properties of gold might explain its use in creating jewellery in almost every culture that discovered it? What chemical property also explains its widespread use?

Think Critically

16. Carbon dioxide cools so much as it is released from a CO_2 fire extinguisher that it comes out as a fine solid—like snow. This cools as well as smothers the fire, but it has an inherent danger. What is it?
17. When water is sprayed on a fire it turns into steam. Explain how this combats the fire in two different ways.
18. A student read that 1 m^3 of helium gas could lift a 1 kg mass. He came up with what he thought was a brilliant application of this special property. He decided that he would find a way to compress 50 m^3 or 60 m^3 of helium into the frame of his bike. He thought that this would enable him to ride more easily and, possibly, allow him to fly. What do you think? Use the kinetic molecular theory to explain why it will or will not work.

Reflect On Your Learning

19. How useful was the kinetic molecular theory in helping you understand how certain substances behave? Did it change your thinking in any way?

Visit the Quiz Centre at
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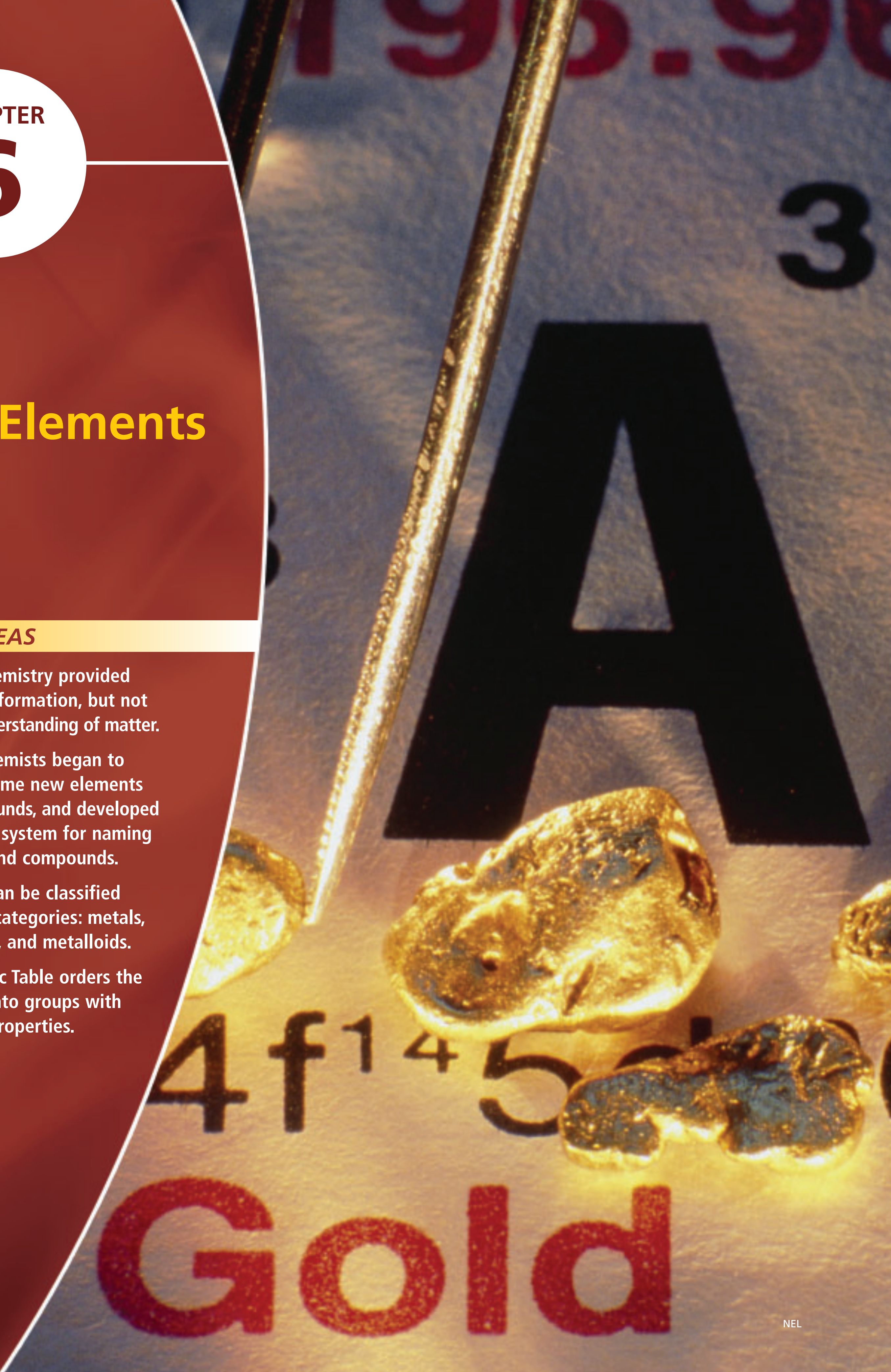
CHAPTER

6

The Elements

KEY IDEAS

- Ancient chemistry provided practical information, but not a good understanding of matter.
- Modern chemists began to find and name new elements and compounds, and developed a universal system for naming elements and compounds.
- Elements can be classified into three categories: metals, non-metals, and metalloids.
- The Periodic Table orders the elements into groups with the same properties.



Chapter Preview

Think about the different types of matter you use every day. Did you include what you use to wash your face or brush your teeth, what you had for breakfast, or what you wear or write with? Learning about matter can help us understand why three different states of water are common, why food changes when it is cooked, and why different clothing has a variety of characteristics.

Some of the materials we use every day are mixtures, some are compounds, many are elements, but all are made from elements. Elements are the basic building blocks for everything in our universe, and their number and possible combinations may seem overwhelming. Like all forms of matter, elements can be organized according to their characteristics. How does it help you when things are organized? Are there different ways to organize the same things?

This chapter will introduce you to the language of chemistry and how the elements have been classified according to their properties.

TRY THIS: Finding Elements

Skills Focus: analyzing, inferring

In this activity, you will work with a group to find out what you already know about elements.

1. In a small group, make a list of pure substances that you are familiar with. Remember that pure substances contain only a single type of particle. Don't forget to consider substances that are found in all three states of matter.

A. Analyze your list of pure substances and decide which are elements and which are compounds. How many elements did you list?

B. How do you know that the compounds you listed are not mixtures?

C. How easy do you think it is to isolate or produce an element? Explain your thinking.

6.1 The History of Chemistry

LEARNING TIP
Skim through the Key Ideas (on the previous page), headings, diagrams, photographs, and words in bold to get an idea of what you will be learning in Chapter 6. What do you think you will be learning?

How do you know that gold, silver, carbon, and oxygen are elements? How do you know that air is a mixture or that salt is a compound?

What people know can have a powerful influence on how they view the world. Sometimes, when new ideas are formed, a time of great learning and activity occurs. The beginnings of modern chemistry replaced the beliefs of the alchemists and created a revolution in understanding that created much of the chemistry we use today.

Ancient Chemistry

Ancient chemistry's purpose was to find and purify new substances for as many uses as possible. Metals were probably the first substances to be discovered. The earliest metals used were those that could be found naturally in their pure form. Copper and gold have been found in very ancient remains of both Egypt and Mesopotamia. Can you imagine what it must have been like to discover pure gold and copper in a world of rocks and trees?

As methods for making hotter fires were discovered, metals could be obtained from ore and purified. This science, known as metallurgy, became an important part of the culture of Egypt and Babylon, and a close association between metals and the priests, temples, and gods was established. Other examples of ancient chemistry include the following:

- making and colouring glass
- colouring textiles using dyes from plants and animals
- making inks
- manufacturing bricks and ceramic products
- producing charcoal and lime
- using fermentation to make alcoholic beverages
- preserving food
- making perfumes and ointments or salves

The Alchemists

To many of us, the word "alchemy" calls up a picture of a medieval laboratory in which an aged, black-robed wizard mixes strange potions in search of the philosopher's stone—the legendary substance that was believed to change common metals to gold, cure all diseases, and prolong life indefinitely. In reality, alchemy was a reflection of the serious religious beliefs of the Middle Ages. Alchemy flourished in Chinese, Hindu, Arabic, and European cultures. It was a study of the natural world in an attempt to blend the natural world with the spiritual world—a search for perfection. Much of the study of alchemy was very secretive. There was little sharing

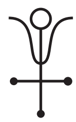
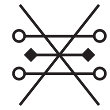
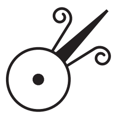
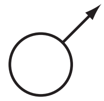
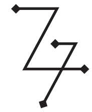
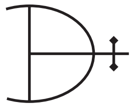
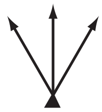
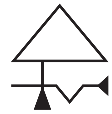
Did You KNOW?

Fact and Fiction

Nicholas Flamel, a character in *Harry Potter and the Philosopher's Stone*, was based on a real French alchemist of the same name, who claimed to have found the philosopher's stone and made gold.

among alchemists. In fact, the symbols for what we now know as elements were chosen to prevent knowledge about the elements from becoming known and shared (Table 1).

Table 1 Alchemy Symbols of Some Elements

 antimony	 arsenic	 copper
 gold	 iron	 lead
 magnesium	 silver	 sulfur or brimstone

In Europe, alchemy contributed to the manufacture of amalgams (alloys of mercury and other metals) and to advances in many other chemical processes and the apparatus required for them. It failed to create, however, any new understanding of matter. The alchemists still believed, as the Greeks had, that all the substances in the world were composed of some combination of the four basic elements: fire, earth, air, and water (Figure 1).

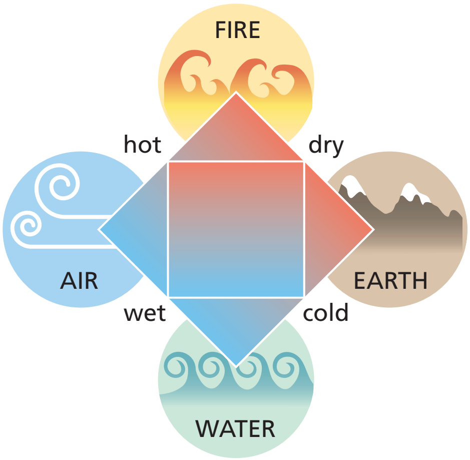


Figure 1 The four elements: Fire is both hot and dry. Earth is both cold and dry. Air is both hot and wet. Water is both cold and wet.

By the 16th century, the alchemists in Europe had separated into two groups. One group continued to look at the more spiritual side of alchemy—the search for immortality and the ability to change common metals into gold. This led to the modern-day idea of alchemy. The second group, including such great scientists as Sir Isaac Newton and Sir Robert Boyle, focused on the discovery of new compounds and their reactions, leading to what is now the science of chemistry.

Did You KNOW?

A Little Luck

Hennig Brand was one of the last alchemists. Using the model of the alchemists, he was searching for gold by condensing urine when he discovered something that glowed in the dark. He had discovered phosphorus, the last of the elements discovered by alchemy, although Brand did not know that it was an element. This story gives some insight into the role of luck or serendipity in the study of science.

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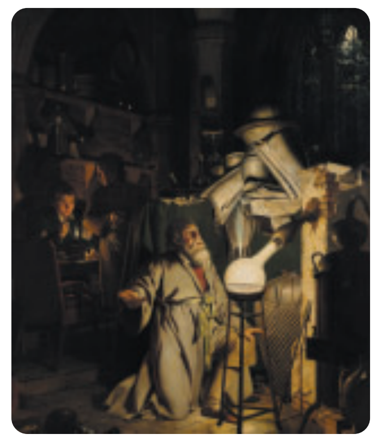


Figure 2 Robert Boyle said that a scientist should doubt the universal laws unless there was experimental evidence of them. He used equipment like this for his experiments.

LEARNING TIP

Share your thinking with a partner. How did the introduction of experimental investigations and observation changes the face of modern chemistry?

The Beginnings of Modern Chemistry

The early chemists began to question the alchemists' use of a model without testing it in the real world. Experimentation and observation became important. Robert Boyle (1627–1691) told the chemists of his day to be skeptics or doubters (Figure 2). As chemists recognized the existence of two types of pure substances (compounds and elements), they began to test many substances to see if the substances could be broken down into simpler substances. If a substance could be broken down, they measured the proportions (ratios) and described a new compound. If a substance could not be broken down, they had discovered a new element! These scientists began to forge a new chemistry, different from that of the alchemists—what is referred to as "the reformed chemistry movement."

Elements began to be discovered at a rapid pace. Between the time of the Greeks and the discovery of true elements, a period of about 1800 years, only four new elements had been discovered. The early chemists, armed with their new knowledge of elements and compounds, discovered 20 new elements during the 1700s and 51 during the 1800s. Suddenly, they had a new challenge. The large increase in the number of elements and the discovery of proportion in compounds required a new system of names and symbols so that chemists could describe and discuss their findings with others. This was another great change from the secrecy of the alchemists' period. With scientific societies arising in many countries, it became very important to develop ways to improve communication. Naming and organizing the elements and compounds was an important task that early chemists needed to accomplish.

TRY THIS: Getting the Message Across

Skills Focus: communicating, analyzing

In today's world of the Internet, e-mail, and text messaging, the power of a few letters to act as a symbol is not surprising. In this activity you will explore the process of symbolic communication.

1. With a partner, translate the meaning of these common abbreviations that are used in text messaging: LOL, THX, 14AA41, BCNU, CUL, GFN, ICBW, SFETE.
2. Write a note to your partner using text messaging abbreviations and/or symbols. See if your partner can "get the message."
3. With your partner, create some secret symbols to use in a text message. Write a second message with your secret symbols and share it with another pair of students. Can they figure out your message? Can you decipher their message?

A. What is the difference between the messages used in the first two steps above and in the last step?

B. Describe a situation in which it might be important to build a good code. When might it be important to break a code?

C. Which approach did the alchemists take? Why? Which approach did early chemists take? Why? What effect do you think the new approach had on the development of the understanding of matter?

6.1

CHECK YOUR Understanding

1. When you use different materials, what are they most likely to be made from: elements, compounds, or mixtures? Which of the three is the most rare?
2. The alchemists were looking for control over their world. What would the philosopher's stone enable them to do? How would this give them control?
3. In ancient Greece, what were the only pure elements? What was everything else?
4. Which of the alchemy symbols is used today with a completely different meaning? What does the symbol mean today?
5. What effect did the belief that most matter was mixtures have on chemistry?
6. When an alchemist did an experiment that did not create gold, was it considered a success or a failure? Was the production of gold a good criterion for an experiment? Explain.
7. What stimulated the rapid discovery of new elements during the 1700s?
8. What was different about how the alchemists and early chemists communicated their knowledge?
9. Do you think there is very much practical chemistry in today's world? Can you give any examples?
10. When is it beneficial to have a language that can only be understood by a few people? What is the benefit of having an open language that everyone can use and access?
11. Is the world flat? How do you know? Is your knowledge based on believing a model someone told you about or is it based on some observation you have made. Share your thinking.
12. Observation became the most important skill of the early chemists, and it is still the most important skill in science. Divide a sheet of paper into two columns. In the left column, accurately record five observations you have made in one day. In the right column, add any ideas, inferences, or speculations based on your observations. Be careful to write clearly so you will be able to read and understand your notes in a few days, weeks, or months.
13. In the Middle Ages, education was mainly based on the beliefs and rules handed down from the Church and the ancient Greeks. One of the great breakthroughs of the early scientists was the concept of doubt. The great scientist and mathematician Rene Descartes told his pupils to "doubt everything." What do you think is the purpose of doubting something in science?
14. You have learned about many models, including the kinetic molecular theory. Should you, like the early chemists, doubt these models or just accept them as fact? Explain your thinking.
15. The alchemists started with knowledge and applied it to the world, often ignoring their own observations. Scientists start by observing and experimenting and end by creating new knowledge. Describe the differences between these two approaches. Give an example of each approach that you have taken lately.
16. If practising science is a struggle between models and new observations, how do experiments fit in? Is their purpose to support theories or is it to prove theories wrong? Explain your thinking.

6.2

Naming and Classifying the Elements

To learn more about the origins of the names of the elements, visit **www.science.nelson.com** GO

The names of the elements have varied origins. Some elements are named for special properties such as "light giving" (phosphorus) and "water forming" (hydrogen). Many are named to honour scientists (for example, einsteinium), countries (for example, germanium), or cities (for example, berkelium). Most of the ancient elements were given Latin names, such as plumbum for lead. This name later became the basis for the name of the repair people who often work on pipes that were originally made of lead—plumbers. GO

With over a hundred elements and many thousands of compounds to describe and discuss, scientists needed a symbolic system that could describe every element and compound precisely. The system that was developed, based on the names of the elements, is both elegant and simple.

Symbols

The Workplace Hazardous Materials Informatoin System (WHMIS) system is a good example of the power of symbols to communicate. When you see a WHMIS symbol, it can both change and guide your behaviour instantly. There are only a few WHMIS symbols, so remembering them is easy. (See the Skills Handbook for examples of WHMIS symbols.) For a system to describe every element and compound, many more symbols are needed.

In the early 1800s, Swedish chemist Jons Jakob Berzelius rose to the challenge. He started by suggesting a symbolic system to describe all the elements using the letters of either their common name or their Latin name. Examine the elements in Table 1, and see if you can recognize the rules he used to decide which letters are allowed, how many are permitted, and which should be capitalized.

Table 1 Some Elements and Their Symbols

Name	Symbol	Name	Symbol	Name	Symbol	Name	Symbol
aluminum	Al	chromium	Cr	indium	In	nobelium	No
antimony	Sb	cobalt	Co	iodine	I	oxygen	O
arsenic	As	copper	Cu	iron	Fe	palladium	Pd
barium	Ba	erbium	Er	krypton	Kr	phosphorus	P
beryllium	Be	europium	Eu	lead	Pb	platinum	Pt
bismuth	Bi	fluorine	F	lithium	Li	plutonium	Pu
boron	B	francium	Fr	manganese	Mn	polonium	Po
bromine	Br	gallium	Ga	magnesium	Mg	potassium	K
cadmium	Cd	germanium	Ge	mercury	Hg	radium	Ra
calcium	Ca	gold	Au	neon	Ne	radon	Rn
carbon	C	helium	He	nickel	Ni	scandium	Sc
chlorine	Cl	hydrogen	H	nitrogen	N	selenium	Se

Table 1 Some Elements and Their Symbols (continued)

Name	Symbol	Name	Symbol	Name	Symbol	Name	Symbol
silicon	Si	sulfur	S	titanium	Ti	ytterbium	Yb
silver	Ag	technetium	Tc	tungsten	W	yttrium	Y
sodium	Na	terbium	Tb	uranium	U	zinc	Zn
strontium	Sr	tin	Sn	xenon	Xe	zirconium	Zr

To give every element a unique symbol, Berzelius suggested the following:

- Every element is represented by the first letter of its name or by the first letter of its name and a second letter from its name. For the elements that were identified first, the letters were taken from their Latin names.
- When a first letter was previously used, a letter from the rest of the name is added; for example, C was used for carbon, so calcium became Ca, cobalt became Co, and chromium became Cr.
- The first letter is always capitalized and the second letter is always lower case.

LEARNING TIP

Explain to a partner the rules governing the chemical notations in Table 1. Did you find any symbols that did not follow the rules exactly?

Although having a symbol for every element was an accomplishment, Berzelius considered the second part of his symbolic system the most important. As chemists came to recognize many compounds that were previously thought to be mixtures, they discovered that the ratio or proportion of the elements in a compound is always small whole numbers. The identification of compounds not only required symbols for each element, but also symbols to show the proportion of the elements in each compound. Berzelius stated that every compound can be identified by a formula that shows the elements and their proportions in the compound.

You already know some of these formulas, such as H_2O for the compound water and CO_2 for the compound carbon dioxide (Figure 1). The formula for water tells you that there are two parts hydrogen and one part oxygen. The formula for carbon dioxide tells you that there is one part carbon and two parts oxygen. You will learn more about these formulas in Chapter 8.

(a) **(b)**

Figure 1 (a) The compound water is two parts hydrogen and one part oxygen. (b) The compound carbon dioxide is one part carbon and two parts oxygen.

Classifying the Elements

All elements are different from each other. The properties of any element are unique to this element and can therefore be used to identify it. Some elements, however, have similar chemical and physical properties. These elements are often grouped together. Grouping elements together according to their properties helps predict how they might react.

Metals, Non-Metals, and Metalloids

One common way to classify elements based on their physical and chemical properties is to group them as as metals, non-metals, or metalloids. Although you may be more familiar with metals, you will discover that there are a few non-metals and metalloids you have used and others you have heard about.

TRY THIS: *Grouping Elements*

Skill Focus: conducting, observing, recording, analyzing, evaluating, classifying

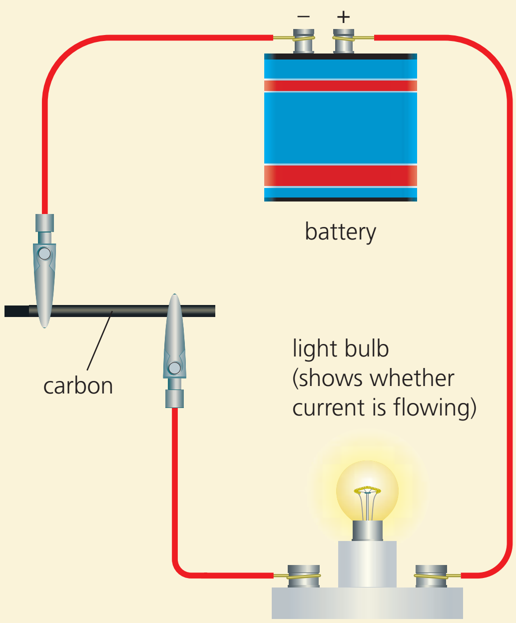


Figure 2

Materials: index cards; 3 connecting wires, battery, light bulb with base; samples of the elements carbon, tin, silicon, copper, zinc, magnesium, sulfur, aluminum

Elements can be grouped in many ways. In this activity, you will group some elements according to two properties.

1. Write the chemical symbol for each element at the top of a card, and the name of the element beneath.
2. Assemble the conductivity apparatus as shown in Figure 2. Place the connecting wires at opposite ends of each sample. If the bulb glows, the element can conduct electricity. Record your observations on the card.
3. Observe the lustre (shininess) of each element. Does the element reflect light? Record your observations on the card.

A. Which elements have the properties of lustre and electrical conductivity? Which elements do not have either of these two properties? Are there any elements that have one of the properties, but not the other? If so, which elements?

B. Generally, the elements that have lustre and conduct electricity are classified as metals. Which of the elements can be classified as metals? Which of the elements can be classified as non-metals?

Did You KNOW?

Precious Metals

Certain metals are considered to be precious—an element with high monetary value. Precious metals include gold, silver, platinum, and palladium. Today, these metals are generally used to make art, jewellery, and high-value coins for collectors. In the past, however, precious metals were used as currency.

Metals

Most of the elements discovered first were metals. Certainly much of the interest of the alchemists was to convert the common and inexpensive metals into gold. You may be surprised, however, to know that most of the elements known today are metals. Metals have a wide range of both chemical and physical properties, but they all share some important ones that make them metals. Most **metals** have the properties listed in Table 2.

Table 2 Properties of Metals

Property	Characteristic
lustre	shiny
malleability	malleable (can be formed or shaped)
ductility	ductile (can be stretched into wire)
conductivity	good conductors of heat and electricity
state	solid at room temperature (except mercury, which is liquid at room temperature)
density	usually denser than non-metals
reactivity	active metals react with acid, and very active metals react with water

Tungsten, iron, copper, nickel, lead, zinc, tin, magnesium, aluminum, mercury, and chromium are some of the elements that are classified as metals (Figure 3).

Non-Metals

The elements that do not have the characteristics of metals are usually classified as non-metals. Most **non-metals** typically have the properties listed in Table 3.

Table 3 Properties of Non-Metals

Property	Characteristic
lustre	dull appearance
malleability	likely to be brittle or shatter when struck
melting point and boiling point	usually lower melting and boiling points than metals
state	often gases at room temperature
conductivity	poor conductors of heat and electricity

LEARNING TIP

As you study Table 3, ask yourself, "Would non-metals make very good jewellery?" Explain your thinking to a partner.

Fluorine, phosphorus, chlorine, bromine, iodine, and sulfur are some of the elements that are classified as non-metals (Figure 3).

(a) **(b)**

Figure 3 Metals, such as chromium (a), tend to be shiny and malleable, while non-metals, such as sulfur (b), tend to be dull and brittle.

Metalloids or Semi-Metals

A few elements do not fit exclusively into either group and are called **metalloids** (semi-metals or semiconductors). Silicon, germanium, arsenic, antimony, and tellurium exhibit some of the qualities of both metals and non-metals. For instance, silicon is shiny and a solid at room temperature (like a metal) but is a poor conductor of electricity and is brittle (like a non-metal) (Figure 4). Many of the metalloids are semiconductors of electricity, meaning that they have a partial ability to conduct electricity—from almost no ability to full conductivity. This property is useful in the electronics industry and has made the metalloids a very important group in today's world.

Figure 4 Silicon has qualities of both a metal and a non-metal.

6.2 CHECK YOUR Understanding

1. Look at Table 1 (pages 188–189). Match each element with its proper symbol.

Element	Symbol
mercury	W
arsenic	Pd
tin	Sn
potassium	Fr
francium	Fe
palladium	As
antimony	P
phosphorus	Hg
iron	K
tungsten	Sb

2. Look at Table 1 (pages 188–189). Make a list of at least five elements that are named after places.
3. Which elements do you think have symbols based on their Latin name? Why? Can you find at least five?
4. Use Table 1 (pages 188–189) to find the names of the elements with the symbols Tc, Co, Cu, Sc, Y, Ar, Ag, Pb, Pd, and Kr.
5. Summarize the rules for writing the symbols for the elements.
6. What two things does the formula of a compound tell us?
7. The formulas of some compounds are listed in Table 4. Copy the table into your notebook and complete the second column by writing the names of the two elements in each compound.

Table 4

Compound	Elements in the compound
ZnS	
H_2O	
NaCl	
CaS	
CH_4	
$CuCl_2$	
PbO_2	
K_2S	

8. One element in Table 1 on pages 188 and 189 does not have a Latin name, but its symbol is not taken from its name in the table. Which element is it?
9. Name three physical properties that you would expect to find in a metal.
10. Which metal is a liquid at room temperature?
11. Based on the differences between metals and non-metals, answer the following questions.
    (a) Does copper conduct heat well?
    (b) Does lead shine?
    (c) Does sulfur conduct electricity?
    (d) Is germanium a metalloid?
    (e) Is phosphorus malleable?
    (f) Is chlorine ductile?
12. Argenta is a town in British Columbia. What do you think might have been mined there? Can you think of a country that used the same root for its name?
13. Do you think that non-metals would make very good jewellery? Explain your thinking.
14. What evidence suggests that some elements are more rare than others?
15. Some elements were named for their physical or chemical properties. Unfortunately, for many of us, the Greek language was used for these properties. Which element might each of the following be?
    (a) water forming
    (b) light bearing
    (c) stench
16. If there were an award for having the most elements named after a location, it would certainly be won by a small village in Sweden called Ytterby. Four elements were named after this village. Can you find two of these elements? Can you find all four?
17. Suggest a name and a symbol that could be used if a new element were to be named after Canada. Now suggest a name and a symbol that could be used for an element named after you. (Remember that you cannot duplicate any existing symbols).

6.3 Putting the Elements in Order

By 1864, chemists had identified 63 unique elements. To identify these elements, chemists described many of their chemical and physical properties. They grouped the elements according to these properties, just as you grouped some elements in the previous section. Antoine Lavoisier, a French scientist in the late 1700s, classified the known elements into four groups: metals, gases, non-metals, and "earths." This classification was based on physical properties, such as electrical conductivity, lustre, and ductility. Other scientists had classified the elements by how they reacted with other elements. Neither classification, however, included all the elements.

Ordering by Properties

Working in the mid-1800s, a Russian scientist named Dmitri Mendeleev (Figure 1) tried to find a way of organizing all the elements to do more than just provide a listing of the known elements and their properties. At that time, it was known that each element had a specific and unique mass. Scientists such as John Dalton had discovered that the masses of the elements involved in chemical reactions are always in certain proportions. For example, two parts hydrogen and one part oxygen always combine to form water (H_2O). When the reaction is complete with no hydrogen or oxygen left over, the mass of oxygen used is eight times the mass of hydrogen. This means that the mass of oxygen is 16 times the mass of hydrogen because there is one part oxygen to two parts hydrogen. By studying reactions, scientists could tell how heavy one element was in relation to another. When the elements were listed in order of increasing mass (from lightest to heaviest), Mendeleev noted that certain other properties seemed to repeat with a regular pattern, as shown in Figure 2.

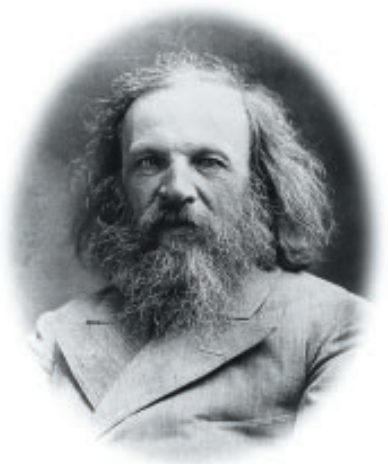


Figure 1 Dmitri Mendeleev observed patterns which allowed him to organize the elements into groups.

LEARNING TIP

As you study Figure 2, explain to a partner how Mendeleev's Periodic Table of Elements simplified the complex world of chemical reactions.

H	Li	Be	B	C	N	O	F	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr

Figure 2 Mendeleev noted that elements with common properties appear at regular intervals when ordered by mass, like the low-density reactive metals highlighted (in red) above.

To order the elements, Mendeleev wrote the known elements on cards, and listed their properties. He laid out the cards like a game of solitaire, moving and grouping them in different ways. Eventually, he sorted out the cards in order of increasing mass, from left to right. When the properties of elements periodically repeated, he began a new row each time to create a Periodic Table of the Elements. This periodic table listed the elements in horizontal rows (periods), with masses increasing from left to right. It also formed vertical columns (groups) of elements with common properties.

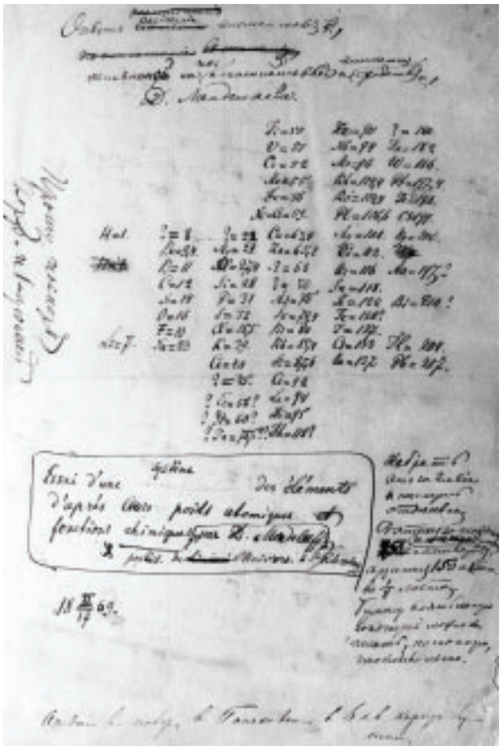
6A *Investigation*

6A *Investigation*

Creating a Periodic Table

To perform this investigation, turn to page 197.

In this investigation, you will create a periodic table using properties of hypothetical elements.



(a)

Groups		I	II	III	IV	V	VI	VII	VIII
Formulas of Compound		R_2O —	RO —	R_2O_3 —	RO_2 H_4R	R_2O_5 H_3R	RO_3 H_2R	R_2O_7 HR	RO_4 —
Periods	1	H(1)							
	2	Li(7)	Be(9.4)	B(11)	C(12)	N(14)	O(16)	F(19)	
	3	Na(23)	Mg(24)	Al(27.3)	Si(28)	P(31)	S(32)	Cl(35.5)	
	4	K(39)	Ca(40)	–(44)	Ti(48)	V(51)	Cr(52)	Mn(55)	Fe(56) Co(59) Ni(59) Cu(63)
	5	[Cu(63)]	Zn(65)	–(68)	–(72)	As(75)	Se(78)	Br(80)	
	6	Rb(85)	Sr(87)	?Yt(88)	Zr(90)	Nb(94)	Mo(96)	–(100)	Ru(104) Rh(104) Pd(105) Ag(108)
	7	[Ag(108)]	Cd(112)	In(113)	Sn(118)	Sb(122)	Te(125)	I(127)	

(b)

Figure 3 (a) This is a page from Mendeleev's original notes, showing the Periodic Table as a work in progress. (b) The version of the Periodic Table that was published in 1872.

Figure 4 Sodium metal, like all the elements in the Group I column, reacts with water to produce hydrogen gas. The heat that is released in this reaction can ignite the hydrogen.

Other scientists had proposed something similar to Mendeleev's table, but Mendeleev used a breakthrough approach: he left gaps when the properties of the next-heaviest element did not match the properties above it in the column (Figure 3).

Events that occur over and over, in a regular pattern, are called "periodic" events. The observation that patterns of properties would repeat was stated as the following: when elements are arranged in order of increasing mass, chemical and physical properties form patterns that repeat at regular intervals. Mendeleev's Periodic Table is based on this.

Predicting with Properties

The vertical groups of elements in Mendeleev's table share properties. Look at the Periodic Table in Figure 3. In the Group I column are lithium, sodium, potassium, and rubidium. These low-density metals all react violently with water (Figure 4).

Based on the properties of the elements in these groups, Mendeleev predicted some of the properties, (such as density and melting point) of elements that would fill the gaps in his table. He predicted that elements would eventually be isolated or discovered to fill his table. Soon, scandium (1879), germanium (1886), and gallium (1895), were discovered, and they displayed properties in accordance with Mendeleev's predictions.

Sometimes, elements did not fit into the right groups if Mendeleev kept them in order of increasing mass. In these situations, he always moved the elements into the vertical groups based on their physical and chemical properties. In later years, other scientists re-measured most of these "out of order" elements, and found that the new, more accurate measurements agreed with most of the chemical groupings. They found only two pairs that remained out of sequence. Argon and potassium are one of these pairs.

The predictive power of the Periodic Table made it extremely useful to chemists, and it was continually modified and updated as new elements were discovered and fit into the puzzle. In 1892, Sir Walter Raleigh and William Ramsay discovered the atmospheric gas argon, which was important for its non-reactive nature. Noting that argon needed a new column (Group 0) in the Periodic Table, Ramsay searched for more non-reactive gases and soon isolated neon, krypton, and xenon from Earth's atmosphere. These elements form a group that we now call the noble gases (Figure 5).

Figure 5 Mendeleev's updated Periodic Table of the Elements, which includes the newly-discovered noble gases in Group 0.

Pointing the Way to the Future

Mendeleev's table was not perfect. It contained some errors and inconsistencies due to incomplete or incorrect data. Manganese, for example, was included with the chemical grouping of chlorine, bromine, iodine, and fluorine. Like most scientific ideas, however, the Periodic Table is a model that has evolved through the work of others, adapting to new information. The table most often used (and reproduced at the back of this book) achieved its general form in 1940. This table also identifies elements that are metals, non-metals, and metalloids. GO

Mendeleev, by using the collective observations and analysis of the chemistry community, created a model that not only explained how the elements are grouped, but also pointed the way to understanding the nature of matter itself.

Did You KNOW?

Other Periodic Tables

Julius Meyer studied under the same university professor as Mendeleev, and also noted the periodic appearance of properties. Meyer produced his own periodic table, but Mendeleev published one year earlier, and so is given credit for the invention of the Periodic Table. But neither scientist was the first to note that properties appeared in a regular pattern.

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To learn more about different versions of the Periodic Table, visit
www.science.nelson.com GO

6.3 CHECK YOUR *Understanding*

1. (a) Explain the process of classification.
   (b) Give an example from your everyday life of how things are classified.
   (c) Describe the advantages of classifying a collection of objects or materials.
2. State the periodic law in your own words.
3. Explain why the word "periodic" is used in the name of the table of the elements.
4. Which property did Mendeleev primarily use to classify the elements?
5. (a) Why did Mendeleev leave gaps in his Periodic Table?
   (b) What did Mendeleev predict about the "undiscovered" elements in the gaps?
6. Which elements, discovered in the late 1800s, matched closely with Mendeleev's predictions?
7. (a) Which was the first noble gas discovered on Earth?
   (b) Where is this gas found?
   (c) Why did Ramsay search for more noble gases?
   (d) Why did the elements argon, neon, krypton, xenon, and helium need their own, new group in the Periodic Table?
8. What feature(s) of Mendeleev's table made it so useful and accepted by chemists?
9. Name two undiscovered elements that Mendeleev predicted. Did the eventual discovery of these elements provide evidence for the concept of the Periodic Table? Explain your thinking.
10. Refer to Mendeleev's Periodic Table on the right and compare it with the modern Periodic Table at the back of this book.
    (a) Which elements are no longer included in Group I?
    (b) Which element from Mendeleev's seventh column is now considered out of place?
11. When Mendeleev had to make a choice between grouping based on mass or grouping by similar properties, which did he choose? Why do you think he made this choice?
12. The quality of any model is how well it explains what happens in the world. How well did Mendeleev's table explain the chemistry of his time? Does it still have the power to explain? Why or why not?
13. Was the Periodic Table invented by Mendeleev or discovered by him? Explain your thinking.
14. The Periodic Table was welcomed by chemists because it organized and included all the known elements. Did the table explain why or how this organization occurred? Explain your thinking.
15. Suggest three possible questions that Mendeleev may have asked when he was attempting to organize the elements.

Groups		I	II	III	IV	V	VI	VII	VIII
Formulas of Compound		R_2O / —	RO / —	R_2O_3 / —	RO_2 / H_4R	R_2O_5 / H_3R	RO_3 / H_2R	R_2O_7 / HR	RO_4 / —
Periods	1	H(1)							
	2	Li(7)	Be(9.4)	B(11)	C(12)	N(14)	O(16)	F(19)	
	3	Na(23)	Mg(24)	Al(27.3)	Si(28)	P(31)	S(32)	Cl(35.5)	
	4	K(39)	Ca(40)	–(44)	Ti(48)	V(51)	Cr(52)	Mn(55)	Fe(56) Co(59) Ni(59) Cu(63)
	5	[Cu(63)]	Zn(65)	–(68)	–(72)	As(75)	Se(78)	Br(80)	
	6	Rb(85)	Sr(87)	?Yt(88)	Zr(90)	Nb(94)	Mo(96)	–(100)	Ru(104) Rh(104) Pd(105) Ag(108)
	7	[Ag(108)]	Cd(112)	In(113)	Sn(118)	Sb(122)	Te(125)	I(127)	

Figure 6

6A Investigation

Creating a Periodic Table

Mendeleev saw the need for a system of organizing elements that would include important information about them, and allow relationships between different elements to be easily seen. In this Investigation, you will be given information about some hypothetical elements, and create a system to arrange them.

INQUIRY SKILLS

- ● Questioning
- ○ Hypothesizing
- ● Predicting
- ● Planning
- ○ Conducting
- ○ Recording
- ● Analyzing
- ● Evaluating
- ○ Synthesizing
- ● Communicating

Question

Write a question for this Investigation.

Design

You will be given information about some hypothetical elements and you will design a system to arrange these elements. Using your system, you will make a prediction about the properties of (an) unknown element(s).

Materials

- set of 20 to 24 blank cards (per group)

Procedure

1. Work with a group. Examine the list of 16 imaginary elements and their properties in Table 1. Write the symbol and properties of each element on a card (Figure 1).
2. Mass will be the most important property in your arrangement. Rank the rest of the properties in order of importance.
3. Arrange the element cards in groups, based on your property ranking in step 2. You may choose to use blank cards to fill in gaps in your arrangement.
4. Draw a diagram of your arrangement.
5. If you have gaps in your arrangement, make a prediction about the properties of the unknown element(s).

H

Mass—64.0 g
Density—9.0 g/cm^3
State—solid
Reactivity—tarnishes slowly
Electrical Conductivity—good

Figure 1

Table 1

Element (symbol)	Mass (g)	Density (g/cm^3)	State	Reactivity	Electrical conductivity
litium (L)	4.0	0.2	gas	none	poor
fermium (F)	7.0	0.5	solid	reacts with water	good
langlium (La)	11.0	2.3	solid	reacts with oxygen	good
orcium (O)	14.0	1.3	gas	low	poor
weirdium (W)	16.0	1.4	gas	reacts with most metals	poor
clownium (Cl)	20.0	0.9	gas	none	poor
probium (P)	27.0	2.7	solid	reacts with oxygen	good
albertium (A)	28.0	2.5	solid	low	fair
marium (M)	31.0	1.8	solid	low	poor
irenium (I)	32.0	2.1	solid	reacts with most metals	poor
bearium (Br)	40.0	0.9	solid	reacts with water	good
spuzzium (S)	56.0	7.9	solid	tarnishes quickly	good
atlium (At)	59.0	8.9	solid	does not tarnish	good
heavium (H)	64.0	9.0	solid	tarnishes slowly	good
densium (D)	70.0	5.9	solid	reacts with oxygen	good
salmoium (Sa)	73.0	5.4	solid	low	fair

Analysis

(a) What was your ranked order of properties?

(b) Was there a pattern of repeating properties?

(c) What were your predicted properties for the unknown element(s)?

(d) Compare your arrangement to other groups. How are they the same? How are they different?

(e) Compare your predictions for the unknown element(s) to those of another group. How are they the same? How are they different?

Evaluation

(f) How would you improve your arrangement? Draw a diagram of your improved arrangement.

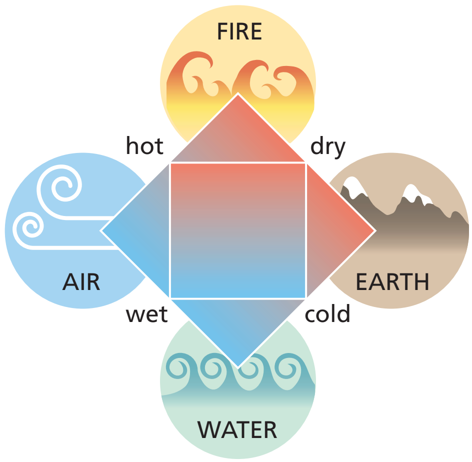
CHAPTER 6 Review

The Elements

Key Ideas

Ancient chemistry provided practical information, but not a good understanding of matter.

- Ancient chemistry was about either the practical use of materials or their connection with the spiritual world.
- Thinking of matter as combinations of only four elements limited new learning about chemistry for many centuries.
- A new era of chemistry began when scientists started to observe and experiment.



Modern chemists began to find and name new elements and compounds, and developed a universal system for naming elements and compounds.

- The modern chemists started to do experiments and hastened the discovery of elements and compounds.
- Observation and experimentation were used to see if substances could be broken down. New elements were identified when substances could not be broken down further.
- The system Berzelius developed gave all elements and compounds a unique symbol.
- The new language of elements and compounds enabled chemists to discuss and share what they learned more easily.

Vocabulary

metals, p. 190

non-metals, p. 191

metalloids, p. 191

Name	Symbol	Name	Symbol	Name	Symbol	Name	Symbol
aluminum	Al	chromium	Cr	indium	In	oxygen	O
antimony	Sb	cobalt	Co	iodine	I	palladium	Pd
arsenic	As	copper	Cu	iron	Fe	phosphorus	P

Elements can be classified into three categories: metals, non-metals, and metalloids.

- Although each element is unique, all the elements can be classified into three main groups that share some of the same properties.
- The majority of all elements are metals, sharing the properties of lustre, electrical and heat conductivity, malleability, and ductility.
- Elements in the smaller, but equally important, group of non-metals mainly share the characteristic that they lack the properties of metals.
- Metalloids are between the metals and the non-metals. They share some of the properties of both groups.



The Periodic Table orders the elements into groups with the same properties.

- Dmitri Mendeleev developed a table based on the increasing mass of the elements and on the repeating properties of groups of elements.
- The Periodic Table was able to predict new elements that had not yet been discovered.

Groups		I	II	III	IV	V	VI	VII	VIII
Formulas of Compound		R_2O ——	RO ——	R_2O_3 ——	RO_2 H_4R	R_2O_5 H_3R	RO_3 H_2R	R_2O_7 HR	RO_4 ——
Periods	1	H(1)							
	2	Li(7)	Be(9.4)	B(11)	C(12)	N(14)	O(16)	F(19)	
	3	Na(23)	Mg(24)	Al(27.3)	Si(28)	P(31)	S(32)	Cl(35.5)	
	4	K(39)	Ca(40)	–(44)	Ti(48)	V(51)	Cr(52)	Mn(55)	Fe(56) Co(59) Ni(59) Cu(63)
	5	[Cu(63)]	Zn(65)	–(68)	–(72)	As(75)	Se(78)	Br(80)	
	6	Rb(85)	Sr(87)	?Yt(88)	Zr(90)	Nb(94)	Mo(96)	–(100)	Ru(104) Rh(104) Pd(105) Ag(108)
	7	[Ag(108)]	Cd(112)	In(113)	Sn(118)	Sb(122)	Te(125)	I(127)	

Review Key Ideas and Vocabulary

1. Which substance was not one of the Greek elements?
   (a) air
   (b) water
   (c) wood
   (d) earth
2. Which element is not correctly matched with its symbol?
   (a) oxygen O
   (b) beryllium Be
   (c) nitrogen Ni
   (d) sodium Na
3. Which of the following elements is represented by the symbol "S"?
   (a) silver
   (b) sulfur
   (c) silicon
   (d) sodium
4. Which of the following is a characteristic of non-metals?
   (a) low lustre
   (b) malleable
   (c) very ductile
   (d) high electrical conductivity
5. Which scientist is credited with the invention of the Periodic Table?
   (a) A Lavoisier
   (b) J.J. Berzelius
   (c) D.I. Mendeleev
   (d) Joseph Priestley
6. List five elements named for geographical locations and give the names of the locations.
7. Match each symbol with the metal it represents.

Symbol	Element
(a) Rn	iodine
(b) Si	potassium
(c) Cd	calcium
(d) P	silver
(e) K	iron
(f) Fe	phosphorus
(g) I	silicon
(h) Ca	radium
(i) Ra	cadmium
(j) Ag	radon

8. Identify each of the following statements as true (T) or false (F). Correct the false statements to make them true.
   (a) The early study of natural substances was called alchemy.
   (b) The main goal of alchemists was to share their ideas.
   (c) Elements are made of compounds.
   (d) Mendeleev organized elements by properties.
   (e) Elements in the same period have the same properties.
   (f) Metals are dull and poor conductors of electricity.
9. Explain the difference between a period and a group in the Periodic Table.
10. A new element has been discovered. All you know at this point is that it is a metal. Based on this information, predict the following:
    (a) its state at room temperature
    (b) whether it will be shiny or dull
    (c) whether it will be brittle or malleable
    (d) whether it will conduct electricity or not
11. A new element has been discovered that is solid, brittle, and shiny, and it conducts electricity. To which group of elements does it belong? Explain your answer.
12. Which group of elements—metals, non-metals, or metalloids—is used to create the semiconductors needed by cell phones and computers?
13. Name an unknown element that Mendeleev predicted would be discovered, based on his understanding of the properties of groups of elements.
14. What happened when the symbols and language of chemistry were developed and shared?

Use What You've Learned

15. Aspartame, the sugar substitute in diet pop, has the formula $C_{14}H_{18}N_2O_5$. Which elements are contained in aspartame, and in what proportions? The formula for sugar (sucrose) is $C_{12}H_{22}O_{11}$. What are the elements in sugar and their proportions?

16. The information in Table 1 has been scrambled. Draw a similar table in your notebook, but place the matching formulas, elements, and proportions in the correct rows.

Formula	Element	Proportion
KF	sodium and sulfur	1 to 1
Al_2S_3	potassium and fluorine	1 to 2
$CaCl_2$	calcium and oxygen	2 to 1
Na_2S	aluminum and sulfur	1 to 1
CaO	calcium and chlorine	2 to 3

17. Why do think the noble gases were the last family to be discovered?
18. Mercury is the only metal that is a liquid at room temperature. What properties do you think mercury has that make it a metal?
19. Which heavenly bodies were the following elements named after: mercury, uranium, neptunium, plutonium, tellurium, selenium, palladium, and cerium? You may need to do some research for some.

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20. A nail head in a seat in a sauna feels very hot. The wood of the seat feels only warm. Since they are in the same sauna at the same temperature, what causes the difference?
21. Imagine that you have a collection of stamps from around the world. Some of the stamps are very old, dating back to almost the first stamps of 1840. You want to display the stamps so that people can appreciate both how old the stamps are and where they are from. Based on your understanding of the Periodic Table, explain how you might organize the collection.

Think Critically

22. The beginning of modern chemistry was an exciting time. Research one of the scientists mentioned in this chapter, and write a one-page report about the contributions he made to the understanding of chemistry.

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23. Many elements are mined to make them available for use. Where might we have to look for these elements if we can no longer find them through conventional mining?
24. Why do you think properties such as colour and taste were not used to arrange elements in the first periodic table?
25. Kryptonite is the green substance harmful to the fictional character Superman. Research the properties of krypton, and decide if the two substances are likely the same.

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26. The Periodic Table that we use today has a very recognizable form, but it is only one of the forms that have been created. Use the Internet to find alternative forms. Research one and write a report, create a poster, or do a PowerPoint presentation to share your chosen form.

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27. Elements in the same group have similar properties. Describe two examples in everyday life where similar substances could be substituted for each other. What other factors would you consider before making the substitution?

Reflect on Your Learning

28. Berzelius's symbols and Mendeleev's Periodic Table are testaments to the power of grouping and classification. Make a table to show the important points in Chapter 6. Does organizing information in this way help you understand or remember the information better?

Visit the Quiz Centre at

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CHAPTER 7

Atomic Theory—Inside the Invisible

KEY IDEAS

- Matter is made of atoms.
- The atomic theory of matter has changed with new discoveries.
- Elements can be classified according to their properties.
- Atoms have a structure that determines their chemical and physical properties.

Chapter Preview

The astronomer Carl Sagan once referred to matter as "the stuff of the universe." But what is this "stuff" made of? In the way that a large building is an assembly of boards, nails, bricks, and mortar, all matter is composed of a few types of "building blocks." Scientists and philosophers have long been intrigued by the nature of matter. In 500 BCE, the Greek philosopher Democritus proposed that all matter was made up of tiny particles, which were too small to be seen, and that these particles were different sizes and shapes. In other words, the particles that made up wood were different from the particles that made up water. He called these small particles "atomos" or "indivisibles." As you will learn, Democritus came remarkably close to our modern atomic theory.

In this chapter, you will learn about the development of some theories and models of the structure of atoms. As new techniques and technologies developed and new information became available, the models and theories changed and adapted.

TRY THIS: *Modelling a Theory*

Skills Focus: creating models, predicting, observing

Scientists often use physical models to help explain or demonstrate theories. Experimenting with models allows scientists to verify parts of a theory, or to revise or replace a theory. In this activity, you will create a model, then use your model to test a prediction based on a theory.

Materials: (per group) small 10 cm aluminum pie plate; about 40 plastic beads in two different sizes (20 of each size), 20 popcorn kernels, 20 steel ball bearings (same size as one size of plastic bead)

The Theory: A collection of particles, when vibrated, should sort out according to size and density.

1. Fill a pie plate half full with the beads, kernels, and ball bearings.
2. Based on the theory, predict what will happen when the plate is vibrated.
3. Test your prediction. Use small, rapid vibrations and try not to spill the contents.

A. How did the contents sort out? Describe the arrangement in detail.

B. Based on your observations, evaluate your prediction.

C. Revise the theory. This may involve adding more detail or changing the theory entirely.

D. Describe how your new theory better fits your observations.

7.1 Development of a Modern Atomic Theory

LEARNING TIP
Set a purpose for your reading. As you read Section 7.1, ask yourself, "How has the atomic theory changed with new discoveries?"

How can we see inside something that is not visible to us? The early Greek philosophers pondered this question, and it continues to challenge scientists 2000 years later. Today, scientists use conceptual and physical models to study phenomena that are not easily observed, and they test those models through experiments. Scientific models predict the behaviour of systems. Scientists evaluate the models they use by observing the behaviour of systems in controlled experiments.

TRY THIS: Seeing the Invisible

Skills Focus: observing, analyzing, inferring, interpreting data

Scientists have learned much about the invisible structure of matter by indirect observations, models, and inferences. In this activity, you will use indirect observations to make inferences about something that you can't see.

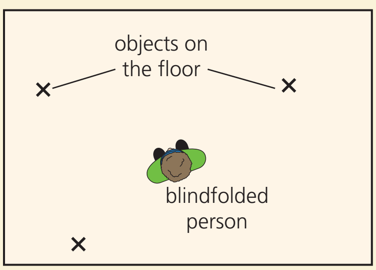

Figure 1

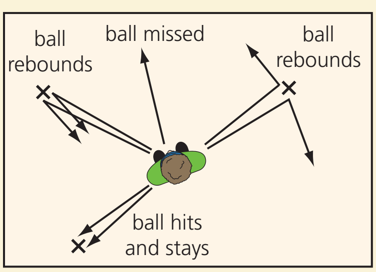

Figure 2

Materials: blindfold; a hard, flat object (a book); a hard, round object (a bucket); a soft object (a balled-up jacket or a backpack); 4–6 table-tennis balls

1. Work in groups. Have one group member sit blindfolded on the floor in a clear area, facing in one direction.
2. Place the three objects on the floor, out of reach of the blindfolded student.
3. Draw a diagram of the setup, showing only the location of the objects and the blindfolded student. With a pencil, draw a small X to show the centre of each object (Figure 1).
4. The blindfolded student will roll the table-tennis balls, one at a time, in a variety of directions to try and hit the objects. Draw the paths of the balls on your diagram, noting if they miss, hit and stay, or hit and rebound off the objects (Figure 2).
5. The blindfolded student will keep rolling the balls until each object has been hit several times. Then remove the objects from the floor and erase the X's from your diagram.
6. Exchange diagrams with another group.

A. Can your group identify the objects and determine their locations from the diagram? Indicate the objects on the diagram. Check with the other group to see if you were correct.

The First Scientific Atomic Theory

By the late 1700s, most scientists agreed that an element was a type of matter that could not be broken down into simpler substances. More than 30 elements had been identified by this time. Scientists knew that elements would combine to form compounds during chemical reactions, but they could not adequately explain how this happened. In 1808, the English chemist John Dalton proposed an atomic theory of matter that could explain the behaviour of chemical reactions (Figure 3). Dalton envisioned the **atom**, the smallest piece of any element, as a smooth solid sphere, without an electrical charge.

Dalton's Theory

- All matter is made of atoms, which are particles that are too small to see.
- Each element has its own kind of atom, with its own particular mass.
- All atoms of any one element are identical.
- Compounds are created when atoms of different elements combine in a specific ratio.
- Atoms cannot be created, destroyed, or subdivided during chemical changes.

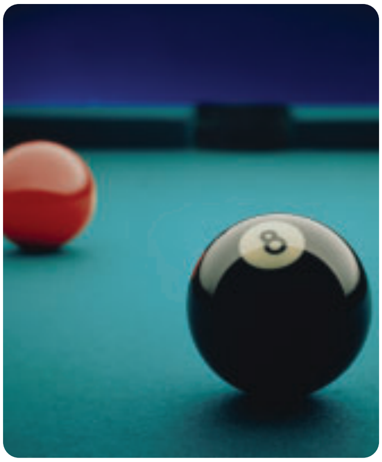

Figure 3 According to Dalton's theory, the atom was a solid sphere—much like this billiard ball.

Atoms and Molecules

The terms "atom" and "molecule" were used interchangeably until the early 19th century. Scientists now consider a molecule to be two or more non-metallic atoms combined—the smallest particle of most compounds (Figure 4.) Compounds that are formed from metals and non-metals technically do not have molecules. You will learn more about these compounds in this chapter and in Chapter 8.

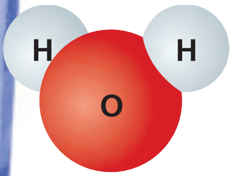

Figure 4 Water is a compound that is made up of molecules. Each water molecule is made up of two hydrogen atoms joined to one oxygen atom.

New Discoveries Revise the Atomic Theory

Have you ever walked across a carpet on a cold, dry day, and received a shock when you touched a doorknob? Dalton's theory explained chemical reactions reasonably well, but it could not account for the shock you received from the doorknob—the phenomenon of static electricity. More importantly, in the 1830s, Michael Faraday showed that atoms could gain electric charges. Dalton's theory did not include charged atoms (Figure 5), and so was modified to include the following ideas:

Revisions to Dalton's Theory

- Matter must contain positive and negative charges.
- Opposite charges attract, and like charges repel.
- Atoms combine to form the particles of a compound because of the electrical attraction between charged atoms.

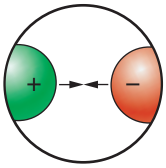

Figure 5 The atoms that form the particles of a compound are held together by the electrical attraction of positive and negative charges.

The revised theory explained how atoms formed compounds, but scientists still did not know how the atoms became charged.

In the late 1800s, the discovery of a particle that is many times smaller than the smallest atom required another major change to the atomic theory. This particle, the negatively-charged **electron**, was discovered by J.J. Thomson in 1898. Thomson proposed that the atom is mostly made up of positively-charged matter, with small negatively charged electrons scattered randomly throughout. By 1904 Thomson's "raisin-bun" model became accepted by most scientists (Figure 6). The atomic theory was once again revised, to include these ideas:

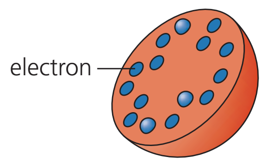

Figure 6 Thomson's "raisin-bun" model of an atom

LEARNING TIP

Explain to a partner (using the key terms from page 204 to 207—atom, electron, nucleus, protons, and neutrons) how the atomic theory has changed with new discoveries.

Thomson's Revision to the Atomic Theory: Electrons

- Atoms contain electrons.
- The electrons have a negative charge and a very small mass.
- The rest of the atom has a positive charge.
- The electrons are embedded randomly in the positive part of the atom.
- Electrons can be removed from, or added to, atoms to create charged atoms.

Did You KNOW?

Cathode Ray Tube

Thomson used a device called a cathode ray tube (CRT) to measure the properties of electrons. The CRT is the basis for older televisions and computer monitors.

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The Theory Is Changed to Explain the Nucleus

In the Try This activity at the beginning of this section, you used small, light table-tennis balls to probe the structure and organization of the space around you. A similar technique was used by Ernest Rutherford to probe the structure of an atom. Working first at McGill University in Montreal, then at Cambridge University in England, Rutherford bombarded a very thin piece of gold foil (only a few atoms thick) with small, positively charged particles. Expecting most of the particles to be deflected slightly by the gold atoms (as predicted by Thomson's revision to the atomic theory), he was shocked to discover that most of the particles passed straight through as if passing through empty space. Moreover, a few particles bounced straight back. Based on this evidence, Rutherford concluded that almost all the matter in an atom is concentrated in a very small space (Figure 7).

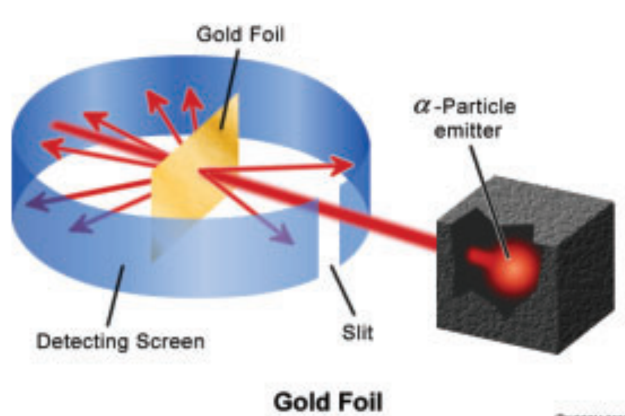


Figure 7 Rutherford's experiment showed that most of the particles fired at the gold atoms passed straight through. Some particles bounced back as if they had struck something of great mass, but very small, with a large positive charge. Rutherford had discovered the nucleus.

This dramatic and unexpected result required a significant change in how scientists viewed the atom. Rutherford reasoned that most of the mass of an atom, and all the positive charge, is concentrated in the centre. This location is called the **nucleus**, and it contains two types of particles: positively charged **protons** and uncharged **neutrons**. The remaining mass, and all the negative charge, is made up of electrons orbiting the nucleus. The electrons are held in orbit by the attraction between charged objects. Thus, there are three **subatomic particles**: electrons, protons, and neutrons. In 1911, Rutherford proposed his nuclear model of the atom (Figure 8). GO

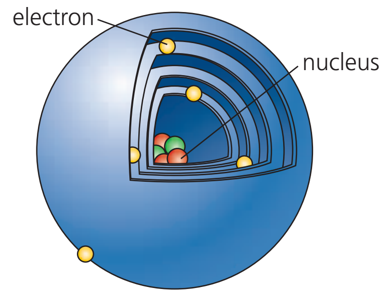


Figure 8 Rutherford's "nuclear" model of the atom

If you would like to learn more about the science and history behind the discoveries that changed the atomic theory, go to **www.science.nelson.com** GO

Rutherford's Revisions to the Atomic Theory: The Nucleus

- The nucleus contains all of the positive charge and most of the mass of the atom.
- The nucleus contains positively charged protons and uncharged neutrons.
- Neutrons have the same mass as protons.
- The nucleus is very small, compared with the size of the atom.
- The electrons orbit the nucleus, like satellites around a planet.
- The mass of an electron is $\frac{1}{1800}$ the mass of a proton.
- The size of the atom is determined by the size of the orbit of the electrons.
- There is only empty space between the electrons and the nucleus.

When Rutherford published his theory, he already knew it was not completely correct. A well-established theory of electromagnetic waves predicted that Rutherford's orbiting electrons should continuously emit energy, which they do not. Atomic theory required a further modification.

Did You KNOW?

Visualizing the Atom

The size of an atom is hard for us to understand, because we don't have the ability to observe it directly. We can, however, imagine the scale of an atom by comparing an atom with something we can see.

- If a hydrogen atom was the size of an apple, then a real apple would be as large as Earth.
- If the nucleus in an atom was the size of a golf ball, the electrons of the atom would be more than one kilometre away and the size of a grain of sand.

TRY THIS: *Building an Atom*

Skills Focus: creating models, communicating

You can demonstrate your understanding of the three atomic theories presented in this section using household materials.

Possible Materials: table-tennis balls, small styrofoam balls, foam packing peanuts, or candies (for an edible model!); hot glue, putty, or cake icing; string, wooden skewers, or toothpicks

Use extreme caution when working with hot glue. Hot glue can cause severe burns.

1. Using a variety of household objects and your creativity, build three models of an atom, based on the theories of Dalton, Thomson, and Rutherford.

A. Write a paragraph that describes the main differences between your three models.

7.1 CHECK YOUR Understanding

1. Who was the first person to propose that matter is made of atoms?
2. Describe the physical appearance of an atom according to each of the following scientists.
   (a) Dalton
   (b) Thomson
   (c) Rutherford
3. (a) What are the main points of Dalton's theory?
   (b) Which of these main points were unchanged in the later theories?
4. (a) What did Michael Faraday discover that led to changes in Dalton's atomic theory?
   (b) What were these changes?
5. Who first proposed each of the following in the development of the atomic theory?
   (a) Atoms cannot be created, destroyed, or subdivided.
   (b) The atom has a nucleus that contains most of the mass and all of the positive charge.
   (c) Small negative particles are spread throughout a positive mass.
   (d) Atoms contain electrons and protons.
   (e) Atoms can become charged.
6. What did Thomson discover and use as the basis of his revision of the atomic theory?
7. Why is Thomson's model of the atom referred to as the "raisin-bun model?"
8. What unexpected result did Rutherford obtain in his gold-foil experiment?
9. Why did Rutherford know that his model would need to be modified right away?
10. What is found between the electrons and the nucleus in an atom (Figure 9)?

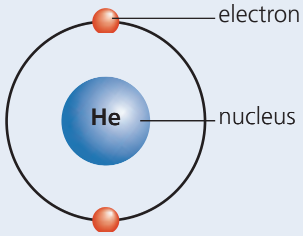


Figure 9

11. According to Rutherford's theory, how do we determine the size of an atom?
12. Neutrons have no charge. What do they contribute to the atom?
13. Look at the three objects below (Figure 10). Each object could be considered a model for one of the versions of the atomic theory.
    (a) Indicate which version of the atomic theory (Dalton, Thomson, Rutherford) matches each object.
    (b) Use one or two sentences to describe how the features of the object match the theory.

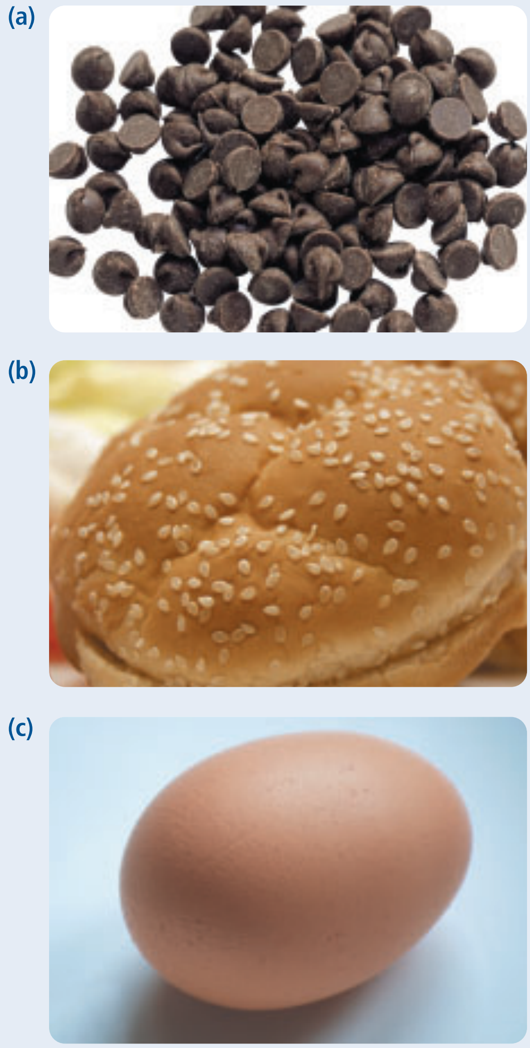


Figure 10 (a) chocolate chips (b) hamburger bun with seeds (c) an egg

7.2 Bohr's Theory of the Atom

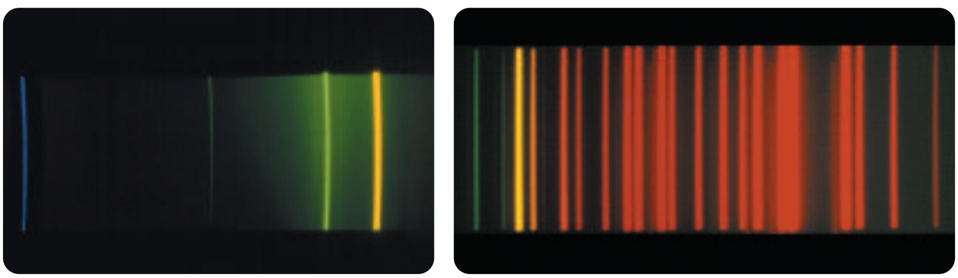
Have you ever seen the light given off by a neon sign? It is a vibrant, orange-red colour. If the tubes of a sign are filled with a gas other than neon, the colour is different. When atoms absorb electrical or heat energy, they can re-emit the energy as light. Each element emits a very specific pattern of wavelengths, or colours, of light. This pattern is called the **emission spectrum** of the element (Figure 1). You can see the emission spectrum of an element in the light given off when the element is heated in a flame. Rutherford's former student and colleague, Niels Bohr, used this property of elements, as well as discoveries by other scientists of the time, to solve the problems with Rutherford's model of the atom. 7A *Investigation*

7A *Investigation*

Flame Colours

To perform this investigation, turn to page 224.

In this investigation, you will observe different flame colours from different elements, and then identify an element from its flame colour.



(a) (b)

Figure 1 The light emission spectrum of mercury (a) is different than that of neon (b).

Bohr's Contribution to the Atomic Theory

Albert Einstein had shown that atoms can only absorb or emit light energy in specific amounts. Bohr used this observation to explain why the electrons orbiting the nucleus do not continuously give off energy. He proposed a theory of the atom in which the electrons are restricted to specific "allowed" orbits, or **shells** as they are now called, around the nucleus (Figure 2), much like the planets have specific orbits around the Sun. The amount of energy an electron has is related to how far it is from the nucleus. Each element has a unique pattern of light emission because it has a unique separation of its allowed electron shells (orbits).

While within a single shell, an electron does not emit energy. Atoms only emit or absorb light energy when their electrons "jump" between shells. Bohr's ideas about the structure of the atom are listed below:

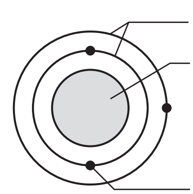
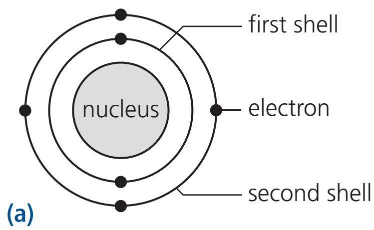


Figure 2 Bohr's model of the atom restricts electrons to specific shells around the nucleus.

Bohr's Revisions to the Atomic Theory: Electrons in Specific Orbits

- Electrons are located in defined shells, which are located certain distances from the nucleus.
- Electrons cannot exist between the defined shells.
- Electrons can gain energy to move up to a higher shell, or they can lose energy to move down to a lower shell.
- Electrons are more stable (have less energy) when they are closer to the nucleus.



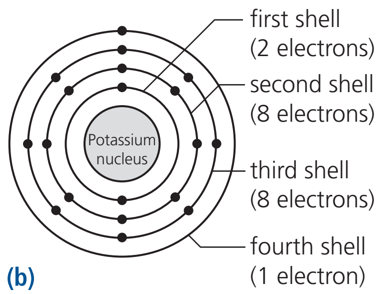


Figure 3 The number of shells (orbits) in an atom depends on the number of electrons in the atom

If you would like to learn more about the atomic theory of matter, go to **www.science.nelson.com** GO

The Atomic Theory of Matter

The development of the atomic theory required new technologies and discoveries to be made in order for it to advance. In the 1920s and later, the atomic theory was again modified as more discoveries were made about the behaviour of electrons in atoms. There are a maximum number of electrons that can occupy any one shell. The first shell can only contain a maximum of two electrons, and the second shell can contain a maximum of eight. The electrons fill the shells starting with the first or innermost shell and work outward. For example, an element with six electrons has two electrons in the first shell and four electrons in the second (Figure 3(a)).

The Number of Shells for an Element

The number of shells that an element will need is related to which row of the Periodic Table it is found in. First-row elements have electrons in the first shell. Second-row elements have electrons in the first and second shells. Third-row elements have electrons in the first, second, and third shells, and so on. For the first 20 elements, the third shell can only contain a maximum of eight electrons. Therefore potassium, in the fourth row, has one electron in its fourth shell (Figure 3(b)). Calcium will have two electrons in its fourth shell. (For elements beyond number 20, the arrangement of the electrons becomes more complicated.) As you will learn in Chapter 8, it is the arrangement of the electrons that determines the characteristics and chemical behaviour of an element.

To summarize, the atomic theory we will use is as follows: GO

The Atomic Theory of Matter

- All matter is made of atoms.
- Atoms are the smallest pieces of an element.
- Elements combine to form compounds. The atoms in the compound are held together by electrical attractions.
- An atom is composed of a nucleus surrounded by electrons.
- The nucleus is composed of positively charged protons and uncharged neutrons.
- All the atoms of an element have the same unique number of protons.
- All the nucleus contains most of the mass of the atom and all of the positive charge.
- There is only empty space between the electrons and the nucleus.
- Electrons have a negative charge and very little mass.
- Electrons orbit the nucleus only in specific, allowed shells.
- For the first 20 elements, the first shell contains a maximum of two electrons, the second shell contains a maximum of eight electrons, and the third shell contains a maximum of eight electrons.
- Electrons absorb or emit specific amounts of energy to change shells.

Standard Atomic Notation

As described earlier, elements give off an emission spectrum when energized. The light emitted is visible light, ultraviolet light, and X-ray energy (all are part of the electromagnetic spectrum). In 1913, Henry Moseley studied the X-ray part of the emission spectra of elements, and noted that a characteristic energy peak increased by one unit for each element in order of increasing atomic mass, with a few exceptions. (You will learn more about atomic mass in the next section.) Thus, the elements could each be given a specific number, called the **atomic number**. Scientists now know that the atomic number is the number of protons in the nucleus. The Periodic Law can now be stated as: *The properties of the elements are a periodic or regularly repeating function of their atomic number.* It is the atomic number (not the atomic mass) that determines the order of the elements in the modern Periodic Table.

The total number of protons and neutrons in the nucleus of an atom is called the **mass number**. The mass number of an element is often written after the element name, as in chlorine-35. The mass number, along with the chemical symbol for an element and the atomic number, can also be written in standard atomic notation (Figure 4). Like the symbols for the elements, standard atomic notation allows scientists to communicate and share their ideas efficiently.

LEARNING TIP

What does Figure 4 tell you? Atomic number is the number of protons in the nucleus of an atom. What is the atomic number for chlorine? An element's mass number is the number of protons and neutrons in its atom. What is the mass number for chorine? What is the symbol for chlorine?

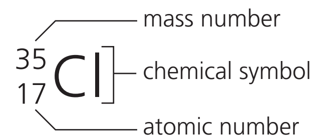


Figure 4 The standard notation for chlorine

Standard Notation for Ions

Normally, an atom has the same number of electrons as protons. Chlorine, atomic number 17, normally has 17 electrons. An atom obtains a charge when electrons are either added or removed. For example, heating a metal drives off electrons from the metal atoms, and friction between a piece of wool and vinyl plastic transfers electrons to the vinyl from the wool.

When an atom becomes charged, there are more or fewer electrons than protons in the atom. A charged atom is called an **ion**. When there are more electrons than protons, the atom has a negative charge and is called a **negative ion**. When there are fewer electrons than protons, the atom has a positive charge and is called a **positive ion**. For example, if there are 2 fewer electrons than protons, the ion has a charge of 2+. If there are 3 more electrons than protons, the ion has a charge of 3−. The charge of an ion, whether positive or negative, is called the **ion charge**. In standard atomic notation the ion charge is written above and to the right of the symbol (Figure 5). If the charge is 1+ or 1−, the "1" is not usually written. It is important to note that, when an atom becomes charged, the number of protons in the atom does not change. The ion charge is due *only* to a change in the number of electrons in the atom.

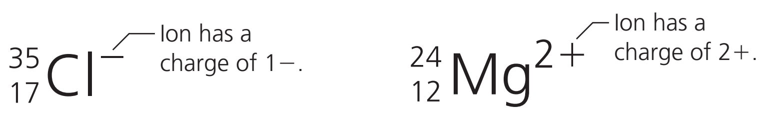


Figure 5 The standard notations for a chlorine ion and a magnesium ion

7.2 CHECK YOUR Understanding

1. Explain how each of the following differs in Bohr's model and Rutherford's model of the atom.
   (a) the location of electrons
   (b) the energy of electrons
2. In Bohr's model of the atom, how many electrons occupy the first shell. How many electrons occupy the second shell and the third shell?
3. Refer back to sections 7.1 and 7.2 and complete Table 1:

Table 1

Particle	Charge	Mass (relative to proton)	Location
proton			
neutron			
electron			

4. Explain why different elements produce different colours when heated in a flame.
5. Write the following elements in standard notation.
   (a) bromine-80; atomic number 35
   (b) calcium-40; atomic number 20
   (c) carbon-14; atomic number 6
   (d) nitrogen-15; atomic number 7
   (e) sodium-20; atomic number 11
   (f) neon-20; atomic number 10
   (g) gold-179; atomic number 79
   (h) uranium-238; atomic number 92
   (i) polonium-210; atomic number 84
6. Write the following ions in standard notation.
   (a) sodium-23; charge of 1+; atomic number 19
   (b) sulfur-32; charge of 2−; atomic number 16
   (c) calcium-40; charge of 2+; atomic number 20
   (d) silver-108; charge of 1+; atomic number 47
   (e) tin-119; charge of 2+; atomic number 50
   (f) gold-179; charge of 3+; atomic number 79
   (g) tin-119; charge of 4+; atomic number 50
   (h) oxygen-16; charge of 2−; atomic number 8
   (i) nitrogen-14; charge of 3−; atomic number 7
7. If an atom contains eight electrons, how many electrons are in each of the first two shells? Explain.
8. Calcium is an element in the fourth row of the Periodic Table.
   (a) How many shells does it have?
   (b) How many electrons does it have in each shell?
9. How many shells would an element in the sixth row of the Periodic Table have?
10. A sample element, E, has 14 protons and 15 neutrons. It has no charge.
    (a) What is its atomic number?
    (b) What is its mass number?
    (c) How many electrons does it have?
    (d) Write the standard notation for the element.
11. A sample element, X, has 17 protons and 18 electrons. The mass number is 35.
    (a) What is the charge?
    (b) Write the standard notation for this element.
12. What property of elements did Bohr use to revise the Rutherford theory of the atom?
13. Electrons in different orbits are similar to balls sitting on different steps of a staircase. A ball on a higher step has more energy than a ball on a lower step. An electron orbiting a nucleus farther away (a higher shell) has more energy than an electron orbiting closer (a lower shell). If an electron "jumped down" to a lower shell, would the atom be absorbing energy or emitting energy (Figure 6)? Explain.

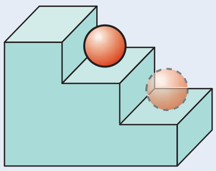


Figure 6

LASERS SHED LIGHT ON CANCER

Scientists are problem solvers who combine knowledge from a variety of fields to reach a solution. Physicists, chemists, physicians, and biochemists are currently working together on an innovative technique for detecting cancer in its early stages.

Laser medicine is being combined with spectroscopy to measure the amount of hemoglobin (the molecule in blood that carries oxygen) in the mucous membrane of skin. Spectroscopy is a technique used by chemists to identify substances by the spectrum of light they absorb or emit. Each element has a characteristic spectrum based on its atomic structure. Similarly, each compound has an emission pattern that is a combination of the light emissions from the interactions of all the atoms that make up the compound. In the human body, hemoglobin is an essential biological compound that is used for diagnosis because of its distinct spectroscopic pattern.

Researchers shine laser light at the mucous membrane of a suspected cancer patient and analyze the pattern (Figure 1). As light is reflected off the hemoglobin molecules in the patient's blood, it creates a pattern of bright and dark bands similar to the emission spectrum of hemoglobin. This gives physicians a very accurate measurement of hemoglobin levels in the tissue. This, in turn, is a reflection of the number of small blood vessels present in the skin of the patient (Figure 2).

The change in blood delivery to an area is thought to indicate cancer because tumour cells need more nutrients to support rapid growth. Researchers know that cancer cells send out chemical signals to stimulate blood vessel growth before there is any detectable tumour. Therefore, if increased blood vessel growth can be detected before the tumour develops, the cancer has a better chance of being successfully treated.

This interesting technique has a lot of potential as a non-invasive diagnostic tool in the fight against cancer. The application of spectroscopy to medicine is an excellent example of the interconnected nature of the sciences (such as biology, physics, and chemistry) and demonstrates the importance of science in our lives.

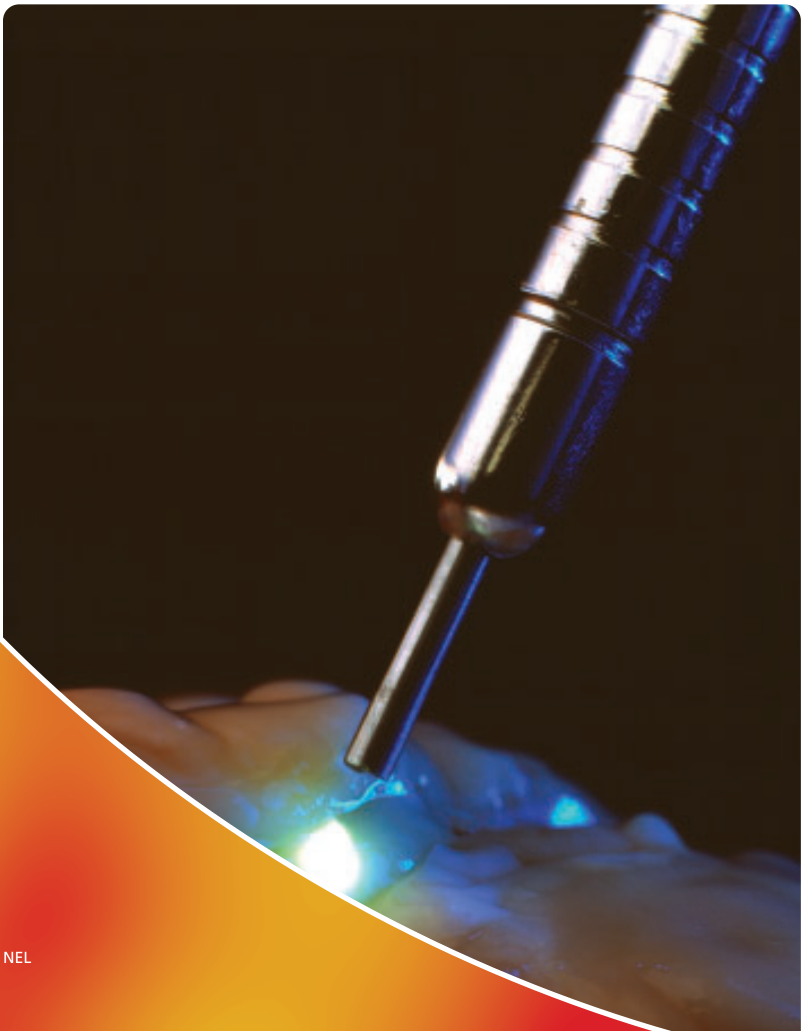


Figure 1 A fibre-optic probe, placed on the patient's tissue, is used to measure the spectrum of the tissue.

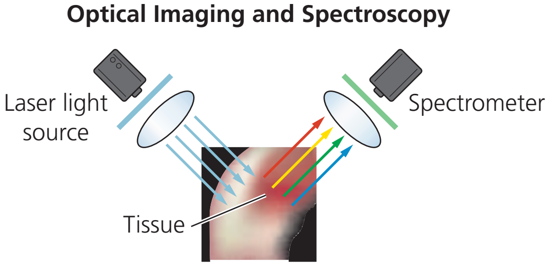


Figure 2 A light source is used to illuminate the tissue being examined. The spectrum of the resulting light is then measured.

7.3 The Modern Periodic Table

There are many different ways that scientists can classify the elements. One way is to separate them by their physical properties into metals, metalloids, and non-metals. As you have learned, in general, most metals conduct electricity, have a shiny lustre, and are malleable and ductile. Most non-metals do not conduct electricity, do not have a shiny lustre, and are gases at room temperature or brittle if solid. Metalloids have some of the properties of metals and some of the properties of non-metals. In the Periodic Table in Figure 1, the metal elements are shaded blue, the non-metal elements are shaded pink, and the metalloid elements are shaded green.

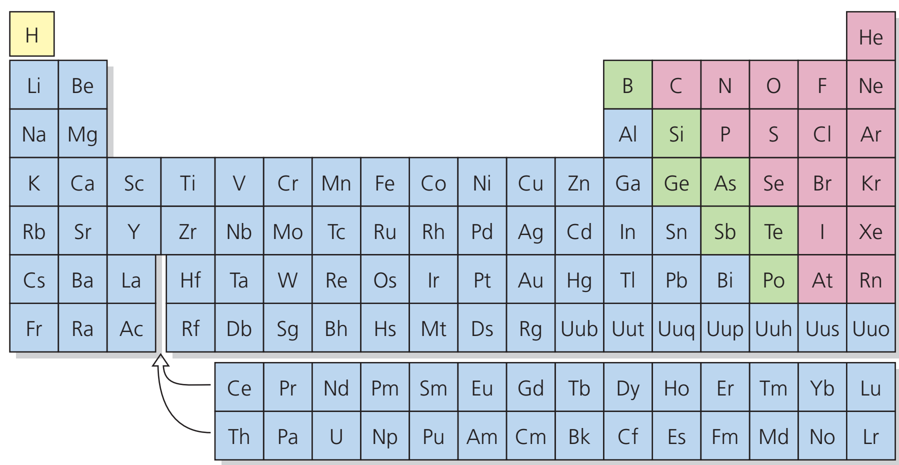


Figure 1 Periodic Table showing metal (blue), non-metal (pink), and metalloid elements (green)

LEARNING TIP

What does Figure 2 tell you? Try reading the Periodic Table up and down (in columns), rather than left to right (in rows). Ask yourself, "How many groups are there? How are the elements in each group like members of a family?"

Another way to classify the elements is by family, based on common physical and chemical properties. The Periodic Table in Figure 2 shows the major families highlighted in different colours. A third way to classify the elements is by group. The groups are the columns in the Periodic Table, and are numbered from 1 to 18, starting at the left.

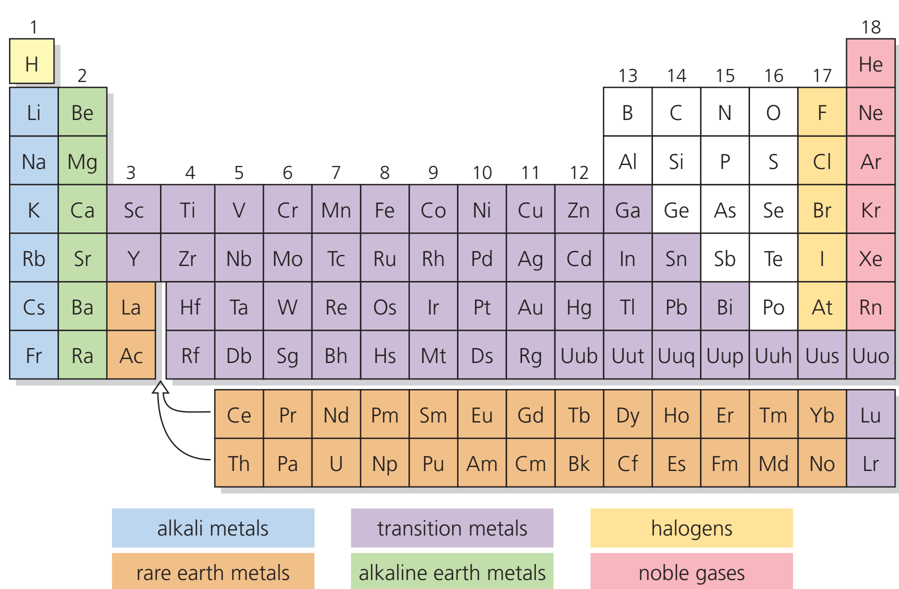


Figure 2 Periodic Table showing major families of elements and group numbers

The elements can also be classified according to their ion charges, atomic number, or electron arrangement. The modern Periodic Table, based on Mendeleev's design, allows us to include all of these classifications in one model. It is a model that chemists use to explain and predict the chemical and physical behaviour of the elements.

Finding Information in the Periodic Table

Examine the following sample entry below from the Periodic Table (Figure 3). Note the location of the element name, chemical symbol, atomic number, ion charge, and atomic mass.

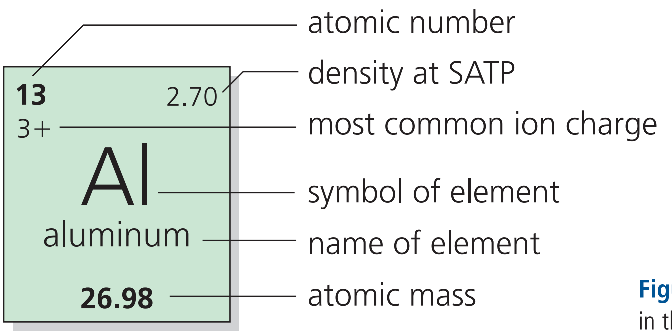


Figure 3 The entry for aluminum in the Periodic Table

LEARNING TIP
Check your understanding. Examine Figure 3 closely. Then cover the labels. What vital information can you learn from Figure 3? Identify the element's name, symbol, atomic number, ion charge, and atomic mass.

What do the different parts of the entry tell you? The element name and chemical symbol tell you that Al is the chemical symbol for aluminum. The atomic number tells you the number of protons in the nucleus of the atom (13). Since the number of electrons in a neutral atom is equal to the number of protons, the atomic number also tells you the number of electrons. The ion charge of 3+ tells you that the aluminum atom will form an ion that has 3 fewer electrons than protons.

Unlike the mass number, the atomic mass is not an integer. Many elements have more than one isotope—an atom with the same number of protons, but a different number of neutrons. Therefore, the mass numbers of isotopes are different, but the atomic numbers are the same. GO

To learn more about isotopes, go to **www.science.nelson.com** GO

The **atomic mass** of an element is the average of the mass numbers of all the naturally occurring isotopes. The mass number is the mass of one particular isotope of an element. You can determine the mass number of the most common form of an element by rounding the atomic mass to the nearest whole number. The mass number of the most common form of aluminum is 27 (26.98 rounded up), so the number of neutrons in the most common form of the element is 14.

Did You KNOW?

Mass of Ions

The mass spectrometer is used to measure the mass of ions using electric and magnetic fields. Thomson's student, Francis Aston, constructed the first mass spectrometer in 1919 and used it (and later versions) to identify 212 of the 287 naturally occurring isotopes.

Calculating the Number of Electrons in an Ion

The number of protons in the nucleus of an atom does not change when the atom forms an ion—only the number of electrons orbiting the nucleus can change. Aluminum's atomic number is 13, so its atoms have 13 protons. Aluminum's ion charge is 3+. Therefore, an atom of aluminum has 13 electrons. An ion of aluminum will have only 10 electrons, 3 *fewer* electrons than protons. Oxygen's atomic number is 8, and its ion charge is 2−. Oxygen atoms have 8 electrons, but oxygen ions have 2 *more* electrons than protons or 10 electrons.

The size of the ion charge tells you the difference between the number of protons and the number of electrons in the ion. The + or − sign tells you if there are fewer (+) or more (−) electrons than protons (Table 1).

Table 1 Examples of Atoms and Ions

Element	Atomic number	Number of electrons in the atom	Ion charge	Number of electrons in the ion
aluminum	13	13	3+	10
oxygen	8	8	2−	10
sodium	11	11	1+	10
phosphorous	15	15	3−	18

LEARNING TIP

Check your understanding. Work with a partner to answer the questions in the paragraph on the right.

Examine the Periodic Table at the back of the book. Can you find any other patterns in the way that information about the elements is presented? How are metals and non-metals indicated? How does ion charge change across a row or down a column? How do atomic mass and atomic number change across rows or down columns?

TRY THIS: Atoms and Ions

Skills Focus: recording, analyzing, interpreting data

You can find out a lot about an element from the Periodic Table. In this activity, you will organize the information about the first 20 elements in the Periodic Table.

1. Copy Table 2 into your notebook. Refer to the Periodic Table at the back of the book, and complete your table for the first 20 elements. Note that the elements in Group 18 usually do not form ions.

Table 2

Atomic number	Element name	Ion charge	Number of protons	Number of electrons for atom	Number of electrons for ion
1	hydrogen	1+	1	1	0
2	helium	0	2	2	does not form an ion
19	potassium				
20	calcium				

A. Do you see a pattern in the number of electrons in the ions of elements? Explain the pattern.

7.3 CHECK YOUR Understanding

Refer to the modern Periodic Table at the back of the book to answer questions 1 to 9.

1. Where on the Periodic Table are the elements that form ions with a positive charge?
2. Where are the metals?
3. Where are the elements that form ions with a negative charge?
4. Where are the non-metals?
5. Where are the metalloids?
6. What shape does the arrangement of the metalloids form in the Periodic Table?
7. Starting from carbon, what happens to the ion charge as you move to the right?
8. Starting from carbon, what happens to the ion charge as you move to the left?
9. As you move to the right, and down, what happens to the atomic mass and the atomic number? Are there any exceptions to your answers?
10. What is the relationship between the number of protons in the nucleus of an atom and the atomic number of the element?
11. Describe how to determine the number of electrons in the atom of an element.
12. Describe how to determine the number of electrons in the ion of an element.
13. A certain element has 12 protons and 14 electrons.
    (a) Is the element an atom or an ion?
    (b) Which element is it?
    (c) What charge, if any, does it have?
14. A certain element has 34 protons and 36 electrons.
    (a) Is the element an atom or an ion?
    (b) Which element is it?
    (c) What charge, if any, does it have?
15. A certain element has 24 protons and a charge of 3+.
    (a) Is the element an atom or an ion?
    (b) How many electrons does the element have in this form?
    (c) Which element is it?
16. Look at the Periodic Table entry for sulfur in Figure 4.

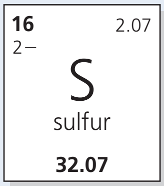


Figure 4

    (a) What is the atomic number?
    (b) What is the atomic mass?
    (c) What is the ion charge?
    (d) How many electrons does the sulfur atom have?
    (e) How many electrons does the sulfur ion have?
17. Look at the Periodic Table entry for calcium in Figure 5.

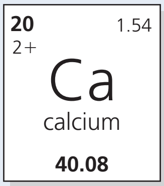


Figure 5

    (a) What is the atomic number?
    (b) What is the atomic mass?
    (c) What is the ion charge?
    (d) How many electrons does the calcium atom have?
    (e) How many electrons does the calcium ion have?
18. Look up each of the following elements in the Periodic Table, list its atomic number and atomic mass, and state if it is a metal, non-metal, or metalloid.
    (a) tellurium
    (b) osmium
    (c) arsenic
    (d) yttrium
    (e) manganese
    (f) silicon
    (g) phosphorous

7.4 Using the Bohr Theory

LEARNING TIP

Models such as Figures 1 to 4, on pages 218 and 219, help you visualize scientific explanations. As you examine Figures 1 to 4, look back and forth between the diagrams and the related information in the text to ensure you understand the information in the figures.

For many years, chemists determined through experiments the amounts of substances that go into reactions and the amounts of substances that are produced. They learned, for example, that the compound zinc iodide always contained two atoms of iodine for every one atom of zinc. Through experiments chemists also determined the ion charges of the elements.

The Periodic Table gave scientists a tool to model the behaviour of elements during reactions and to make predictions about the compounds that can be formed from specific elements. This is because the Periodic Table is arranged according to properties, and elements with similar chemical properties are grouped vertically. The way that one member of a chemical group reacts with other substances will likely be repeated for any other member of this group. For example, iodine and chlorine are in the same group. How many atoms of each element would you expect the compound zinc chloride (the compound formed from zinc and chlorine) to have? Zinc chloride has two atoms of chlorine for every one atom of zinc.

The arrangement of elements in the Periodic Table agreed with Dalton's, Thomson's, and Rutherford's theories of the atom, and it also works for Bohr's theory.

Did You KNOW?

A Prize Winning Theory

Niels Bohr received the Nobel Prize in Physics in 1922 for his work on atomic theory. His son Aage Bohr also won the Nobel Prize in Physics in 1975 for his work on the structure of the nucleus.

Using the Bohr Theory to Describe Atoms and Ions

Recall that Bohr's theory of the atom places protons and neutrons in the nucleus of the atom, and electrons around the nucleus in specific shells. There is a maximum number of electrons that can occupy each shell. The first shell can contain a maximum of two electrons, and the second and third shells can contain a maximum of eight electrons. (This is true only for the first 20 elements.) The outermost shell is involved in chemical reactions. What happens in chemical reactions can be shown using a model of Bohr's atoms.

Bohr Diagrams

You can draw models called **Bohr diagrams** to help you to visualize the arrangement of electrons in different atoms. Bohr diagrams help to explain the mechanism by which elements combine to form compounds. Bohr diagrams are a series of concentric rings (the shells) around a nucleus, with electrons shown as dots on the rings. Figure 1 shows the Bohr diagram for phosphorous. Inside the nucleus is the chemical symbol for phosphorous, P. The number of protons and neutrons are often written in the centre, but this is not strictly necessary for a Bohr diagram.

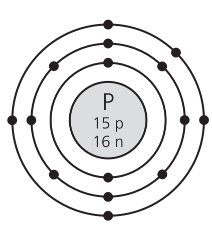


Figure 1 The Bohr diagram for phosphorous

Phosphorous has a full first shell (two electrons), a full second shell (eight electrons), and five electrons occupying the third shell. When an atom forms an ion, it either acquires extra electrons and becomes negatively charged, or gives up electrons and becomes positively charged. Phosphorous contains five electrons in its outer shell, so there is room for up to three more. Therefore, for phosphorous to form an ion, it has to acquire three extra electrons (Figure 2).

Experimentation has determined that phosphorous has an ion charge of 3−, which corresponds to the 3 "vacancies" available in its outer shell, as shown in the Bohr diagram.

You can use Bohr diagrams to show ions as well. The phosphorous ion is shown in Figure 3. The outer shell is now fully occupied with the three extra electrons. Metal elements tend to give up electrons when they form ions, as shown in the Bohr diagrams for the magnesium atom and ion (Figure 4).

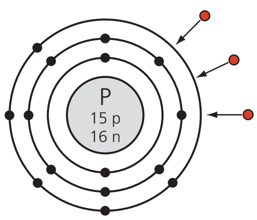


Figure 2 This phosphorous atom is acquiring three electrons to fill its outer shell and form an ion.

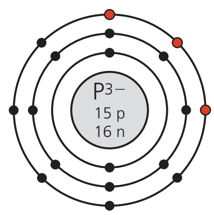


Figure 3 The Bohr diagram for the phosphorous ion, showing the full outer shell. Can you determine the charge of this ion from the diagram?

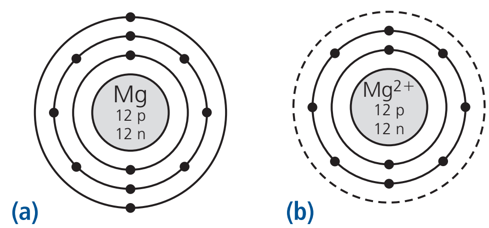


Figure 4 The Bohr diagrams for the magnesium atom (a) and the magnesium ion (b). The magnesium ion has lost two electrons, and now has a full outer shell. The third shell is empty. Higher, empty shells are ignored when drawing Bohr diagrams.

TRY THIS: *Drawing Bohr Diagrams*

Skills Focus: creating models, inferring, interpreting data

Materials: blank paper or prepared Bohr diagram templates; Periodic Table

In this activity, you will draw the Bohr diagrams for the atoms of the first 20 elements using information from the Periodic Table.

1. Draw a Bohr diagram for each of the first 20 elements, hydrogen through calcium.
2. Below each diagram, write the number of electrons in the outer shell.
3. Write the ion charge of the element above each diagram. Figure 5 shows a sample for magnesium.

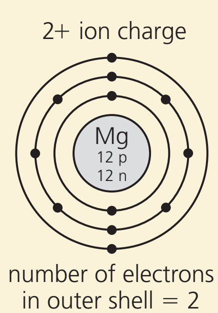


Figure 5

A. For the metal elements, what is the relationship between the ion charge and the number of electrons in the outer shell?

B. For the non-metal elements, what is the relationship between the ion charge and the number of electrons in the outer shell?

C. Compare the number of vacancies, or empty spaces, in the outer shell of the non-metals with the ion charges. What is the relationship?

D. How many electrons are in the outer shell of the elements Li and Na in Group 1?

E. How many vacancies are in the outer shell of the elements F and Cl in Group 17?

F. Is there a pattern between the number of electrons in the outer shell of an element and its position along the row in the Periodic Table? If so, what is the pattern?

G. How many shells are needed for the elements in each of the first four rows of the Periodic Table?

When ions are formed, they will have a full outer shell. Consider one of the Group 18 elements, like neon. It has 10 protons, and therefore its atom has 10 electrons. Two of these occupy the first shell, and the remaining eight electrons fully occupy the second shell. With a fully occupied outer shell as an atom, neon cannot acquire or give up electrons and retain a full outer shell. Do you think this explains why elements in Group 18 have an ion charge of 0 in the Periodic Table? GO

To see Bohr diagrams for more elements and ions, go to **www.science.nelson.com** GO

The Bohr Theory and Reactivity

The two most reactive chemical groups are Group 1 (1st column of the Periodic Table) and Group 17 (17th column). The least reactive chemical group is Group 18. The Bohr diagrams for these groups show that the Group 1 metals have only a single outer electron, the Group 17 non-metals have only a single vacancy in their outer shells, and the Group 18 non-metals have a full outer shell (Figure 6). The Group 1 elements are the most reactive metals because their single outer electron is easily given up. The Group 17 elements are the most reactive non-metals because they easily acquire one more electron to fill their outer shells completely. The Group 18 elements are non-reactive because their outer shells are full.

LEARNING TIP

Check your understanding. How does Bohr's theory help to explain the placement of the elements in the Periodic Table?

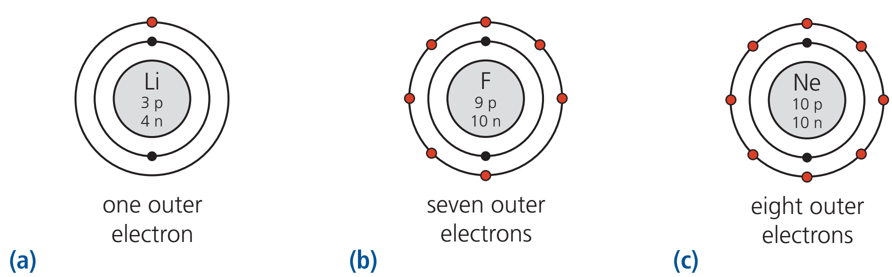


Figure 6 The reactivity of elements is determined by the number of electrons in their outer shells. Both (a) lithium (Li) and (b) fluorine (F) are very reactive, but (c) neon (Ne) has very low reactivity.

Using the Bohr Theory to Predict the Composition of Compounds

In the Try This activity, you saw that the outer shells of all the elements in a chemical group are similar. For example, lithium and sodium have a different number of electrons and a different number of shells. Both, however, have a single electron in the outer shell of their atoms. Similarly, fluorine and chlorine both have seven electrons in their outer shells (and, therefore, only one vacancy each). For most of the chemical groups, all the elements have the same number of electrons in their outer shells (Figure 7). For the first 20 elements in the Periodic Table, the number of electrons in the outer shell of an atom determines in which column (and group) the element appears in.

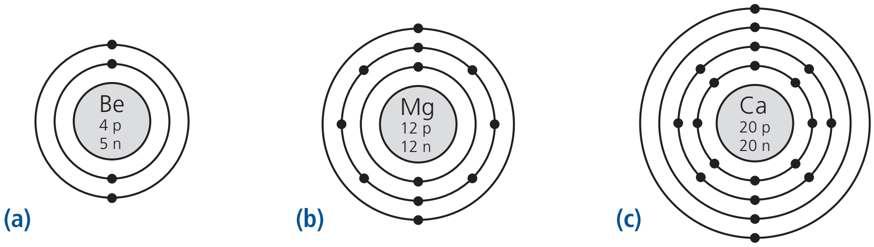


Figure 7 The Bohr diagrams for three of the Group 2 elements—(a) beryllium (Be), (b) magnesium (Mg), and (c) calcium (Ca). Note that there are two outer electrons for each atom.

All members of a chemical group react with other substances in a similar manner. It would seem that the number of electrons in the outer shell is important to the way that an element reacts. It is this interaction between the outer electrons of elements that drives all chemical reactions.

Ionic Compounds

When a metal atom reacts with a non-metal atom, they form an **ionic compound**. Consider the collision of an atom of fluorine with an atom of lithium. Lithium has a single electron in its outer shell. Fluorine has a single vacancy in its outer shell. During the collision, the lithium atom gives up its outer electron (to empty its outer shell), and the fluorine atom captures this electron (to fill its outer shell). Lithium, having lost an electron, becomes a positive ion, and fluorine, having gained an electron, becomes a negative ion. The pair of oppositely charged ions are held together by the electrostatic force that exists between charged objects. This process of **electron transfer** between metals and non-metals is what creates an **ionic bond**—metal ions joined to non-metal ions. The bonded lithium and fluorine ions form the compound lithium fluoride (LiF). Figure 8 illustrates the process of electron transfer between the metal and non-metal. 7B *Investigation*

Ionic Compounds and Molecular Compounds

Compounds can be classified as either ionic compounds or molecular compounds. Molecular compounds are composed of **molecules**; two or more atoms joined together to form the smallest particle that has the same properties as the compound. Molecular compounds are usually formed from a collection of non-metal atoms, such as hydrogen and oxygen (water) and nitrogen and oxygen (nitrogen dioxide). The bond between atoms in molecules is not due to electron transfer, but to the sharing of electrons in the outer shells of the atoms. This is called a covalent bond.

Strictly speaking, ionic compounds do not have discrete molecules. The description of electron transfer above is a simplified version of the process that leads to the formation of positive and negative ions. In a real chemical reaction, an extremely large number of both positive and negative ions are formed at once. The ionic compound formed is, in reality, a collection of positive and negative ions that occupy the same space. When in solid form,

LEARNING TIP

Try to work out your own explanation of how lithium fluoride is formed. Read the paragraph a few sentences at a time, translate the meaning of the sentences into your own words, and create a picture in your head.

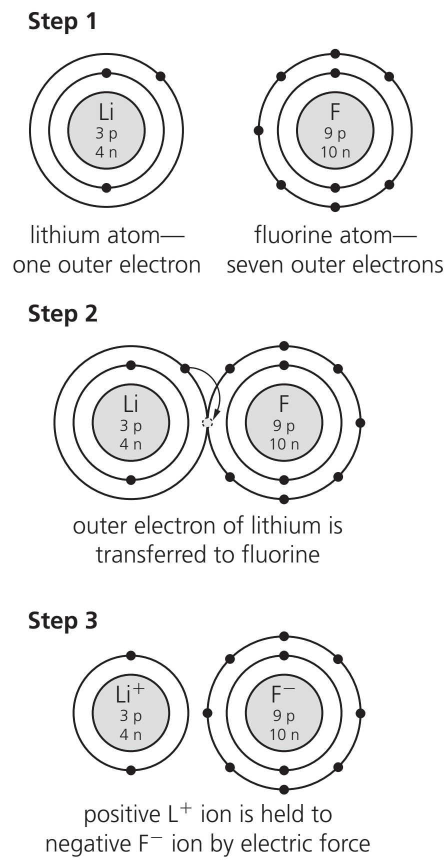


Figure 8 The formation of the ions of lithium and fluorine, and the compound LiF

7B ***Investigation***

Ions and Atoms

To perform this investigation, turn to page 226.

In this investigation, you will explore the differences in the properties of an atom and its ion.

the negative and positive ions collect and arrange themselves in a specific structure, forming a crystal. Each positive ion is attracted to several negative ions and repels the other positive ions. Each negative ion is attracted to positive ions, and repels the other negative ions. You can see a similar behaviour when several small compasses are placed near each other (Figure 9).

When dissolved in a solution, or in the liquid or gaseous state, the individual ions move about freely, independent of other ions. There is no definite grouping of atoms that could be considered molecules of the compound. In contrast, in liquid water for example, the three atoms of H_2O move around together as a unit. The water molecules may move past each other, but the three atoms stay together.

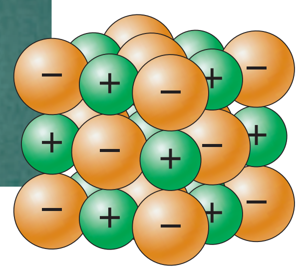


Figure 9 The compass needles show a particular pattern in how they align. The positive and negative ions in the ionic compound, NaCl (sodium chloride), also form a particular pattern when in solid form.

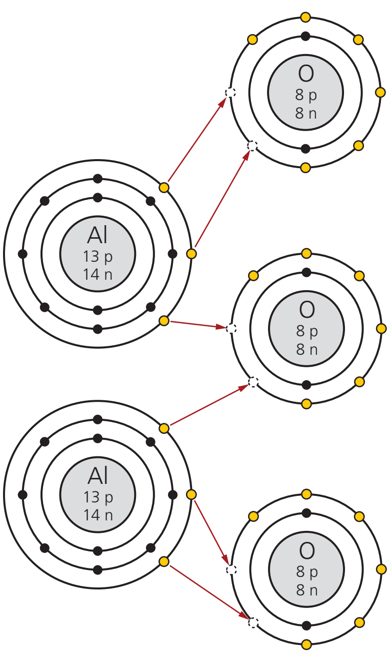


Figure 10 For aluminum and oxygen to form a compound, the atoms must form ions. Each aluminum atom must give up three electrons to become an ion, and each oxygen atom must accept two electrons to become an ion. Two aluminum atoms must transfer six electrons to three oxygen atoms for all the outer shells to be full.

The Ionic Bond and Ion Charge

As you have seen, for elements to form an ionic compound, they must first form ions. Recall that the ion charge is the number of electrons that must be given up or acquired to form an ion. Lithium has an ion charge of 1+, meaning it gives up one electron to form an ionic bond. Fluorine has an ion charge of 1−, meaning it acquires one electron to form an ionic bond. You can see this in Figure 8 on the previous page.

If oxygen atoms (ion charge 2−) contact aluminum atoms (ion charge 3+), each aluminum atom must give up its three outer electrons to form an ion. Each oxygen atom must acquire two electrons to form an ion. Therefore, two aluminum atoms must transfer six electrons to three oxygen atoms to form the ions that make up aluminum oxide, as shown in Figure 10. The metal atoms lose electrons and become positive ions, and the non-metal atoms gain electrons and become negative ions. The total number of electrons given up by the metal ions must equal the total number of electrons accepted by the non-metal ions. The total positive charge of the metal ions must be the same as the total negative charge of the non-metal ions. In the next chapter, you will learn how this balancing of ion charge determines the proportions of the elements in an ionic compound.

7.4

CHECK YOUR Understanding

1. What is an electron shell?
2. In the first three rows of the Periodic Table, what is the maximum number of electrons that can occupy the first shell? What is the maximum number of electrons that can occupy the second shell and third shell?
3. Consider an atom of oxygen.
   (a) How many electrons are in the first shell?
   (b) How many electrons are in the second shell?
   (c) How many electrons are in the third shell?
4. Consider an atom of nitrogen.
   (a) How many electrons are in the first shell?
   (b) How many electrons are in the second shell?
   (c) How many electrons are in the third shell?
5. When an atom forms an ion, describe the outer shell of the ion.
6. Draw a Bohr diagram for each of the following atoms:
   (a) nitrogen
   (b) boron
   (c) neon
   (d) potassium
7. Draw a Bohr diagram for each of the following ions:
   (a) sodium
   (b) sulfur
   (c) carbon
8. Do noble gases such as helium and neon normally form ions? Explain.
9. Consider the first three rows of the Periodic Table. State the column (or group) that has an element with
   (a) one outer electron
   (b) two outer electrons
   (c) three outer electrons
   (d) four outer electrons
   (e) five outer electrons
   (f) six outer electrons
   (g) seven outer electrons
   (h) eight outer electrons
10. Draw a Bohr diagram for the ions of the compound sodium chloride.
11. Refer to the two Bohr diagrams (Figures 11 and 12) below.
    (a) What is the number of protons in each atom or ion?
    (b) What is the number of electrons in each atom or ion?
    (c) Which element does each diagram represent?
    (d) Is each diagram an atom or an ion?

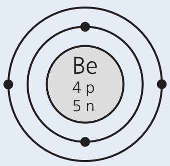


Figure 11

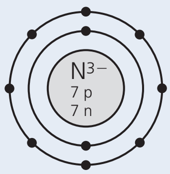


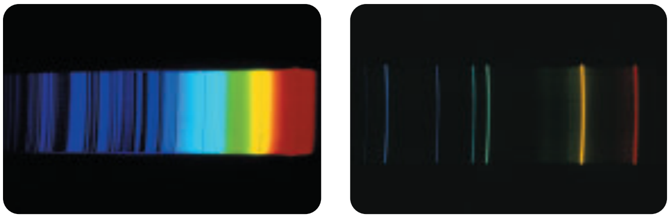
Figure 12

12. If a new element that has seven outer electrons is discovered, in which column or group do you think it should be placed?
13. If a new element that has two outer electrons is discovered, in which column or group do you think it should be placed?
14. Describe the process by which aluminum sulfide is formed from atoms of aluminum and sulfur. How many atoms of each element are required? How many electrons are transferred? Which atoms give up electrons, and which atoms accept electrons?
15. Sodium is stored in oil to keep it away from water. Magnesium has fewer special storage requirements. Explain why sodium is so much more reactive than magnesium.
16. Describe a situation that could be used as an analogy to explain the formation of ions in ionic compounds.
17. Does sodium chloride (an ionic compound) exist as molecules? Explain why or why not.

7A Investigation

Flame Colours

According to Bohr's atomic theory, when atoms absorb energy (as heat, electricity, or electromagnetic radiation), some of the electrons temporarily jump up to higher shells. The electrons are not stable at these higher shells, so they eventually fall back down. As they do, they shed the excess energy as light. The number of shells that the electrons fall and the size of the gaps between these shells determine the amount of energy released and the wavelength of the light. Short wavelength light (blue) has more energy than long wavelength light (red). Because each element has only certain allowed shells, and the size of the gaps between the shells is different for each element, only certain colours of light are emitted. This is called the emission spectrum of the element. Therefore, every element has a unique emission spectrum. The spectra of the elements are like human DNA or fingerprints, and can be used to identify them (Figure 1).



(a) (b)

Figure 1 (a) Sunlight produces a near-continuous spectrum of all the wavelengths of light. (b) An element such as helium emits light of only a few specific wavelengths. The spectrum pattern is unique to each element.

One way to observe the different colours of elements is to use a flame test, in which the atoms of elements are heated in the hot flame of a Bunsen burner.

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Question

Can an element be identified from the colour of flame it produces?

Prediction

Write a prediction based on the Question.

Experimental Design

In this Investigation, you will use an experimental technique called a flame test to observe the different colours (and spectra) emitted by different elements when heated. As well, you will attempt to identify an unknown element by its flame colour.

Materials

- safety goggles
- apron
- Bunsen burner
- flint lighter
- 8 cm pieces of platinum or nichrome wire
- 250-mL beaker containing 100 mL of dilute hydrochloric acid solution
- 7 beakers (50 mL) containing small sample 0.1 mol/L solutions of lithium nitrate, barium nitrate, potassium nitrate, calcium nitrate, copper(II) nitrate, and two unnamed solutions (labelled A and B), one of which is sodium nitrate.
- spectroscopes (optional)

Assume that all solutions used are poisonous. Do not place a red-hot wire into the solution samples. Take care to avoid drips and wipe up all spills promptly. If any solution splashes on skin or in eyes, flush immediately with plenty of cold water and inform your teacher.

Procedure

1. Work with a partner. Read through the procedure and make a table to record your observations.
2. Review the safety rules for working with a Bunsen burner. Put on your safety goggles and apron.
3. Ignite the Bunsen burner. Your teacher will show you how to adjust it to produce the hottest flame possible.
4. Bend a small loop at the end of the wire, about the size of a pencil lead (2 mm to 3 mm in diameter).
5. Holding the wire at the opposite end, dip the loop in the dilute acid solution to clean it. Remove the excess acid by touching the loop to the inside of the beaker.
6. Dip the loop in the lithium nitrate solution. Do not remove the excess.
7. Slowly place the loop into the hottest part of the flame (Figure 2). The tip of the inner cone is the hottest part of a flame.

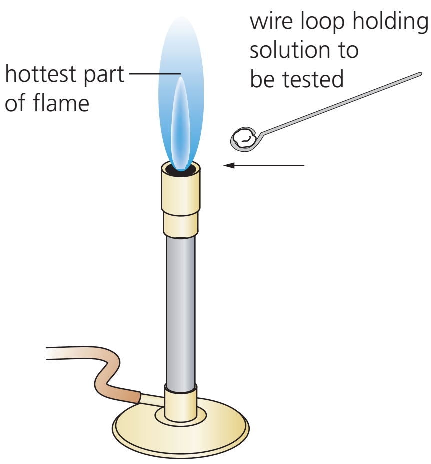


Figure 2 Step 7

8. Record your observations about the colour of the flame. If you have spectroscopes available, try to observe the spectra of the flames while your partner inserts the loop in the flame.
9. Repeat steps 5 to 8 for each of the other four named solutions.
10. Refer to the spectrum of sodium shown below in Figure 3. Repeat steps 5 to 8 for the two unnamed solutions labelled A and B.

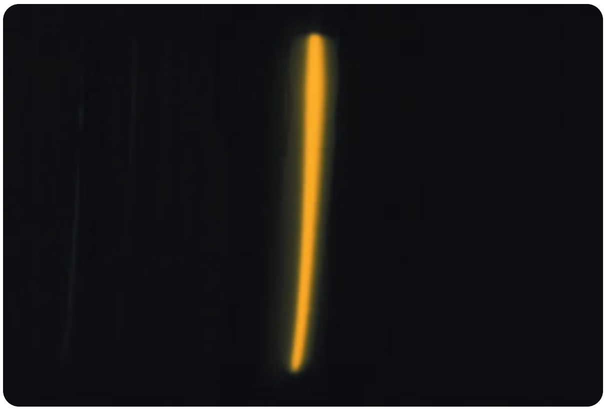


Figure 3 The spectrum of sodium

Analysis

(a) Did each solution have a unique flame colour? If not, which solutions had the same (or similar) flame colours?

(b) Which of the two unnamed solutions, A or B, was sodium nitrate? Explain.

(c) Why were nitrate compounds used for all the solutions?

Evaluation

(d) Were you able to identify which unnamed solution, A or B, was sodium nitrate? How could the test be improved to make the identification easier?

Synthesis

(e) Explain how you might determine if an unknown white solid was sodium chloride (table salt). Note that a taste test is never recommended!

7B Investigation

Ions and Atoms

Ionic compounds form when a metal reacts with a non-metal. The reaction creates oppositely charged ions that are chemically different from the original atoms. Some elements are very reactive and form ionic compounds with a variety of elements. Chlorine is an example of a reactive element. As an element (atom), it is a yellowish-green gas that is extremely corrosive. It was used as a weapon by both sides in the First World War causing many deaths and casualties. Yet the chloride ion is an essential part of nutrition. It is found as a safe and stable part of many important compounds. Sodium chloride is an essential part of your diet, even though it is made from the ions of two very reactive chemicals.

The properties of an element's atoms are quite different from the properties of an element's ions. In this Investigation, you will compare the properties of an atom and its ion.

Copper(II) chloride is corrosive and poisonous. Take care to avoid drips and wipe up all spills promptly. If any solution splashes on skin or in eyes, flush immediately with plenty of cold water and inform your teacher.

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	● Synthesizing
○ Predicting	● Analyzing	● Communicating
○ Planning		

Question

Are the properties of an ion different than the properties of the element?

Prediction

If aluminum metal is reacted with copper chloride, it will become an aluminum ion, Al^{3+}. The copper ion, Cu^{2+}, will become copper metal (atoms).

Experimental Design

In this experiment, you will react an ionic compound with a metal. You will use your observations of the reaction to compare some of the properties of the metal ions.

Materials

- safety goggles
- apron
- copper(II) chloride ($CuCl_2$)
- 3 250-mL beakers
- water
- aluminum foil
- scissors
- stirring rod
- ring stand
- ring clamp
- funnel
- filter paper

Procedure

1. Read the Procedure, and create a table to record your observations.
2. Put on your safety goggles and apron.
3. Your teacher will supply you with a beaker that contains approximately 1.0 g of copper(II) chloride. Observe and record the properties of this compound.
4. Add approximately 100 mL of water and stir until the copper(II) chloride is completely dissolved. Observe and record the properties of the copper(II) chloride solution.
5. Cut a 3 × 3 cm square of aluminum foil. Observe and record the properties of the aluminum metal.
6. Crumple the foil square and place it in the copper(II) chloride solution. Immediately begin to watch for any changes to the solution or the square of aluminum. Record your observations.

7. Use the stirring rod to ensure that all the foil is submerged. Continue to add small scraps of foil until the blue-green colour disappears from the solution.
8. Set up the ring stand with the funnel and filter paper, as demonstrated by your teacher.
9. Swirl the solution gently, and then pour it into the funnel, pouring along the stirring rod as shown in Figure 1. Touch the stirring rod to the spout of the beaker so that the liquid flows down the rod into the filter cone.

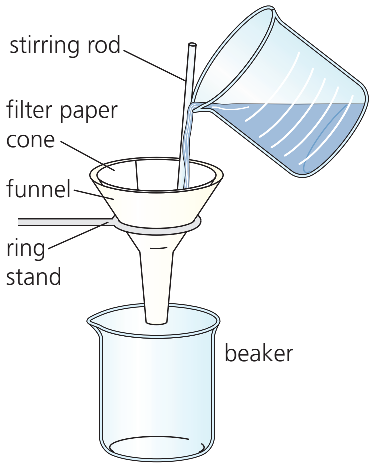


Figure 1 Step 9

10. When all the solution has been poured, add some water to wash out the remaining solids.
11. Allow the filter paper to dry as directed by your teacher. Pour any remaining solutions into the container designated by your teacher. Rinse the beaker, stirring rod, and funnel. Return the equipment as directed by your teacher.
12. Observe the solid on the filter paper. Record your observations.

Analysis

(a) What ions are present in a solution of copper(II) chloride? What colour do you think the copper(II) ions are? Explain.

(b) What are the properties of aluminum that confirm it is a metal?

(c) What observations convinced you that a chemical reaction was occurring between the aluminum foil and the copper(II) chloride solution?

(d) What happened to the aluminum atoms in the foil? Explain.

(e) What happened to the copper(II) ions in the solution? Explain.

(f) What happened to the chloride ions in the solution? Explain.

(g) Are the ions of a metal very different from the atoms of a metal? Give some important differences in the properties you observed.

Evaluation

(h) Did the Investigation verify the prediction? Why or why not?

Synthesis

(i) Some metal ions are serious pollutants if they get into rivers, lakes, or oceans. Do you think this method would be a reasonable way to remove copper ions from waste water? On what would it depend?

CHAPTER 7

Review

Atomic Theory—Inside the Invisible

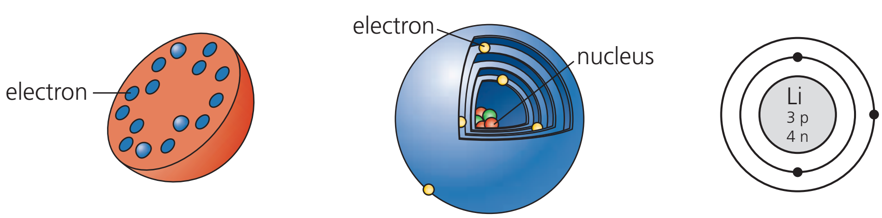
Key Ideas

Matter is made of atoms.

- Each element has its own kind of atom.
- Atoms of different elements combine to form compounds.

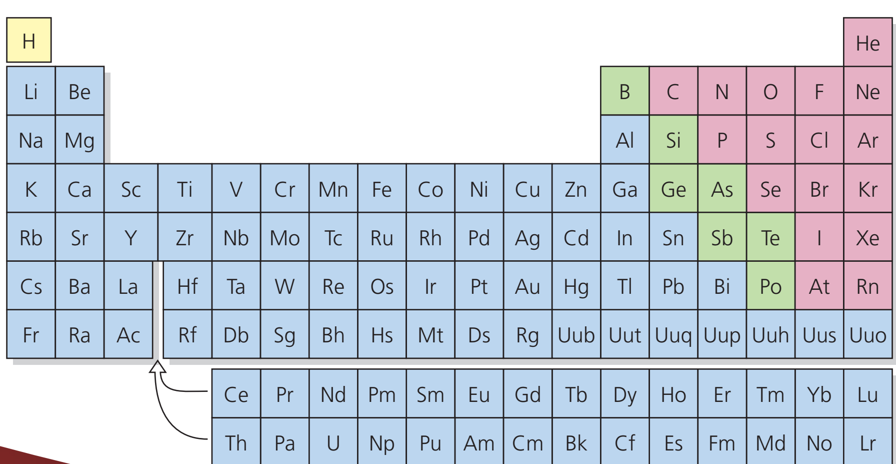
The atomic theory of matter has changed with new discoveries.

- The discovery of the electron led to Thomson's "raisin-bun" model of the atom.
- Rutherford's discovery of the nucleus required a new model, one with most of the mass concentrated in a small space at the centre of the atom.
- Bohr's model of the atom explained the behaviour of electrons in orbit around the nucleus.



Elements can be classified and ordered according to their properties.

- Metal elements are on the left side of the Periodic Table.
- Non-metal elements are on the right side of the Periodic Table.
- Metalloid elements fall on a zigzag line between the metal and non-metal elements.
- The Periodic Table arranges elements in vertical columns, or chemical groups, with similar properties.

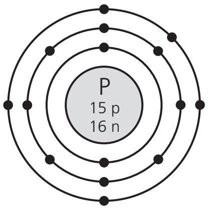


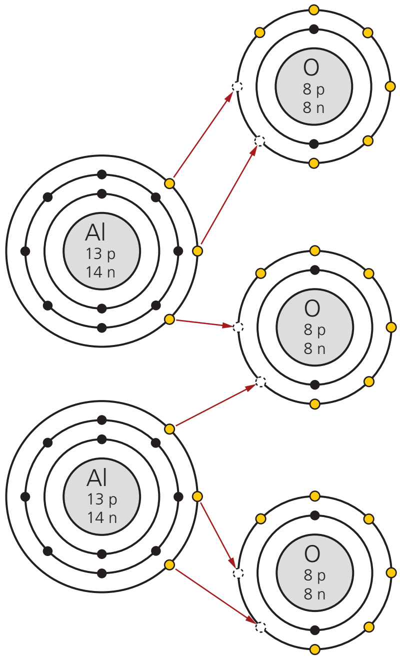
Vocabulary

atom, p. 204
electron, p. 206
nucleus, p. 207
protons, p. 207
neutrons, p. 207
subatomic particles, p. 207
emission spectrum, p. 209
shells, p. 209
atomic number, p. 211
mass number, p. 211
ion, p. 211
negative ion, p. 211
positive ion, p. 211
ion charge, p. 211
atomic mass, p. 215
Bohr diagrams, p. 218
ionic compound, p. 221
electron transfer, p. 221
ionic bond, p. 221
molecules, p. 221

Atoms have a structure that determines their chemical and physical properties.

- Atoms are made up of subatomic particles: protons, neutrons, and electrons.
- Protons have a positive charge, have the same mass as neutrons, and are in the nucleus.
- Neutrons have no charge, have the same mass as protons, and are in the nucleus.
- Electrons have a negative charge, have $\frac{1}{1800}$ the mass of a proton, and orbit the nucleus at specific locations, or shells.
- For the first 20 elements, the first three orbits can contain a maximum of two, eight, and eight electrons.
- Bohr diagrams can help you visualize the structure of atoms and ions.
- Atoms form ions by either acquiring electrons (non-metals) or losing electrons (metals) so that their outer shell is full.
- Ionic compounds are formed when metal and non-metal atoms transfer electrons to become positive and negative ions. The ions are attracted to each other by the electric force.





Review Key Ideas and Vocabulary

1. Four solid substances are examined. The substance most likely to be a metalloid is
   (a) shiny, conductive, and bendable
   (b) shiny, conductive, and brittle
   (c) dull, non-conductive, and brittle
   (d) dull, non-conductive, and bendable
2. An element is a gas at room temperature. It is likely to be a
   (a) metal
   (b) metalloid
   (c) non-metal
   (d) compound
3. For the first 20 elements, the maximum numbers of electrons that can occupy the first three electron shells are
   (a) 8, 8, and 8
   (b) 2, 2, and 8
   (c) 8, 18, and 18
   (d) 2, 8, and 8
4. In the modern Periodic Table, the upper right is where you can find the
   (a) non-metals
   (b) metals
   (c) transition metals
   (d) alkali metals
5. The nucleus of an atom
   (a) makes up one-third of the mass
   (b) makes up almost all of the mass
   (c) takes up most of the diameter
   (d) holds all of the negative charge
6. (a) How many electrons are in the outer shell of the atoms of the elements in the second and third rows of the Periodic Table?
   (b) How many electrons are in the outer shell of an atom in the second row of the Periodic Table once it has become an ion?
7. What does the atomic number of an element represent?
8. What tells you the total number of protons and neutrons in the nucleus of an atom?
9. Which scientist first described the nucleus as a dense inner core containing all the positive charges in an atom?
10. List three types of information about elements that you can expect to find in the Periodic Table.
11. Explain why Thomson's atomic model is sometimes called the "chocolate-chip cookie" model.
12. What are the ion charges of each of the following elements?
    (a) oxygen
    (b) chlorine
    (c) sodium
    (d) nitrogen
    (e) neon
13. An ion has a charge of 3− because
    (a) there are 3 electrons missing
    (b) there are electrons in three shells
    (c) there are 3 extra electrons
    (d) there are 3 missing protons

Use What You've Learned

14. Draw Bohr diagrams for sodium, magnesium, aluminum, silicon, oxygen, and neon.
15. Draw Bohr diagrams for the ions of nitrogen, boron, and potassium.
16. How many electrons will occupy the outer shell of an element in the third row of Group 15 (15th column) of the Periodic Table?
17. For each of the four Bohr diagrams shown below (Figures 1 to 4), determine
    (a) the atomic number
    (b) the element name
    (c) the number of electrons
    (d) the number of neutrons
    (e) the atomic mass
    (f) whether the diagram represents an atom or an ion

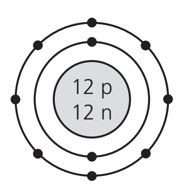


Figure 1

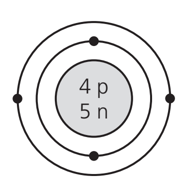


Figure 2

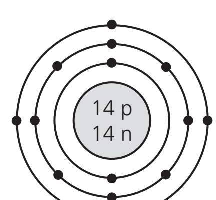


Figure 3

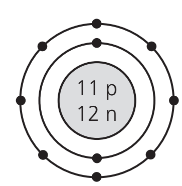


Figure 4

18. Describe the process in which a metal atom in Group 2 becomes an ion. What charge does the ion have?
19. Describe the process in which a non-metal atom in Group 17 becomes an ion. What charge does the ion have?
20. How do the properties of aluminum and copper atoms differ from the properties of their ions?
21. Zinc and iodine react to form ions. Zinc has an ion charge of 2+, and iodine has an ion charge of 1−. Determine how many ions of iodine form for each zinc ion.
22. When the compound magnesium nitride is formed, there are three magnesium ions for every two nitrogen ions in the compound. Explain why.
23. Describe how Bohr's theory of the atom explains the emission spectra of elements.
24. The electrons in the outer shell of an atom are sometimes referred to as valence electrons. Using print and electronic resources, research the meaning of the word "valence." Write a paragraph to summarize your research.

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Think Critically

25. "Energy levels" is another term used for the electron shells in the Bohr theory. Explain why this is an acceptable term.
26. Conduct research to learn about the limitations of Bohr's atomic theory. Summarize your results in a brief presentation.

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27. Could a flame test be used to identify any element? Explain.
28. Which element do you think would be more reactive, bromine or selenium (Figure 5)? Explain.

(a)

(b)

Figure 5 (a) Bromine (b) Selenium

29. Describe four objects that you could find in a hardware store or a toy store and use as models for the atomic theories of Dalton, Thomson, Rutherford, and Bohr. Briefly describe how each model would demonstrate the key ideas of the theories.
30. You have discovered a new substance that may or may not be an element. Write five questions you can ask to help you determine whether the substance is an element and, if it is a new element, where it should be placed in the Periodic Table.

Reflect on Your Learning

31. Do you believe Bohr's model describes the actual positions of the electrons in an atom if it were possible to see them? Why or why not?
32. Write a short paragraph to describe a situation in your life when you changed your idea or viewpoint of the situation after learning more information about it. Which ideas did you find most difficult to change? Which ideas were easiest to change? Why?

Visit the Quiz Centre at
www.science.nelson.com GO

CHAPTER 8

Ionic Compounds: Names and Formulas

KEY IDEAS

- Elements combine to form compounds in exact proportions.
- The formulas of ionic compounds can be determined from their names.
- The names of ionic compounds can be determined from their formulas.
- Chemical families are groups of elements that have similar chemical and physical properties.

Chapter Preview

How many different words for the word "apple" do you think there are in all the world's languages? If you've been to a restaurant that serves food from another country or culture, did the menu use English to describe the food? If the menu used another language, how did you know what was in the food? Perhaps you have an allergy to peanuts. Would it be important to know the word for "peanut" in other languages?

You have learned the symbols that are used for elements. You have also learned how the Periodic Table organizes elements into groups with similar properties. When an element from one group forms a compound with an element from another group, scientists everywhere in the world need to know what the compound is and how much of each element is in it. In this chapter, you will learn the standard system that scientists use to describe ionic compounds—both names and formulas.

TRY THIS: Symbolic Cookies

Skills Focus: recording, communicating, interpreting data

Imagine you found the best recipe for chocolate chip cookies. The recipe calls for 240 mL butter, 495 mL brown sugar, 15 mL vanilla extract, 2 eggs, 15 mL baking powder, 15 mL baking soda, 495 mL flour, 630 mL rolled oats, and 495 mL chocolate chips.

1. Create a symbol for each ingredient.
2. Assume you only have a 15 mL measuring scoop. Determine how many scoops of each ingredient are needed.
3. Write out the recipe using the symbols you created. Indicate the number of scoops or "units" of each ingredient with a subscript number (a small number written slightly below the symbol). For example, CC_{33} could mean "33 scoops of chocolate chips." Remember to describe how to put the ingredients together, just like a real recipe.
4. Exchange recipes with a classmate.

A. Would you be able to make the cookies with their recipe? Why or why not?

B. Would it be easier to follow the recipe if everyone were using the same symbols? Explain.

C. Explain how you would change the recipe to double or triple the batch.

8.1 Writing Chemical Formulas

As scientists came to recognize that many materials previously thought to be mixtures were actually compounds, they discovered that the ratio of the elements in a compound is always made up of small whole numbers. This meant that the identification of a compound not only required symbols for each element, but also ways to show the ratio of the elements in the compound. Recall that Berzelius created the standardized system of symbols for the elements. More importantly, he stated that every compound can be identified by a **chemical formula**, which shows the elements and their ratio.

A chemical formula for a compound such as water, which has two parts hydrogen and one part oxygen, is created using the symbols for the elements, and numbers for the relative proportions of the elements—H_2O. The number of particles of each element is shown using a subscript, which is a number following and slightly below the element symbol it describes. If there is no subscript after an element symbol (for example after the O in H_2O), it is understood to be 1. Table 1 shows a few other compounds and their formulas. 8A *Investigation*

8A *Investigation*

Separating the Elements from a Compound

To perform this investigation, turn to page 258.

In this investigation, you will separate the elements that form water and verify their proportions in the compound.

LEARNING TIP

Check your understanding. Use Table 1 to explain to a partner what a chemical formula is and how it is used.

Table 1 Some Simple Compounds, Their Formulas, and Their Proportions

Formula	Elements	Proportions	Particles
CuS	copper and sulfur	1 to 1	1 copper ion to 1 sulfur ion
Ag_2S	silver and sulfur	2 to 1	2 silver ions to 1 sulfur ion
CO_2	carbon and oxygen	1 to 2	1 carbon atom to 2 oxygen atoms
Al_2O_3	aluminum and oxygen	2 to 3	2 aluminum ions to 3 oxygen ions

The order of the elements in a chemical formula is important. By convention, when a compound is composed of a metal and a non-metal, the metal is shown in the formula ahead of the non-metal. For example, the formula CuS shows that copper is the metal and sulfur is the non-metal. The formula for the compound formed from silver and sulfur is written Ag_2S.

Polyatomic Ions

Some groups of atoms, called polyatomic groups, can occur together in a compound. When polyatomic groups are formed, they often have an imbalance between the total number of electrons and the total number of protons—in other words, they have a charge like an ion. Therefore, they are referred to as **polyatomic ions**. Most of the polyatomic ions are negative, and these ions behave as non-metals in a compound. Two common negative polyatomic ions are CO_3^{2-} (the carbonate ion) and OH^- (the hydroxide ion). A common positive polyatomic ion is NH_4 (ammonium), which has an ion charge of 1+. Ammonium behaves as a metal in a compound.

Polyatomic ions are treated as if they were a single element's ions. If one ion is present, it is written without a subscript. If there is more than one of the ion present, the ion is enclosed in brackets and a subscript is used to show the number present. For example, $CaCO_3$ shows there is one ion of calcium and one carbonate ion in the compound (Figure 1). $Al_2(CO_3)_3$ contains 2 aluminum ions for every 3 carbonate ions. The subscript refers to everything in the brackets, so in $(CO_3)_3$ there are 3 carbonate ions, but there are 3 carbon atoms and 9 oxygen atoms in total.

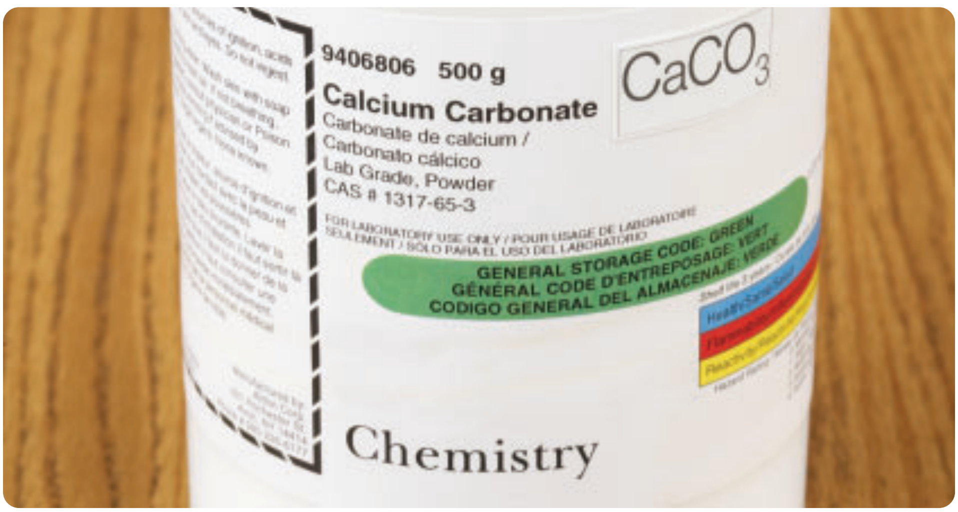


Figure 1 Chemical supply bottles always show the chemical name and the formula.

If you would like to learn about other polyatomic icons, go to **www.science.nelson.com** GO

Table 2 provides the names, symbols, and ion charges for some polyatomic groups. GO

Table 2 Common Polyatomic Ions and Their Names, Symbols, and Ion Charges

Name	Symbol	Ion charge	Name	Symbol	Ion charge
ammonium	NH_4	1+	hydrogen carbonate (also known as bicarbonate)	HCO_3	1−
carbonate	CO_3	2−	chlorate	ClO_3	1−
hydroxide	OH	1−	nitrate	NO_3	1−
phosphate	PO_4	3−	sulfate	SO_4	2−

Below are some examples of compounds that contain polyatomic ions. Notice how brackets are sometimes used. How many of each ion are in each formula?

- sodium phosphate, Na_3PO_4
- strontium nitrate, $Sr(NO_3)_2$
- aluminum hydroxide, $Al(OH)_3$
- calcium hydrogen carbonate, $Ca(HCO_3)_2$

TRY THIS: *Writing and Decoding Chemical Formulas*

Skills Focus: interpreting data

A chemical formula is a code. It gives you information about the composition of a compound. On the other hand, you can write the formula of a compound if you know the composition.

1. Complete Table 3. The first row has been done for you.

Table 3

Common name	Proportion of metal ion	Proportion of non-metal ion	Formula
baking soda	1 sodium	1 bicarbonate	$NaHCO_3$
caustic soda (oven cleaner)	1 sodium	1 hydroxide	
cinnabar (red stone used in jewellery)	1 mercury	1 sulfur	
cubic zirconia			ZrO_2
dentist's fluoride			SnF_2
epsom salt	1 magnesium		$MgSO_4$
Glauber's salts (a laxative)	2 sodium	1 sulfate	
gypsum (drywall)	1 calcium	1 sulfate	
lime			CaO
milk of magnesia	1 magnesium	2 hydroxide	
washing soda	2 sodium	1 carbonate	

A. Which description of a chemical—the common name or the formula—provides clearer and more concise information about the compound? Explain.

B. Which description would be better to use when talking to a person who speaks a different language? Explain.

Visual Representations of Compounds

LEARNING TIP

As you study Figure 2, ask yourself, "How many atoms, and what kind, are found in each article? How do colour, shape, and size help you "see" the chemical formula for each compound?"

Sometimes it is convenient to visualize a compound and its formula using a visual representation. Look at the representations of chemical formulas in Figure 2. Look at the number and kinds of atoms in each compound.

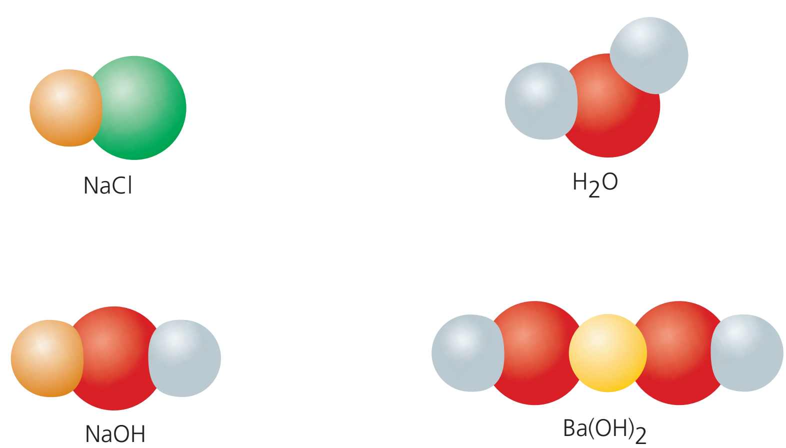


Figure 2 The formulas for compounds can be represented visually.

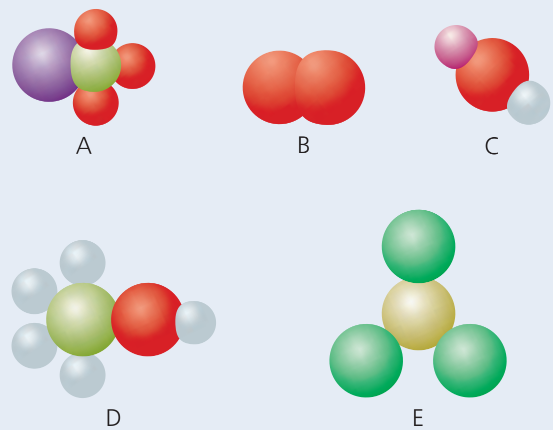
8.1 CHECK YOUR Understanding

1. Copy Table 4 into your notebook, and complete it.

Table 4

Formula	Elements	Proportions	Particles
PbO_2			
Al_2O_3			
N_2O_3			
$SnCl_4$			
Na_2S			
H_2S			
MnO_2			
WF_6			

2. Identify the elements, the polyatomic groups, and their proportions in the following compounds.
   (a) NH_4Cl
   (b) Na_2CO_3
   (c) $KClO_3$
   (d) $BaSO_4$
   (e) NH_4OH
3. Write the chemical formula for each ionic compound.
   (a) 2 ammonium with 1 carbonate
   (b) 1 iron with 2 fluorine
   (c) 1 calcium with 2 nitrate
   (d) 2 aluminum with 3 oxygen
   (e) l nickel with 2 chlorine
   (f) 3 magnesium with 2 phosphorous
   (g) 1 potassium with 1 bicarbonate
   (h) 1 lead with 2 hydroxide
4. Consider sodium hydroxide, NaOH.
   (a) How many atoms of sodium are indicated in the formula?
   (b) How many atoms of hydrogen are indicated?
   (c) How many atoms of oxygen are indicated?
   (d) How many hydroxide ions are indicated?
5. Consider aluminum sulfate, $Al_2(SO_4)_3$.
   (a) How many atoms of aluminum are indicated in the formula?
   (b) How many atoms of sulfur are indicated?
   (c) How many atoms of oxygen are indicated?
   (d) How many sulfate ions are indicated?
6. How many atoms of oxygen are there in a particle of aluminum nitrate, $Al(NO_3)_3$?
7. Match each chemical formula with a possible visual representation.
   (a) $CrCl_3$
   (b) O_2
   (c) KNO_3
   (d) NH_4OH
   (e) LiOH



8. Draw a visual representation of each compound.
   (a) $CaCO_3$
   (b) $Pb(NO_3)_2$
   (c) HCl
   (d) Li_2SO_4
   (e) $CrPO_4$
   (f) $Mg(HCO_3)_2$
   (g) $(NH_4)_2S$
   (h) Li_3PO_4

8.2 Ion Charge and the Formulas of Ionic Compounds

LEARNING TIP

Make connections to your prior knowledge. In mathematics, you learned that a ratio is one thing compared with, or related to, another thing. How does this relate to what you are learning about The Law of Definite Proportions?

An important discovery that led to modern chemistry was the discovery that elements combine with other elements in specific proportions to form compounds that always have the same proportions. The alchemists believed that finding the right mixture would create the substance they desired, but experiments showed that elements could not be combined in just any proportion. For example, when sodium and chlorine react, they never form $NaCl_2$, Na_2Cl, or any combination other than NaCl. This was a spectacular discovery. Joseph Proust proposed the **Law of Definite Proportions** in 1799: *A specific compound always contains the same elements in definite proportions.* Early chemists understood how elements combined. They didn't understand, however, why elements combine in specific ways.

Ionic Compounds: Metals Combining with Non-Metals

As you learned in Chapter 7, ions are charged atoms. Ions are formed when an atom gains or loses sufficient electrons to have a full outer shell. When a metal atom collides with a non-metal atom, electrons are transferred to form ions, and the ions are bonded by the electrical force to form compounds. These compounds are called ionic compounds. They are electrically neutral because they have positive and negative charges of equal size. Many common compounds are examples of ionic compounds, such as table salt (sodium chloride), chalk (calcium carbonate), and a decay-preventing ingredient in toothpaste (sodium fluoride).

Formulas for Ionic Compounds with Two Elements Combining

Knowing the ion charge of an element makes it possible to predict how the element will react to form compounds with other elements. Tables 1 and 2 provide ion charges of some metals and non-metals. The common ion charge of elements is also indicated in the Periodic Table at the back of this book.

When ionic compounds form, every electron that is given up by a metal atom must be accepted by a non-metal atom. If the elements have equal but opposite ion charges, then they will combine in the ratio 1:1. For example, if magnesium and oxygen combine, then for every one magnesium atom that gives up two electrons, there will be one oxygen atom that accepts two electrons. If the two elements have unequal and opposite ion charges, then the elements will combine in a ratio so that the total number of electrons transferred equals the total number of electrons accepted. For example, if magnesium and chlorine combine, for every one magnesium atom giving up two electrons, there will be two chlorine atoms accepting one electron each (for a total of two accepted).

To summarize, *the total number of electrons transferred to form a single unit of the compound will be the lowest common multiple (LCM) of the two ion charges.*

Table 1 Ion Charge of Some Metals

Element	Symbol	Ion charge
aluminum	Al	3+
barium	Ba	2+
beryllium	Be	2+
bismuth	Bi	3+
boron	B	3+
calcium	Ca	2+
cesium	Cs	1+
lithium	Li	1+
magnesium	Mg	2+
potassium	K	1+
silver	Ag	1+
sodium	Na	1+
strontium	Sr	2+
zinc	Zn	2+

Table 2 Ion Charge of Some Non-Metals

Element	Symbol	Ion charge
bromine	Br	1−
chlorine	Cl	1−
fluorine	F	1−
iodine	I	1−
oxygen	O	2−
phosphorous	P	3−
sulfur	S	2−

If calcium (2+) combines with phosphorous (3−), the LCM of 2 and 3 is 6. Therefore, 3 calcium atoms (3 × 2+) will be required for every 2 phosphorous atoms (2 × 3−) in order to balance the charges.

Here is a simple procedure for writing the formulas of ionic compounds with two elements.

1. If the ion charges are balanced, the ratio of the ions in the compound is 1:1 (Table 3):

Table 3

Metal	Non-metal	Charge balance	Formula
magnesium Mg^{2+}	sulfur S^{2-}	2+ to 2−	MgS
lithium Li^{+}	bromine Br^{-}	1+ to 1−	$LiBr$

2. If the ion charges are not balanced, use subscripts to create multiples to balance the total charges (number of electrons given/accepted) (Table 4):

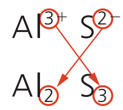
Table 4

Metal	Non-metal	Charge balance	Formula
calcium Ca^{2+}	iodine I^{-}	2+ to 2(1−)	CaI_2
potassium K^{+}	oxygen O^{2-}	2(1+) to 2−	K_2O
aluminum Al^{3+}	sulfur S^{2-}	2(3+) to 3(2−)	Al_2S_3

Al^{3+}	S^{2-}
Al	S

Quick Trick to Balance Charges

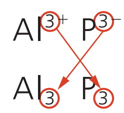
- Write the metal and non-metal elements in their ion form.
- Below them, write the metal and non-metal elements again, without the ion charges (see box to the left).
- Bring the number above the metal element down to be the subscript of the non-metal, and vice versa, as shown below. This is called the crisscross method.



The formula is Al_2S_3. This can be verified using Bohr diagrams (Figure 1).

LEARNING TIP
Check your understanding. Use Figure 1 to explain to a partner how electrons are given and accepted when an ionic compound is formed.

- If there is a common factor in the subscripts generated, you must reduce the subscripts as a final step.



The formula is not Al_3P_3, but simply AlP.

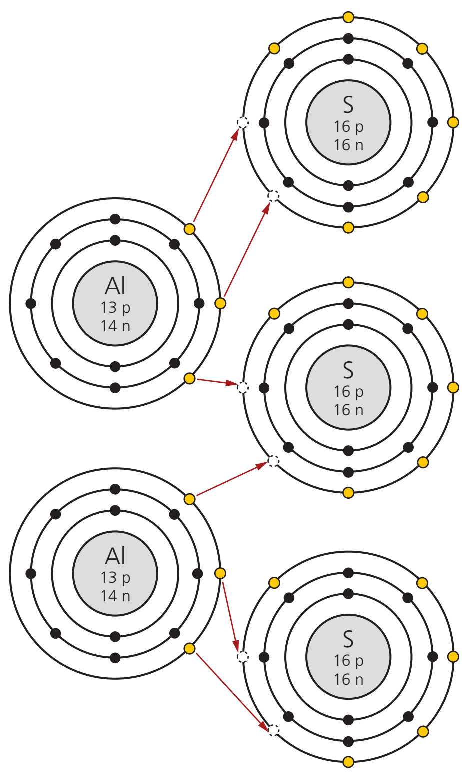


Figure 1 Bohr diagrams for aluminum and sulfur can be used to verify the balance of electrons transferred. The two aluminum atoms give up a total of six electrons, and the three sulfur atoms acquire a total of six electrons.

TRY THIS: *The Compounding Party*

Skills Focus: creating models, communicating

In this activity, you and your classmates will play the roles of metals and non-metals trying to form compounds. The metal atoms must meet non-metal atoms and transfer electrons to become ions. There is a catch, however. Electrons cannot be transferred until an exact match is arranged first.

Materials: approximately 50 pennies, marbles, or other token of exchange; name tags or sticky notes, labelled with an element name and its ion charge (for example, "Hi, my name is Mag Nesium (2+).")

1. Obtain your name tag from your teacher. Metal students will get a number of tokens equal to their ion charge.
2. Metals must give up all their tokens when compounding. Non-metals must accept the number of tokens equal to their ion charge.
3. Circulate around the room and match up with another element to form a compound by transferring tokens. Depending on which element you are, you may need more than two people to form your compound.
4. After the transfer, turn your name tags upside down to indicate that you have formed ions and are no longer available to other atoms. Write down how many people in your compound have the metal name and how many have the non-metal name.

A. What was the formula of your compound?

B. Other compounds were formed in the room? What were their formulas?

C. Was every student in the room able to become part of a compound? Explain why or why not.

Formulas for Ionic Compounds with Polyatomic Ions

Recall that polyatomic ions act as a unit with a shared ion charge (Table 5). To write the formulas for compounds with polyatomic ions, you use the same method you used for two elements combining, but you must keep the atoms of the polyatomic ion together.

Table 5 Ion Charges of Common Polyatomic Ions

Group	Formula	Ion charge
ammonium	NH_4	1+
carbonate	CO_3	2−
hydrogen carbonate	HCO_3	1−
hydroxide	OH	1−
nitrate	NO_3	1−
phosphate	PO_4	3−
sulfate	SO_4	2−

Below is a simple procedure for writing the formulas of ionic compounds with one element and one polyatomic group.

1. If the ion charges are balanced, the ratio of the ions in the compound is 1:1 (Table 6).

Table 6

Metal	Non-metal	Charge balance	Formula
ammonium NH_4^+	chlorine Cl^-	1+ to 1−	NH_4Cl
barium Ba^{2+}	sulfate SO_4^{2-}	2+ to 2−	$BaSO^4$

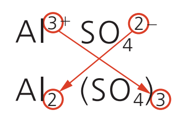
2. If the ion charges are not balanced, use subscripts (Table 7). Use brackets to show if more than one polyatomic ion is needed. The number of polyatomic ions goes outside the brackets.

Table 7

Metal	Non-metal	Charge balance	Formula
calcium Ca^{2+}	nitrate NO_3^-	2+ to 2(1−)	$Ca(NO_3)_2$
ammonium NH_4^+	sulfur S^{2-}	2(1+) to 2−	$(NH_4)_2S$
aluminum Al^{3+}	sulfate SO_4^{2-}	2(3+) to 3(2−)	$Al_2(SO_4)_3$

Quick Trick to Balance Charges

Use the same procedure that you used to balance formulas with two elements, but make sure the number of polyatomic ions is outside the brackets.



LEARNING TIP

The prefix *mono* indicates one ion charge. The prefix *multi* indicates more than one, or multiple, ion charges.

Formulas for Ionic Compounds with More Than One Ion Charge

Many elements are **monovalent**—they have only one ion charge. Through experiments, however, chemists found that some elements have multiple ion charges. These elements are called **multivalent** and only occur after atomic number 20. Their electron shells are more complicated than those of the first 20 elements in the Periodic Table. Some common examples are shown in Table 8. Note that Roman numerals are used in the name to indicate the different ion charges of the same elements.

Table 8 Common Multivalent Metals and Their Ion Charges

Element	Symbol	Ion charge
chromium(II)	Cr	2+
chromium(III)	Cr	3+
copper(I)	Cu	1+
copper(II)	Cu	2+
iron(II)	Fe	2+
iron(III)	Fe	3+
lead(II)	Pb	2+
lead(IV)	Pb	4+
nickel(II)	Ni	2+
nickel(III)	Ni	3+

A difference in the ion charge makes copper(I) and copper(II) very different ions. The compounds they form have different properties. For example, copper(II) ions form compounds that tend to be blue or blue-green in colour. Copper(I) ions form compounds that tend to be white. Copper metal left unprotected outdoors acquires a patina on the surface (Figure 2). Which ion of copper is in a patina? Another example is iron(II) and iron(III): iron(III) oxide (rust) is dark red and often used in pigments, while iron(II) oxide is jet-black.

Figure 2 The Legislative Building in Victoria, B.C. The blue-green colour of the copper roof is due to copper(II) ions that form as the copper metal reacts with the atmosphere.

Some examples of compounds made from multivalent elements are given in Table 9.

Table 9 Formulas for Some Compounds with Multivalent Elements

Name	Formula
iron(III) chloride	$FeCl_3$
iron(II) chloride	$FeCl_2$
copper(I) hydroxide	$CuOH$
copper(II) hydroxide	$Cu(OH)_2$

The name of the multivalent ion indicates the ion charge (Table 10). The rules for writing formulas with multivalent ions are the same as the rules you previously learned in this section.

Table 10

Metal	Non-metal	Charge balance	Formula
chromium(II)	chlorine	2+ to 2(1−)	$CrCl_2$
iron(III)	sulfate	2(3+) to 3(2−)	$Fe_2(SO_4)_3$
lead(IV)	oxygen	4+ to 2(2+)	PbO_2

8.2

CHECK YOUR Understanding

1. Define the Law of Definite Proportions in your own words.
2. How do you recognize the difference between the ion charge of a metal and the ion charge of a non-metal?
3. What happens to the charge on individual ions when they form compounds?
4. Define "polyatomic ion". Give three examples of polyatomic ions.
5. What is the ion charge of each of the following individual or polyatomic ions?
   (a) calcium
   (b) aluminum
   (c) copper(II)
   (d) ammonium
   (e) iron(II)
   (f) sulfur
   (g) oxygen
   (h) fluorine
   (i) nitrate
   (j) carbonate
6. What is the basic rule for predicting how the ions of a metal and a non-metal will react to form a compound? Give an example.
7. Define monovalent and give an illustrative example.
8. Explain why the names of some metal ions such as iron(III) have a Roman numeral after them.
9. Write the symbol for each of the following ions
   (a) sodium
   (b) chloride
   (c) sulfate
   (d) ammonium
   (e) chromium(II)
   (f) chromium(III)
10. Write the formulas for the compounds formed in each of the following:
   (a) magnesium and chlorine
   (b) silver and sulfur
   (c) cobalt(III) and oxygen
   (d) zinc and bromine
   (e) calcium and nitrogen
   (f) copper(I) and nitrate
11. Write the names of the two ions in each of the following compounds.
   (a) $Al_2(SO_4)_3$
   (b) $CaCl_2$
   (c) Na_2O
   (d) $AgCl$
   (e) Na_3PO_4
   (f) CaF_2
   (g) NH_4OH
   (h) $Ca(NO_3)_2$
12. Identify which of the following compound formulas are *incorrect*. Provide the correct formula for those that are incorrect.
   (a) calcium and oxygen, CaO_2
   (b) sodium and oxygen, NaO_2
   (c) barium and chlorine, $BaCl_3$
   (d) strontium and oxygen, SrO_2
   (e) sulfur and sodium, SNa_2
   (f) ammonium and nitrate, NH_4NO_3
   (g) sodium and calcium, NaCl
13. You are given a sample of copper compounded with chlorine. The sample is in the form of a blue-green powder. What is the name and the formula of the compound? Recall that copper ions are either copper(I) or copper(II).

8.3 Naming Ionic Compounds

Are you familiar with any of the pure compounds that are commonly called baking soda, cream of tartar, vinegar, aspirin, and sugar (Figure 1)? Have you ever wondered why chemistry uses complicated names rather than the simple, common names like these? Table salt is perhaps the clearest example of a well-known compound. Its important role in nutrition and food preservation has given it a different common name in every culture. From the time of Berzelius, the language of chemistry was intended to be universally understood. So the scientific naming of ionic compounds is the same whether you are studying in a school in Russia, South Africa, or British Columbia.

LEARNING TIP

Since there are many elements and compounds, explain to a partner why it is important to have clear chemical names for elements and compounds.

Figure 1 Vinegar and baking soda also have chemical names that scientists use.

Rules for Naming Ionic Compounds

The rules for writing chemical formulas are universal. If you know what ions are present in a compound, the rules predict both the formula and the compound name. The rules for writing the name, when you know the formula, are relatively simple.

Naming Monovalent Metals

Monovalent metals have only one possible ion charge. All the metals in the first 20 elements and all the metals in the first two columns of the Periodic Table (alkali and alkaline earth metals) are monovalent metals.

- The name of the metal ion is written first in a formula.
- The name is written in lower case and is spelled exactly the same as the element name: Na is *sodium* and Al is *aluminum*.

Naming Non-metal Ions

- The non-metal ion is written second in a formula.
- To distinguish non-metal ions from polyatomic ions, the names of non-metal ions are given the suffix *ide*: oxygen becomes *oxide*, and chlorine becomes *chloride*.

Naming Polyatomic Ions

- Positive polyatomic ions are written first, like metals.
- Negative polyatomic ions are written second and the name of the ion is not changed: SO_4^{2+} is named *sulfate*.

Naming Multivalent Metals

- If the metal is multivalent, such as iron (Fe^{2+} and Fe^{3+}) or copper (Cu^{+} and Cu^{2+}), the ion charge of the metal must be in its name.
- The ion charge is written as a Roman numeral in brackets following the metal name, with no space between them: the Cu^{2+} ion is named *copper(II)* and read "copper two"; the Cu^{+} ion is named *copper(I)* and read "copper one."

Did You KNOW?

Past Naming System

In the past, chemists had to remember the ion charges of multivalent metals—the charges were not part of the name (for example, copper(II) chloride). This older system of naming metals used the suffixes *ous* and *ic* to refer to the different ion charges. Copper(II) chloride was cuprous chloride and iron(II) oxide was ferrous oxide. To learn more about this naming system, go to

www.science.nelson.com GO

Determining the Ion Charge from a Formula

The ion charge of a multivalent metal is not shown directly in the formula of a compound. Recall that the total ion charges must balance, and you can work backward from the non-metal ion charge to determine the metal ion charge. For example, $CuCl_2$ has chloride as the non-metal ion, with an ion charge of 1−. There are two chloride ions, so the one copper ion must be copper(II). CrP has phosphide as the negative ion, with an ion charge of 3−. There is only one chromium ion, so it is chromium(III). Fe_2S_3 has three sulfur ions, each with a charge of 2−, for a total negative charge of 6−. The two iron ions must therefore have a total charge of 6+, so they are iron(III).

The rules for naming ionic compounds are summarized in Table 1.

LEARNING TIP

Check your understanding. Review tables 1 and 2. Then, with a partner, explain in your own words how the ionic compounds in Table 2 are names.

Table 1 Summary of Naming Rules

Positive (metal) ion (written first)	Negative (non-metal) ion (written second)
Monovalent: Use name of element.	Single element: Use element name ending in *ide*.
Multivalent: Use name of element followed by Roman numeral in brackets.	Polyatomic ions: Use name of the polyatomic ion with no changes.
Polyatomic: Use name of ion.	

The examples in Table 2 will help you name ionic compounds.

Table 2 Examples of Ionic Compounds

Ionic compounds containing single ions
1. CaO: The positive ion (Ca^{2+}) can only have one ion charge (monovalent), so it keeps the element name, *calcium*. The negative ion (O^{2-}) is named *oxide*. The name of the compound is *calcium oxide*.
2. FeS: Fe is iron, and it is a multivalent metal. S is sulfur and has an ion charge of 2−. Since there is only one ion of iron, it must have an ion charge of 2+. Therefore, the iron ion must be *iron(II)*. The negative ion (S^{2-}) is named *sulfide*. The name of the compound is *iron(II) sulfide*.
3. LiCl: The positive ion (Li^{+}) is named *lithium* (monovalent). The negative ion (Cl^{-}) is named *chloride*. The name of the compound is *lithium chloride*.
4. K_2S: The positive ion (K^{+}) is named *potassium*. The negative ion (S^{2-}) is named *sulfide*. The name of the compound is *potassium sulfide*.
Ionic compounds containing polyatomic ions
5. $Ca(OH)_2$: The positive ion (Ca^{2+}) is named *calcium* (monovalent). The negative polyatomic ion (OH^{-}) is named *hydroxide*, and it does not change. The name of the compound is *calcium hydroxide*.
6. $BaCO_3$: The positive ion (Ba^{2+}) is named *barium* (monovalent). The negative ion (CO_3^{2-}) is named *carbonate*. The name of the compound is *barium carbonate*.
7. $CrSO_4$: Cr is chromium, and it is a multivalent metal. The polyatomic group SO_4 has an ion charge of 2−. Since there is only one ion of chromium, it must have an ion charge of 2+. Therefore, the chromium ion must be *chromium(II)*. The negative ion (SO_4^{2-}) is named *sulfate*. The name of the compound is *chromium(II) sulfate*.
8. $(NH_4)_3PO_4$: The positive ion NH_4^{+} is named *ammonium* (a polyatomic positive ion). The negative ion (PO_4^{3-}) is named *phosphate*. The name of the compound is *ammonium phosphate*.

8.3

CHECK YOUR Understanding

1. What are monovalent metals?
2. Will two metals form an ionic compound? Explain.
3. Write the name and symbol for the ion of each element listed below.
   (a) sodium
   (b) chlorine
   (c) copper with an ion charge of 2+
   (d) aluminum
   (e) phosphorous
4. Write the name for each ion.
   (a) Ca^{2+}
   (b) F^{-}
   (c) Br^{-}
   (d) Fe^{3+}
   (e) Pb^{2+}
   (f) Fe^{2+}
   (g) Pb^{4+}
   (h) P^{3-}
5. Write the name of the ion for each of the following non-metal elements.
   (a) chlorine
   (b) bromine
   (c) iodine
   (d) phosphorous
   (e) oxygen
   (f) sulfur
   (g) nitrogen
6. Write the name of each polyatomic ion.
   (a) SO_4^{2-}
   (b) PO_4^{3+}
   (c) NO_3^{-}
   (d) OH^{-}
   (e) HCO_3^{-}
   (f) CO_3^{2-}
7. Write the names of the compounds formed by the following combinations of elements.
   (a) sodium and iodine
   (b) lithium and bromine
   (c) silver and phosphorous
   (d) barium and oxygen
8. Use the tables of metals, non-metals, and polyatomic ions on pages 239 to 242 and the Periodic Table at the back of this book to name the following ionic compounds.
   (a) $NaBr$
   (b) $CaSO_4$
   (c) K_2S
   (d) $Ni(NO_3)_2$
   (e) Mg_3N_2
   (f) $Fe_2(CO_3)_3$
   (g) Cr_2O_3
   (h) $Al_2(SO_4)_3$
   (i) Cu_2SO_4
   (j) $Pb(NO_3)_4$
9. Chromium is reacted with oxygen to form two chromium ions for every three oxide ions. What is the name of the compound?
10. There are two correct formulas for the reaction of nickel and oxygen: NiO and Ni_2O_3. What are the names of these compounds? Explain why two different names are necessary.
11. Does a compound called calcium aluminide exist? Explain.
12. Which of the following chemical formulas are correct? Explain why the incorrect formulas are incorrect.
    (a) Al_2O_3
    (b) $CrSO_4$
    (c) Fe_3O_2
    (d) $Fe_2(SO_4)_2$
13. How does using a common naming system for chemical compounds benefit scientists?

8.4 Chemical Families

What makes up a family? Your parents or caregivers, siblings, and yourself make up a family. You may all share certain characteristics, but are you identical? A **chemical family** can be defined as a group of elements that have similar properties and form compounds with similar properties. A chemical family can also be described as a column, or numbered group, in the Periodic Table. A chemical family is a further classification of elements beyond metal, metalloid, or non-metal. In this section, you will explore some chemical families in more detail (Figure 1). 8B *Investigation*

8B *Investigation*

Chemical Families and Compounds

To perform this investigation, turn to page 260.

In this investigation, you will compare elements from Groups 1, 2, 16, and 17.

LEARNING TIP

You can use a table to help you organize information for studying. Make a five-column table with the headings: Alkali metals, Alkaline earth metals, Halogens, Noble gases, Hydrogen. Under the appropriate heading, record information in point-form notes to indicate where the chemical family is located in the Periodic Table, its group number, the elements found in each group, and a summary of the properties of each group.

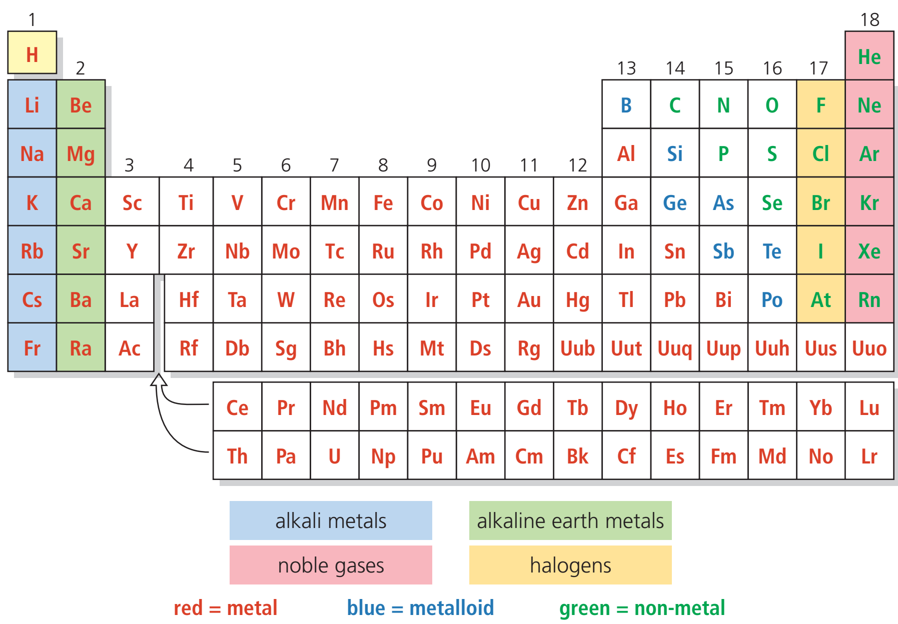


Figure 1 Chemical families are special groups of elements that have similar properties.

Figure 2 Sodium metal is soft enough to be cut with a knife.

Alkali Metals

The **alkali metals** are found in the first column (Group 1) of the Periodic Table with the exception of hydrogen. They are lithium, sodium, potassium, rubidium, cesium, and francium. They all have an ion charge of 1+ and are soft, low-density metals that can be cut with a knife (Figure 2). Lithium, sodium, and potassium can float on water. They are not found free in nature because they react with air and water. They are commonly found as ions in salt deposits and in seawater. Sodium and potassium are the sixth and eighth most abundant elements in Earth's crust.

Refined alkali metals are stored under oil because they react with water to form hydrogen gas and an alkaline (or caustic) solution, from which they get their name. (Alkaline solutions are solutions with more hydroxide ions than hydrogen ions). Sodium, potassium, and the other alkali metals generate enough heat in this reaction to ignite the hydrogen gas produced (Figure 3). Cesium, which sinks in water, produces hydrogen gas so rapidly that it generates a shock wave that can shatter a glass container. Lithium is used in lightweight high-capacity batteries and in grease. Sodium is used in the manufacture of other chemicals. Potassium is a primary ingredient in fertilizers as potassium oxide (potash). GO

If you would like to learn more about alkali metals and other chemical families, go to **www.science.nelson.com** GO

Figure 3 Potassium metal reacts with water, producing hydrogen gas. The hydrogen is ignited by the heat released in the reaction.

Table 1 summarizes some of the properties of the alkali metals.

Table 1 Some Properties of the Alkali Metals

Colour	silvery-grey
Density	0.53 g/cm^3 to 1.88 g/cm^3
Melting point	low; solid at room temperature
Conductivity	very good for electricity and heat
Reactivity	very reactive
Ion charge	1+

Did You KNOW?

Elements in Gemstones

Emeralds are crystals formed from mineral compounds that contain beryllium, aluminum, and silicon (beryl). If you would like to learn more about elements that make up gemstones, go to

www.science.nelson.com GO

Alkaline Earth Metals

The **alkaline earth metals** are found in the second column (Group 2) of the Periodic Table. They are beryllium, magnesium, calcium, strontium, barium, and radium. They all have an ion charge of 2+. They are hard, have low density, and react with air and water. They are primarily found as ions in rock minerals, such as calcium carbonate (also called chalk and limestone), but magnesium is often recovered from seawater (as magnesium chloride). Calcium and magnesium are the fifth and seventh most abundant elements in Earth's crust.

Calcium and barium react violently with water (Figure 4). Barium must be stored under oil. Magnesium burns brightly in air (it is used in flash powder and fireworks). and reacts with carbon dioxide, so magnesium fires cannot be extinguished with CO_2 fire extinguishers (Figure 5).

Figure 4 Calcium metal reacts with water to form bubbles of hydrogen gas.

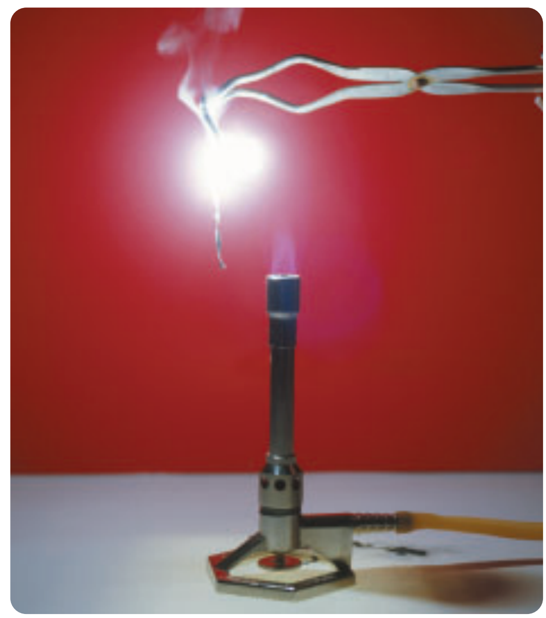


Figure 5 Magnesium metal burns with a bright white light.

Magnesium and beryllium are important metals for many industrial alloys. Magnesium is often alloyed with aluminum to increase its strength yet maintain its low density. On its own, magnesium has the highest strength-to-weight ratio of any metal. Beryllium and all of its compounds are toxic. Table 2 summarizes some of the properties of the alkaline earth metals.

Table 2 Some Properties of the Alkaline Earth Metals

Colour	silvery-white
Density	1.55 g/cm^3 to 5.00 g/cm^3
Melting point	higher than alkali metals; solid at room temperature
Conductivity	good for electricity and heat
Reactivity	very reactive
Ion charge	2+

Halogens

The **halogens** are the second-last column (Group 17) of the Periodic Table. They are fluorine, chlorine, bromine, iodine, and astatine. They are not found free in nature because they react with most other elements, but they are often found in compounds with alkali metals. They all have an ion charge of 1− and they are all toxic in their elemental form.

Fluorine and chlorine are gases at room temperature, bromine is a liquid, and iodine is a solid. Iodine sublimes directly to a gas. All of the halogens have bright colours as gases: chlorine is yellow, bromine is orange, and iodine is purple (Figure 6).

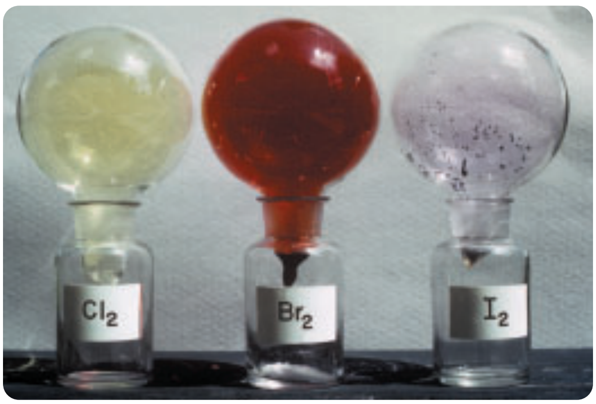


Figure 6 Chlorine, bromine, and iodine have vivid colours as gases.

Iodine dissolved in alcohol is a common disinfectant used to treat cuts and scrapes. Chlorine is an important industrial chemical, used in plastics (PVC stands for polyvinyl chloride), household bleach, and to purify water supplies. Sodium fluoride and tin(II) fluoride are additives for toothpaste. Table 3 summarizes some of the properties of the halogens.

Table 3 Some Properties of the Halogens

Colour	range of bright colours as gases
Density	0.0017 g/cm^3 to 4.93 g/cm^3
Boiling point	low
Health effects	very toxic
Reactivity	very reactive; reacts with hydrogen to form acids
Ion charge	1−

Noble Gases

Noble gases are the elements in the last column (Group 18) of the Periodic Table. They are helium, neon, argon, krypton, xenon, and radon. They are all non-reactive, and they do not readily form ions. They are tasteless, colourless, odourless, and non-toxic (except for radon).

Helium, being less dense than air, is used as a gas for lifting balloons and blimps (also known as airships). Neon gives off a distinctive red-orange colour when electricity passes through it, and is used for neon signs.

Did You KNOW?

Rare Elements

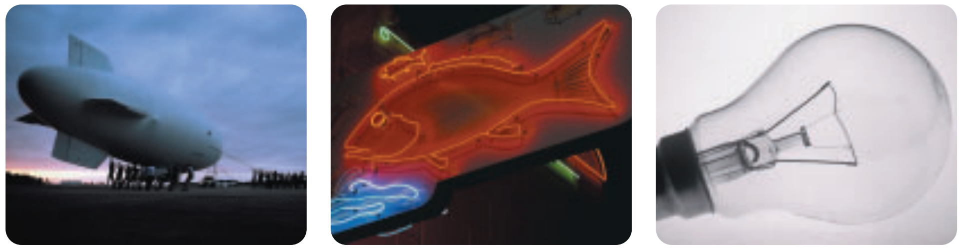
Astatine and francium are the two rarest elements on Earth. At any one time, the total amount of astatine on Earth is less than 30 g, and there is less than 20 g of francium. Predicted by Mendeleev to exist, astatine was first synthesized in 1940.

Did You KNOW?

News about Noble Gases

The noble gases were once called the "inert gases" because they were thought to be completely unreactive. Scientists later discovered, however, that some noble gas can be made to form compounds. This was first accomplished at the University of British Columbia in 1962 by Neil Bartlett when he prepared the compound xenon hexafluoroplatinate ($XePtF_6$). Compounds of most of the noble gases have since been found.

Argon, krypton, and xenon are used to fill incandescent light bulbs. They shield hot tungsten filaments in a light bulb from oxygen (Figure 7). Liquid helium has a temperature of −269 °C and is used to produce extremely low temperatures in a lab or for industry. Radon is denser than air and can accumulate to hazardous levels in the basements of buildings. Table 4 summarizes some properties of the noble gases.



(a) (b) (c)

Figure 7 (a) Helium gas has the lowest density of all gases, and is used to lift balloons and blimps. (b) Neon gas gives off a bright red-orange light when used in electric discharge lights. (c) Noble gases (argon, krypton, and xenon) are used in incandescent light bulbs to prevent the filament from burning off.

(a)

(b)

Figure 8 (a) A hydrogenator is used to add hydrogen to vegetable oils. (b) Automakers are developing cars that use hydrogen as fuel, producing only water as exhaust.

If you want to learn more about fuel cells, go to
www.science.nelson.com

Table 4 Some Properties of the Noble Gases

Colour	colourless
Density	0.00018 g/cm^3 to 0.00973 g/cm^3
Boiling point	very low; for example, helium boils at −269 °C
Reactivity	generally non-reactive
Ion charge	0

Hydrogen

Hydrogen is often referred to as a "family of one." Having only one electron, it can either give up or acquire an electron and can form either positive or negative ions. It has an ion charge of either 1+ or 1−, so it behaves either as a highly reactive metal or as a highly reactive non-metal, depending on the element that it combines with. It is the most common element in the universe and the main component of stars. Because it is so reactive, it is rarely found on Earth in its natural, free state.

Hydrogen is isolated by passing electricity through water. The presence of positive hydrogen ions in water is a property of an acid. It is an important industrial chemical. It is bubbled through liquid vegetable oils to produce hydrogenated oils, or trans fats, which are solid at room temperature (Figure 8(a)). Hydrogen is used as a fuel to burn or react in fuel cells, and is used in the manufacture of many products and chemicals (Figure 8(b)).

Table 5 summarizes some of the properties of hydrogen.

Table 5 Some Properties of Hydrogen

Colour	colourless
Density	0.000090 g/cm^3 (lowest of all elements)
Boiling point	extremely low
Reactivity	very reactive; burns in air; forms a diatomic molecule, H_2; combines with many negative ions to form acids
Ion charge	1+ or 1−

Predicting Formulas Using Chemical Families

If you know about chemical families and understand how the Periodic Table organizes elements, you can predict the formulas of compounds more easily. For example, all the elements in Group 1 of the Periodic Table (alkali metals and hydrogen) have the same ion charge. So, if sodium reacts 1:1 with chlorine (a Group 17 element) to form sodium chloride (NaCl), then each of the Group 1 elements will do the same, for example (KCl and LiCl). You can also predict that sodium and other Group 1 elements will react in a 1:1 ratio with any element in Group 17, (for example, NaF and KF).

Similarly, if magnesium (a Group 2 element) and bromine (a Group 17 element) react in a 1:2 ratio to form magnesium bromide, $MgBr_2$, then magnesium iodide should have a similar formula, MgI_2. What would be the formula of magnesium fluoride? It is MgF_2. What would be the formula of calcium bromide? It is $CaBr_2$. You will find other family relationships in Table 6, which shows some of the compounds formed by different members of the same chemical family. Note the similarities in the formulas.

Table 6 Compounds

Known compound formula	Predictions from periodic table
KCl	KI, KF, KBr, LiCl, NaCl, RbCl, CsCl
$SrBr_2$	SrF_2, $SrCl_2$, SrI_2, $BeBr_2$, $MgBr_2$, $CaBr_2$, $BaBr_2$
$AlCl_3$	AlF_3, $AlBr_3$, AlI_3, BCl_3, $GaCl_3$, $InCl_3$, $TlCl_3$
Mg_3N_2	Mg_3P_2, Mg_3As_2, Be_3N_2, Ca_3N_2, Sr_3N_2, Ba_3N_2

The properties of compounds that are formed from different elements in a chemical family have similar properties. The physical and chemical properties of strontium and calcium are similar, so your body will use strontium compounds like it uses calcium compounds—to build bone tissue. Sodium chloride and sodium iodide look and taste very much the same. All sodium compounds and all potassium compounds are soluble in water. GO

Did You KNOW?

Radium

Radium is very dangerous if ingested because the body will use radium the same way it uses radium's family member, calcium—to build bone cells. The radioactivity of radium atoms will cause damage to the surrounding cells, particularly the bone marrow. To learn more about this and the use of radioactive strontium to treat bone cancer, go to

www.science.nelson.com GO

To find more uses of elements, go to
www.science.nelson.com GO

8.4 CHECK YOUR Understanding

1. State the ion charge of
   (a) the alkali metals
   (b) the halogens
   (c) the alkaline earth metals
   (d) the noble gases
2. What is one distinguishing property of the alkali metals?
3. Describe three uses for elements in the alkali metals family.
4. List three uses for the alkaline earth metals.
5. What is a distinguishing property of the noble gases?
6. What are three applications for noble gases?
7. Which of the chemical families have bright colours as gases?
8. What is an industrial use of chlorine?
9. What is so unique about hydrogen that it is called "a family of one"?
10. If an alkali metal reacts with a non-metal in a 1:1 ratio, what ratio will result when the non-metal reacts with other alkali metals?
11. The formula for aluminum bromide is $AlBr_3$. State the formula for
    (a) aluminum fluoride
    (b) aluminum chloride
    (c) aluminum iodide
12. The formula for calcium nitride is Ca_3N_3. State the formula for
    (a) magnesium nitride
    (b) barium nitride
13. What is the formula for the compound formed when lithium reacts with each of the following elements?
    (a) chlorine
    (b) iodine
    (c) oxygen
    (d) sulfur
    (e) nitrogen
    (f) phosphorus
14. What is the formula for the compound formed when chlorine reacts with each of the following elements?
    (a) magnesium
    (b) strontium
    (c) sodium
    (d) rubidium
15. The halogens are very toxic as elements, but may not be toxic as part of compounds. Give two examples of halogen compounds that we can ingest safely in moderate amounts.
16. Hydrogen gas was used to lift the *Hindenburg* (Figure 9). On May 6, 1937, the hydrogen gas in its hull caught fire during landing. Which member of the noble gas family would have been a safer alternative to hydrogen? Explain.

Figure 9

SEMICONDUCTORS — METALLOIDS IN ACTION

How many of the following have you used in the last 24 h: an MP3 player, a bank machine, a video game, a computer, a cellphone? Have you ridden in an automobile, watched a flat-screen TV, or used a calculator?

All of these devices use semiconductors, microscopic electronic components made from metalloids. Metalloids are the chemical family of elements located between the metals and the non-metals. Semiconductors have the ability to conduct electricity or not, depending on certain conditions. Semiconductors can conduct as well as metals, and they can also be used to create electronic components that control the flow of electricity. When many microscopic semiconductors are linked together on one "chip," the device that is created is called a microprocessor (Figure 1). The world is being transformed by the power of this tiny computer.

To many people, the microprocessor is the ultimate "black box." We may not understand how it works, but we really like what it is able to do. Although many different sciences contributed to its creation, chemistry provided the foundation. Microprocessors are created from mixing pure metalloids. The metalloids' combination of metallic and non-metallic properties is precisely what makes them ideal for microprocessors.

Figure 1 Semiconductors linked together to form a microprocessor

Making a microprocessor starts with pure silicon, the second most abundant element on Earth. Silicon, like carbon above it in the Periodic Table, has four outside electrons that bond with four neighbouring atoms to form a crystal lattice. You know the crystal lattice of carbon as diamond. The crystal lattice of silicon forms a silvery metallic-looking substance that can be sliced into wafers (Figure 2).

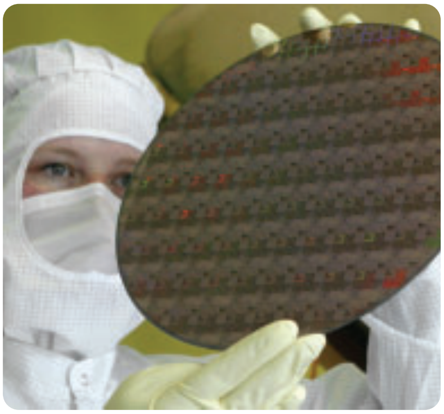


Figure 2 A wafer of silicon, from which dozens of microprocessors will be made

Pure silicon cannot conduct electricity because all of its electrons are tied to neighbouring atoms. Small amounts of other elements are mixed with the silicon to make conduction possible. Phosphorus or arsenic, from the chemical family to the right of silicon in the Periodic Table, contributes extra electrons to the lattice, making it an n-type semiconductor. Boron and gallium, from the family to the left of silicon, lack an electron and create a positive "hole" into which an electron can flow. This is called a p-type semiconductor.

When these two types of semiconductors are placed together, they allow electricity to flow from the n side to the p side, but prevent it from flowing the other way. This is called a diode, and it is used to protect circuits by forcing electricity to flow in one direction only. When semiconductors are put into groups of three (npn or pnp), the flow of electricity can be switched on and off. This device is called a transistor. The switching on and off of many transistors allows semiconductor components to count by twos, store data, and execute instructions. These are the basic functions of computers. Linking millions of microscopic transistors on a single chip of silicon creates a microprocessor—essentially the "brain" of a computer.

All the devices mentioned above use microprocessors to operate. Some of the uses of microprocessors are obvious, such as calculators, but some are not. Automobiles use microprocessors to control the engine, the antilock brakes, even the keyless entry system. Since their development in the 1950s, the metalloid-based semiconductors and the microprocessors made from them have become more important to our society than almost any other technology.

DECISION MAKING SKILLS

- ○ Defining the Issue
- ● Researching
- ○ Identifying Alternatives
- ● Analyzing the Issue
- ● Defending a Decision
- ● Communicating
- ○ Evaluating

Heavy Metals in the Environment

Heavy metals, which are found in the middle of the Periodic Table, have a relatively high density and can be toxic or poisonous at low concentrations (Figure 1). There is a growing concern about our increasing exposure to heavy metals in the environment. The concentration of a heavy metal in animals or people can reach a level that will affect their short-term and long-term health. Heavy metals are important, however, in the design and manufacture of consumer and commercial goods, and the production of energy.

(a)

(b)

(c)

Figure 1 (a) The liquid mercury from a mercury thermometer is hazardous. If the thermometer breaks, the mercury becomes a vapour, which is easily breathed in. (b) These old car batteries contain a significant amount of lead. (c) Tuna are predators that can accumulate high levels of mercury in their bodies.

The Issue: Health and Environmental Risks Due to Heavy Metals

The federal government is conducting a review of its environmental regulations for heavy metals. The government is holding a meeting at which stakeholders can present their opinions and positions on the use of heavy metals in Canada. The review panel contains federal, provincial, and local government representatives, research scientists, and local citizens. The review panel must make a recommendation to the government on whether specific heavy metals should be banned from commercial use.

Background to the Issue

Animals that are higher in the food web (including humans) accumulate higher concentrations of heavy metals. These levels build up in the body systems, and have cumulative effects, both short-term and long-term. For example, mercury as a vapour is easily absorbed by organisms. Mercury is converted to methylmercury, its most damaging form, by bacteria in soil and water. The methylmercury works its way through the food web, accumulating in higher and higher concentrations at each step. This is called bioaccumulation. Fish such as tuna and salmon, and the whales that feed on them, have been shown to have significantly high levels of methylmercury, which can cause serious damage to the brain and nervous system.

Some heavy metals are micronutrients, which are necessary in trace amounts for maintaining good health—copper is needed by the body to help form red blood cells. As well, heavy metals are extremely important to the resource and manufacturing industries. Mercury, for example, is an essential component of energy-efficient fluorescent light bulbs. The amount of mercury is small, however—less than 5 mg. A household thermometer contains up to 500 times more mercury.

Many of our modern technological conveniences or necessities rely on heavy metals. Table 1 provides examples of heavy metals used in industry and consumer goods.

Take a Position

You will assume the role of one of the presenters at the meeting (see the list below), and you will choose one of the following heavy metals to discuss: lead, mercury, cadmium, cobalt, silver, copper, selenium, or chromium. Choose a position for or against the use of the heavy metal. Prepare for your role by considering the health and environmental risks, as well as the benefits to industry, the economy, and society, from the use of the heavy metal. Conduct research to support your position and help you prepare your presentation.

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The Roles

- a representative of one of the primary resource industries that provides significant employment in your community
- an engineer with a manufacturing firm that produces consumer goods at a local factory
- a marketing executive with a chain of large retail stores
- a representative of the local tourism industry
- a member of a local environmental protection group
- a research scientist who is studying the effects of exposure to heavy metals on children
- a member of the provincial medical association
- a representative of the regional health authority

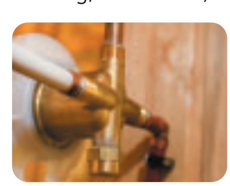
Communicate Your Position

Prepare a presentation that represents the role you assumed and addresses the heavy metal you chose. Consider:

- What arguments support your position?
- Is your position appropriate for the short term, long term, or both?
- Do the risks outweigh the benefits, or vice versa?
- How can you justify your position to the government and the community?

Make your presentation to the panel and be prepared to answer questions.

Table 1
Examples of Uses of Heavy Metals

• lead (batteries, fuel additives, radiation shielding, old paint pigments, solder, old plumbing, roof flashing) 
• selenium (dandruff shampoo, electronics, photographic films and papers) 
• cadmium (rechargeable batteries, metal coatings, pigments, plastics) 
• chromium (alloys, metal coatings, pigments) 
• copper (wood preservatives, plumbing and wiring, roof flashing, electronics) 

8A

Investigation

Separating the Elements from a Compound

There is a great deal of talk about using hydrogen as a fuel when we run out of fossil fuels. It is a proven source of fuel for the space shuttle, where it powers the shuttle's three main rocket engines (Figure 1).

Hydrogen is the most abundant element on Earth and in the universe, making up almost 93 % of all matter. Hydrogen is one of the elements in the compound water; the other is oxygen. Water is abundant on Earth and could be an invaluable source of hydrogen.

In this Investigation, you will separate the elements that form water and verify their proportions in the compound.

Figure 1 The main engines of the space shuttle react liquid hydrogen with liquid oxygen to provide thrust. Notice the blue flames on the right—this is hydrogen fuel being burned.

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Question

What are the proportions of the elements hydrogen and oxygen in the compound water?

Prediction

Make a prediction about the proportions of hydrogen and oxygen in water.

Experimental Design

In this Investigation, you will use electrolysis to separate water into its two elements and verify their proportions.

Materials

- safety goggles
- apron
- electrolysis apparatus
- water
- 2 g of sodium sulfate (Na_2SO_4)
- 6 V power supply
- electrical leads
- wood splints
- Bunsen burner and flint

Procedure

1. Work with a partner. Put on your safety goggles and apron.
2. Read through the Procedure and make a table to record your observations.

3. Assemble the electrolysis apparatus as shown in Figure 2. Mark the test tubes A and B. Place test tube A over the positive terminal and test tube B over the negative terminal.

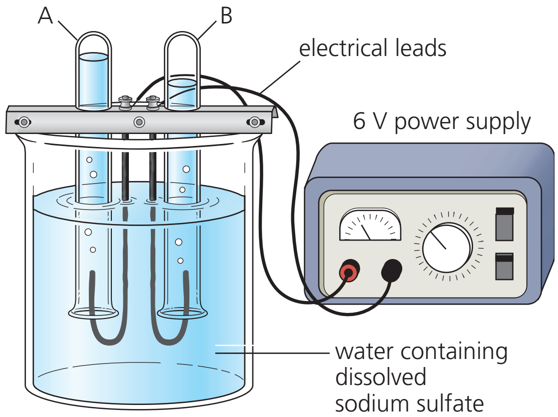


Figure 2 Step 3

4. Add the sodium sulfate (Na_2SO_4) to the water. The purpose of the sodium sulfate is to provide ions so the electric current will flow through the water. Pure water contains too few ions for an effective current to form.
5. Turn on the power. Observe what happens as soon as the power is turned on. Record your observations.
6. Turn off the power as soon as one of the test tubes fills with gas. Observe what happens when the power is turned off. Compare and record the relative amounts of gas in the tubes.
7. With a partner, prepare to check the nature of the gas in each test tube. **Start with test tube A (which was over the positive terminal).** Hold a thumb or finger over the mouth of the test tube. Remove the test tube from the water, keeping it covered and upside down.
8. Light the splint, and then blow out the flame so the splint is glowing. Next, with test tube A still upside down, remove your thumb and immediately place the glowing splint just inside the mouth of the test tube. Record your observations.
9. Repeat the process for test tube B, but **use a burning splint this time**. Record your observations.
10. Dispose of the solution and put the materials away as directed by your teacher. Clean your work area and wash your hands.

Analysis

(a) What was the identity of the gas in test tube B? Provide two pieces of evidence to support your answer.

(b) What was the identity of the gas in test tube A? Provide two pieces of evidence to support your answer.

(c) Write a simple word equation with an arrow connecting the substance you started with and the substances you ended up with.

(d) Write a simple word equation to describe what you think happened at the mouth of test tube B with the lit splint.

(e) What were the relative volumes of the hydrogen and oxygen gases produced? Do these proportions support your prediction?

(f) What do you know about the chemical formula of water that supports your results?

Evaluation

(g) What safety precautions did you take during this Investigation? Why were these precautions necessary?

Synthesis

(h) During the 1800s, electrolysis was a technique used by many chemists all over the world. Why do you think it was so popular at that time?

(i) Do you think hydrogen has the energy needed to replace fossil fuels? Why or why not?

(j) Suggest possible problems or concerns that might arise when switching from gasoline to hydrogen fuel for cars.

8B Investigation

Chemical Families and Compounds

The Periodic Table groups elements by common properties. Can you use the Periodic Table to predict how elements will react? Can you use the properties of elements to predict the properties of the compounds they form? Do elements in the same family form similar compounds?

Question

Write a question for this Investigation.

Prediction

Read the Procedure, and then write a prediction about the behaviour of the elements and compounds.

Experimental Design

In this Investigation, you will compare the elements in Groups 1 and 2 directly by examining their physical appearance and reaction with water. Then you will compare the elements in Groups 1 and 2 and Groups 16 and 17 by examining the solubility of the compounds formed by these elements.

Materials

- microtrays or watchglasses
- toothpicks
- safety goggles
- apron
- water
- small samples of: calcium carbonate, magnesium carbonate, sodium carbonate, potassium carbonate, copper(II) chloride, copper(II) bromide, copper(II) oxide, copper(II) sulfide

Always assume that all chemicals are toxic. If any of these chemicals are spilled on skin, in eyes, or on clothing, wash the area immediately with plenty of cold water and inform your teacher.

INQUIRY SKILLS

- ● Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Procedure

Part 1: Comparing Elements in Groups 1 and 2 (Teacher Demonstration)

1. Read through the Procedure and make a table to record your observations.
2. Your teacher will demonstrate the reactions of calcium and lithium with water. Note the colour of the indicator and determine whether the contents of the beaker are cloudy or clear after each reaction. Record your observations.
3. Sodium is in the same chemical group as lithium. Write a prediction for how sodium should appear and how it should behave in water.
4. Your teacher will next demonstrate the reaction of sodium with water. Record your observations.

Part 2: Comparing Group 1 and Group 2 Compounds (Student Activity)

5. Obtain a microtray and 10 toothpicks. Put on your safety goggles and apron.
6. Fill a cell of the microtray halfway with water. Obtain a small amount of calcium carbonate, just enough to fit on the flat end of the toothpick (Figure 1). Record your observations of the physical appearance of the compound.

Figure 1 Step 6

7. Place the compound into the water in the cell, and stir gently with the toothpick (Figure 2). Does the compound dissolve in water? Record your observations of the compound's solubility (high or low).

Figure 2 Step 7

8. Repeat steps 6 and 7 with a small amount of sodium carbonate.
9. Potassium is an alkali metal (as is sodium), and magnesium is an alkaline earth metal (as is calcium). Write a prediction for the appearance and solubility of potassium carbonate and magnesium carbonate.
10. Test your prediction by repeating steps 6 and 7 with small amounts of potassium carbonate and magnesium carbonate.

Part 3: Comparing Group 16 and 17 Compounds (Student Activity)

11. Repeat steps 6 and 7 with small samples of copper(II) chloride and copper(II) oxide.
12. Bromine is a halogen (as is chlorine) and sulfur is a Group 16 element (as is oxygen). Write a prediction for the appearance and solubility of copper(II) bromide and copper(II) sulfide.
13. Test your prediction by repeating steps 6 and 7 with small samples of copper(II) bromide and copper(II) sulfide.

Analysis

(a) In Part 1, did the two elements from of Group 1, sodium and lithium, appear and behave similarly? Was one reaction with water more vigorous than the other?

(b) How was the element from Group 2, calcium, similar to and different from the Group 1 elements? What is your evidence?

(c) In Part 2, which Group 1 and Group 2 carbonates had a similar appearance and a similar solubility?

(d) Are your observations consistent with the positions of the elements in the Periodic Table? Explain.

(e) In Part 3, which Group 16 and Group 17 copper compounds had a similar appearance and a similar solubility?

(f) Are your observations consistent with the positions of the elements in the Periodic Table? Explain.

Evaluation

(g) Evaluate the three predictions that you made. Were they supported by your observations? Why or why not?

(h) Briefly describe how the Periodic Table can be used to predict the behaviour of elements and their compounds.

Synthesis

(i) Predict what you would expect if potassium metal were added to water.

(j) Predict the solubility of copper(II) iodide and barium carbonate in water.

(k) Zinc oxide is a white solid and zinc sulfide is a black solid. Both are insoluble. Do these properties agree with your observations? Explain.

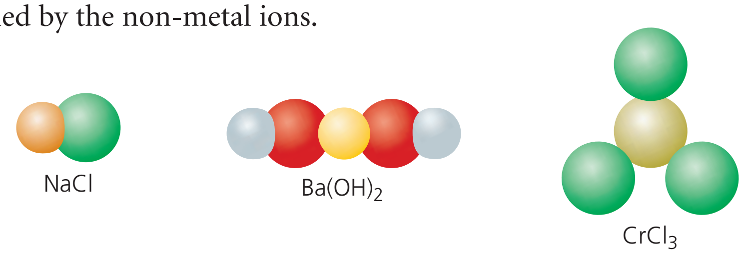
CHAPTER 8

Review

Key Ideas

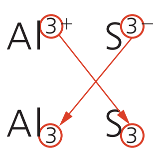
Elements combine to form compounds in exact proportions.

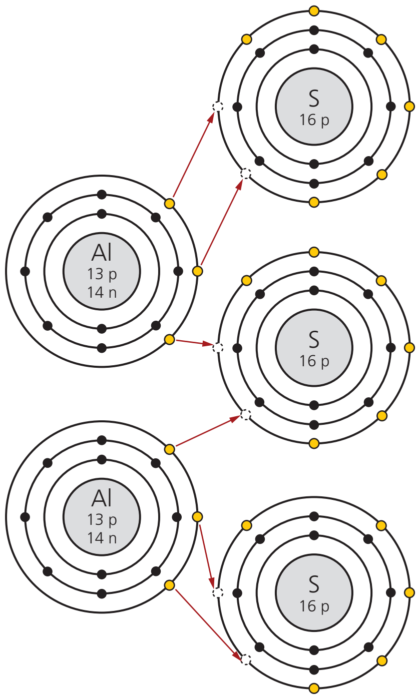
- Metals and non-metals combine by forming ions.
- To form ions, atoms of an element must gain or lose specific numbers of electrons.
- In order to form ionic compounds, the total number of electrons given up by the metal ions must exactly balance the total number of electrons gained by the non-metal ions.



The formulas of ionic compounds can be determined from their names.

- The name of a compound identifies the metal and non-metal ions in the compound. Each ion has a specific ion charge, which is used to determine the formula.
- To determine the number of each ion in a formula, the total ion charges must balance.





Vocabulary

chemical formula, p. 234

polyatomic ion, p. 234

Law of Definite Proportions, p. 238

monovalent, p. 242

multivalent, p. 242

chemical family, p. 248

alkali metal, p. 248

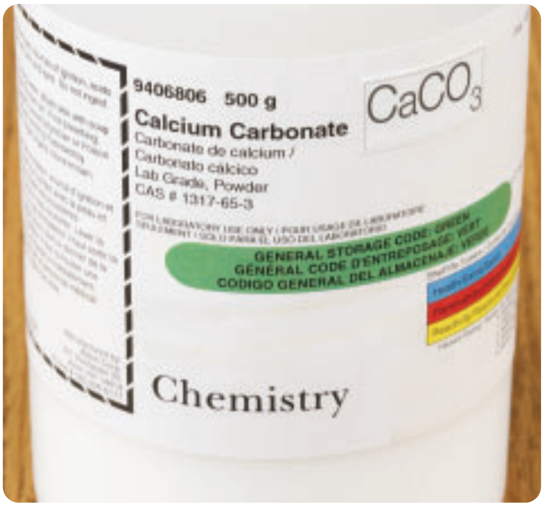
alkaline earth metal, p. 250

halogen, p. 251

noble gas, p. 251

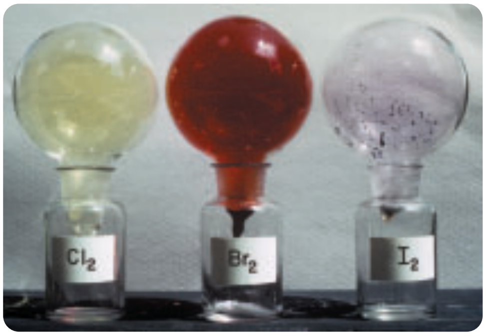
The names of ionic compounds can be determined from their formulas.

- Metal ions have the same name as the metal element.
- Some metal ions (multivalent) can have more than one ion charge. Each ion is identified with a Roman numeral: Fe^{3+} is iron(III).
- Polyatomic groups, or polyatomic ions, have special names. CO_3^{2-} is called the carbonate ion.
- Single non-metals in compounds are given the *ide* suffix. The ion of oxygen is called the oxide ion.
- The name of an ionic compound is the name of the two ions, with the name of the metal ion first. $CaCO_3$ is calcium carbonate.



Chemical families are groups of elements that have similar chemical and physical properties.

- The elements in Group 1 (except hydrogen) are the alkali metals. They are low-density, soft metals that react with water to form hydrogen gas and an alkaline solution.
- The elements in Group 2 are the alkaline earth metals. They are low-density, hard metals, and are common elements in minerals.
- The elements in Group 17 are the halogens. They have bright colours as gases, and are all toxic in elemental form. They are highly reactive.
- The elements in Group 18 are the noble gases. They are non-toxic, colourless, non-reactive gases.



Review Key Ideas and Vocabulary

1. Which of the following best describes a chemical family?
   (a) a group of elements with the same name
   (b) a group of compounds with similar properties
   (c) a group of elements with similar physical properties
   (d) a group of elements with similar physical and chemical properties
2. List the elements in each of the following chemical families.
   (a) noble gases
   (b) halogens
   (c) alkaline earth metals
   (d) alkali metals
3. What is the ion charge of an alkaline earth metal?
   (a) 0
   (b) 1+
   (c) 2+
   (d) 3+
   (e) 4+
4. A gaseous element has a vivid colour and is toxic. Which chemical family does it belong to?
   (a) the noble gases
   (b) the halogens
   (c) the alkaline earth metals
   (d) the alkali metals
5. Which of the following elements is a member of the alkaline earth metals and reacts with water to form hydrogen gas?
   (a) sodium
   (b) aluminum
   (c) strontium
   (d) calcium
6. List three members of the noble gas family.
7. Element A and element B belong to the same chemical family. Element A is soft and ductile, conducts electricity, and reacts with ammonia. What properties would you expect element B to have?
8. Write the formula for each of the following compounds.
   (a) sodium chloride
   (b) potassium chloride
   (c) potassium oxide
   (d) magnesium oxide
   (e) aluminum oxide
   (f) aluminum nitride
9. Write the formula for each of the following ions. Include the ion charge.
   (a) iron(III)
   (b) calcium
   (c) oxide
   (d) carbonate
   (e) ammonium
   (f) bromide
10. Write the formula for each of the following compounds.
    (a) ammonium fluoride
    (b) ammonium sulfide
    (c) magnesium chlorate
    (d) magnesium carbonate
    (e) magnesium phosphate
    (f) aluminum phosphate
11. Write the formula for each of the following compounds.
    (a) copper(II) nitrate
    (b) copper(I) nitrate
    (c) iron(II) carbonate
    (d) iron(III) carbonate
    (e) lead(IV) chloride
    (f) lead(II) fluoride
12. Write the name of each of the following compounds.
    (a) Al_2O_3
    (b) $CaCO_3$
    (c) NH_4Cl
    (d) Fe_2S_3
    (e) $Cr_3(PO_4)_2$
    (f) KOH
13. Some compound formulas such as $Mg(HCO_3)_2$ include brackets. Explain why the brackets are necessary.

Use What You've Learned

14. Copper is reacted with chlorine and the ratio of the ions is determined to be 1:1. In another reaction of the same elements, the ratio of ions is determined to be 1:2. Write the formula for each compound.

15. Many people use the compound sodium bicarbonate to settle an upset stomach. "Bicarbonate" is an older name for the polyatomic ion "hydrogen carbonate." Write the formula for this compound.

16. The compound strontium dihydrogen phosphate has the formula $Sr(H_2PO_4)_2$. What is the ion charge of the dihydrogen phosphate (H_2PO_4) ion? How did you determine the charge?

17. Examine the image in Figure 1. Which chemical family does the metal belong to? What other properties does the metal have?

Figure 1

18. Baking soda and baking powder are two leavening agents that are used by bakers. Baking powder is a dry mixture of baking soda (sodium hydrogen carbonate) and cream of tartar (potassium hydrogen tartrate).

(a) Define the term "leavening" as it applies to baking. Name one other leavening agent.

(b) Write a short description of how baking powder and baking soda produce their effects. Include the chemical formulas of the compounds involved.

(c) Do you think that it is important for bakers and cooks to have some knowledge of chemistry? Explain.

Think Critically

19. Examine the labels of several household items, such as toothpaste, shampoos, breakfast cereals, and cleaners for the chemical ingredients they contain. Write the names of the chemical compounds. Use text and electronic resources to determine their formulas, and research the purposes of the compounds.

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20. You may find older chemical names still in use. The table below gives some examples.

Formula	IUPAC name	Old name
Na_2HPO_4	sodium monohydrogen phosphate	disodium phosphate
Na_3PO_4	sodium phosphate	trisodium phosphate or TSP
SnF_4	tin(IV) fluoride	stannous fluoride
$CuSO_4$	copper(II) sulfate	cuprous sulfate

Conduct research to learn about older naming systems. Why do you think the old names are still used? Should there be a difference between the compound names that scientists use and the names used to market products to consumers?

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21. Silver bromide is a light-sensitive compound used for photographic films and papers. Do you think silver iodide could be substituted instead? Explain.

Reflect on Your Learning

22. The International Union of Pure and Applied Chemistry (IUPAC) determines what naming systems and other standards will be used by chemists. Write a short paragraph to explain why this organization is important for scientists.

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23. Describe everyday situations in which your knowledge of chemical names and formulas could be useful.

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UNIT B

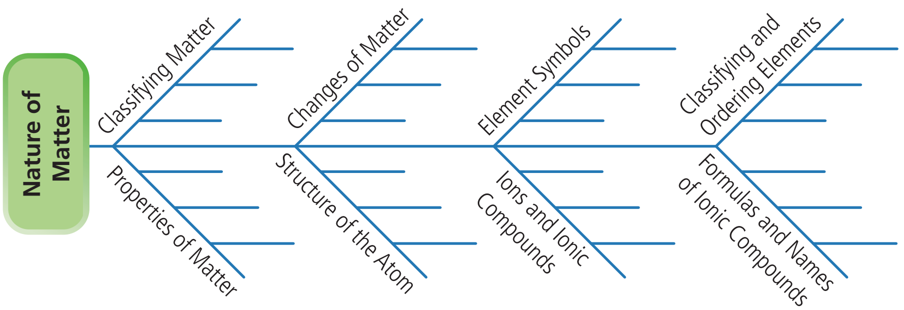
Review

Atoms, Elements, and Compounds

Unit Summary

In this unit, you have learned about matter. You have learned that all matter is made up of atoms and that the structure of the atoms in different substances determines the properties and behaviours of the substances.

Complete the following fishbone organizer in your notebook. Check the chapter reviews and vocabulary lists for the unit to ensure that you have included the important ideas about each major concept.



Review Key Ideas and Vocabulary

1. Which two terms are both pure substances?
   (a) elements, mixtures
   (b) elements, compounds
   (c) compounds, homogeneous mixtures
   (d) homogeneous, heterogeneous mixtures
2. Which of the following properties of paint tell you that it is a heterogeneous mixture?
   (a) The colours run when you paint.
   (b) The paint drips when you paint.
   (c) There is a thick layer at the bottom of the can.
   (d) The paint gets dried up and hard after you open the can.
3. Which two words apply to the air in our atmosphere?
   (a) gas, element
   (b) gas, mixture
   (c) solid, mixture
   (d) liquid, compound
4. Which property can always be used to identify chemical change?
   (a) Energy is given off.
   (b) New properties appear.
   (c) A new substance is produced.
   (d) Previous properties disappear.
5. Which two words apply to the substance carbon dioxide?
   (a) gas, mixture
   (b) gas, element
   (c) liquid, mixture
   (d) gas, compound
6. Which of the following processes are physical changes, and which are chemical changes?
   (a) paper burning
   (b) vinegar and soy sauce mixing
   (c) iron nails rusting
   (d) eyelashes being curled
   (e) aging
   (f) milk souring
   (g) ice cream being scooped out of a container

(h) your mouth watering when you see food
(i) fingernails being cut
(j) mango ripening

7. Which characteristic makes one model better than another?
(a) It has more facts.
(b) It is easier to learn.
(c) It makes better observations.
(d) It explains the evidence better.

8. Melting happens when
(a) the particles get hot
(b) the particles vibrate more
(c) the particles begin to liquefy
(d) the particles' motion increases so they begin to slide past each other

9. The following box lists some characteristics of gases according to the kinetic molecular theory.

A. The particles are very far from each other.
B. The particles move around rapidly in straight lines in all directions.
C. The particles collide with the walls of the container they are in.
D. The particles are too far apart to exert attraction on each other.
E. Heat causes the average speed of the particles to increase.

Write the letter(s) of the characteristic(s) that can explain the following observations.
(a) Gases are easy to compress.
(b) Gases spread out to fill the whole space they are in.
(c) Gases are evenly distributed in whatever container they are in.
(d) Gases are less dense than solids and liquids.
(e) Cooling a gas enough can turn it into a liquid.

10. Who was the first scientist to propose that matter was made of atoms?
(a) Dalton
(b) Priestly
(c) Thomson
(d) Rutherford

11. Which discovery led to Thomson's atomic theory?
(a) Matter is made of atoms.
(b) Atoms contain electrons.
(c) The neutron has no charge.
(d) Noble gases do not form ions.

12. Which idea made Bohr's theory differ from previous theories?
(a) The nucleus contains neutrons.
(b) The atom is not a smooth, solid sphere.
(c) Electrons can only exist in certain "orbits."
(d) Electrons "orbit" the nucleus like planets around the sun.

13. The number of electrons allowed in each shell, in order, are
(a) 2, 2, 2
(b) 2, 8, 8
(c) 8, 8, 8
(d) 8, 2, 2

14. A compound is formed from one lead atom and four chloride atoms. The formula of the compound is
(a) $PbCl$
(b) Cl_4Pb
(c) Pb_2Cl
(d) $PbCl_4$

15. The formula for the compound tin(II) sulfate is
(a) $SnSO_4$
(b) SO_4Sn
(c) Sn_2SO_4
(d) $Sn(SO_4)_2$

16. Explain the difference between the two terms.
   (a) physical property, chemical property
   (b) element, compound
   (c) homogeneous mixture, heterogeneous mixture
   (d) atom, molecule
   (e) ductile, malleable
   (f) atom, ion
   (g) noble gas, halogen
   (h) proton, neutron

17. Match each application with its most related property.

Property	Application
(a) electrical conductivity	A. wooden pot handles
(b) flammability	B. suspension bridge
(c) density	C. plastic cover of wires
(d) ductility	D. limestone caves
(e) corrosion	E. paint
(f) melting point	F. car bodies
(g) heat conductivity	G. rust on the *Titanic*
(h) colour	H. gasoline
(i) reaction with acid	I. lead fishing weights
(j) malleability	J. heater elements

18. Write the formula for each of the following compounds.
   (a) sodium fluoride
   (b) calcium hydroxide
   (c) aluminum nitrate
   (d) manganese(IV) sulfate
   (e) potassium oxide
   (f) lead(II) phosphide

19. Write the name of each chemical compound.
   (a) NH_4OH
   (b) K_2SO_4
   (c) KCl
   (d) MnO
   (e) $FeCl_3$
   (f) Ca_3P_2

Use What You Have Learned

20. When iron is left damp for any length of time, a red-brown coating (rust) soon forms on its surface. Explain why this happens.

21. Make a list of five dangerous chemicals in your home. Based on the household hazard label or the WHMIS symbol, describe the possible danger and the safety precautions required for each chemical.

22. Describe three observations that you would use to help you decide whether a change is physical or chemical.

23. Sulfur dioxide is produced by power plants that burn coal and oil containing traces of sulfur. Unfortunately, the sulfur dioxide reacts with water in the atmosphere to form sulfuric acid (acid rain). Is this a physical or chemical change? Explain.

24. Why did Berzelius' invention of a system of symbols have such a great impact on the discovery of new compounds and elements?

25. Create a small poster of an element. On the poster include the properties, atomic structure, and the use or significance of the element.

26. Make a list of elements that are hazardous to human health, even in small quantities. Describe some of the specific health risks associated with the elements.

27. Two elements are examined. Element A is a colourless, non-reactive gas. Element B is a soft, low-density metal that reacts with water. For each element, give
   (a) the chemical family it belongs to
   (b) the number of electrons in its outer shell
   (c) its ion charge

Think Critically

28. The microscopic world is very different from the one with which you are familiar. Imagine shrinking down to particle size. Now consider the following scenarios. Write what each of these might look like in the microscopic world.

(a) a solid melting into a liquid
(b) water vapour condensing on a bathroom mirror
(c) a solid material being heated
(d) salt water evaporating and leaving some salt in the bottom of a beaker

29. Research the names of some elements. Identify five elements named after countries, five named after astronomical objects, five named after individuals, and five named after towns or cities.

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30. Imagine you are a particle in an ice cube that has fallen out of a cold drink on a hot day. Describe what happens to you in microscopic terms. You can stop when you reach the sky!

31. Carbon fibre is a new material that is transforming the airline industry (Figure 1) and wherever there is a need for strength and lightness in building materials. Use the Internet to find out about the special properties that make carbon fibre a true space-age material.

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Figure 1

32. A new element with the atomic number 118 has just been discovered, or, more correctly, "created." Conduct research to find out the number of protons, neutrons, and electrons in the element. Find out how much of the element was created and how long it existed.

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33. Global warming is a controversial topic, but there is growing agreement that there is a warming trend. Research global warming with some of the following questions in mind: What are the greenhouse gases? Where do they come from? How do they warm the planet?

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34. Visit a garden supply centre and note the information and instructions on the packaging for at least three fertilizers that are not labelled organic and at least one fertilizer that is labelled organic. Examine the labels of the non-organic fertilizers. What are the substances in each fertilizer? What proportions are they in? For what use is each type of fertilizer intended? Examine the label of the organic fertilizer. Does it identify the chemicals in the fertilizer?

35. Much of what you learned about matter and its structure has been in the form of ideas, because atoms, electrons, protons, and neutrons are invisible. Yet, scientists are confident about the existence of atoms and subatomic particles based on experimental evidence. Are there any other subjects in which you are asked to believe something that is an idea? Is the idea connected to experimental evidence?

Reflect On Your Learning

36. Write a short essay entitled "We Live in a Chemical World" to share what you learned about the nature of matter and how this new learning relates to your everyday life.

37. Having completed this unit, write five questions you would like answered about atoms, elements, compounds, chemical names, or formulas, or about anything else that was addressed in the unit.

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UNIT

C

CHARACTERISTICS OF ELECTRICITY

Unit Preview

Static electricity is a buildup of electric charges. How are electric charges produced and transferred? How do static electric charges interact in various materials? How does static electricity differ from current electricity? Electric current results from the movement of electric charges. What factors affect the flow of electricity? How do we use electrical energy in our daily lives? How can we determine the amount of electricity that we consume?

Electricity is an important part of our daily lives. Many of our activities at home and at school depend on electricity. As we investigate the characteristics of electricity, we will learn about electric charges, the movement of electrons, and how we use electricity.

9.1 Types of Electric Charge

Did You KNOW?

Dangerous Experiments

Franklin was lucky to survive his kite experiment. In fact, some scientists have suggested that Franklin survived because he never actually performed the experiment. Franklin took precautions during his experiment: he flew his kite when the thunderstorm was approaching; his kite was not struck by lightning; and he did not touch the kite's string. Other investigators were not as lucky as Franklin. Some repeated the kite experiment and died when lightning struck the kite.

LEARNING TIP

Check your understanding. Ask yourself questions about the ideas in each paragraph. How did Franklin's kite experiment work? What did he discover?

The effects of static electricity are all around you—from the static cling of clothes coming out of a dryer to the spectacular lightning show during a thunderstorm. If you walk across a carpet and touch a metal doorknob, you may get a shock. The friction of your shoes against the carpet causes you to acquire a static electric charge. A **static charge** is an electric charge at rest. The charge that you acquire as you walk across the carpet is called a static charge because it stays on you until you touch a metal doorknob. When you touch the doorknob, the charge moves from you to the door. Although some objects may keep a static charge for some time, eventually the static charge is **discharged**, or lost, to other objects or to the air. Static charges tend to last longer indoors on winter days when the heated air is very dry. The study of static electric charge is called **electrostatics**.

We cannot see electric charge directly. We can only observe the effects of electric charge. For example, when we see lightning, we are seeing the evidence of static electricity being discharged from the clouds.

Benjamin Franklin demonstrated that lightning is a form of electricity by flying a kite during a thunderstorm. His kite was made of silk and had a pointed wire tip about 30 cm long to draw the "electric fire" from approaching thunderclouds (Figure 1). Franklin flew his kite using a piece of twine tied to the ground. A metal key was tied to the twine by a ribbon of silk. Franklin held the other end of the silk ribbon inside a doorway, out of the rain. As thunderclouds approached, the loose fibres of the twine stood out from each other, and he was able to get a spark on his knuckle from the metal key. As a result of experiments by Franklin and others, it was determined that there are two types of electric charges. These charges are called positive charges and negative charges.

Figure 1 Franklin proved that lightning is an electrical discharge during his kite experiment.

TRY THIS: Positive and Negative Charges

Skills Focus: creating models, observing, hypothesizing, predicting

Handle the pith ball carefully.

You can show that different charges exist by rubbing plastic strips to give the strips a charge, and then watching the effect of the charged strip on a pith ball. Acetate is a clear plastic. Vinyl is a type of coloured plastic that is used for raincoats, electrical tape, vinyl siding, and records.

Materials: pith ball on a thread, stand, acetate strip, paper towels, vinyl strip (Figure 2)

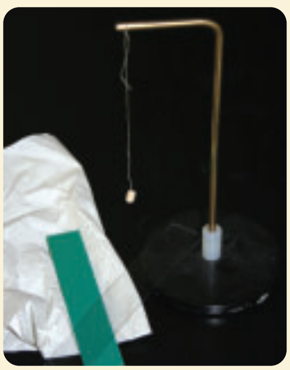


Figure 2

1. Hang a pith ball by a thread tied to a stand.
2. Rub an acetate strip with a paper towel. You can assume that this gives the acetate a positive charge.
3. Bring the acetate strip toward the hanging pith ball. Observe what happens. After the pith ball touches the acetate strip, it will have a positive charge.
4. Rub the acetate strip with a paper towel again, then and bring the strip toward the pith ball. Make a prediction about how objects with similar charges behave. Observe what happens.
5. Rub a vinyl strip with a paper towel and bring it toward the positively charged pith ball. Do not let the strip touch the pith ball. Observe what happens.

A. How do you know that the pith ball has a positive charge?

B. Make a hypothesis to explain your observations. How would you test your hypothesis?

In the Try This activity, you saw that a positively charged hanging pith ball was repelled from a positively charged acetate strip, but was attracted to a charged vinyl strip. This means that the vinyl strip had a different type of charge than the acetate strip; a charged vinyl strip is negative. The activity showed that there are two types of electric charge: positive and negative. We use the + symbol to mean positive and the − symbol to mean negative. An object that has equal amounts of positive charge and negative charge has no overall, or net, charge because the charges cancel each other. An object with no net charge is neutral.

When two objects have the same type of electric charge (like charges), they repel, or push away from, each other. This means that positive repels positive and negative repels negative. However, when two objects have opposite electric charges (unlike charges), they attract each other: positive attracts negative. The **law of electric charges** states that *like charges repel and unlike charges attract.*

Benjamin Franklin imagined that an electric charge was a type of fluid. He believed that every object contained a "natural amount" of the fluid. Objects that contained their natural amount of fluid were neither attracted nor repelled by each other. However, when one object rubbed against another object, one object gained some fluid while the other object lost some fluid, and the objects were attracted to each other. Franklin used the term "positive" to indicate that an object had more than the natural amount of fluid, and "negative" to indicate that an object had less than the natural amount of fluid.

Did You KNOW?

Positive and Negative—Red and Green

Electric charge has two forms, which we now call positive and negative. However, such a naming system is completely arbitrary. The charges could have easily been called red and green. Using the terms "positive" and "negative" makes adding up the total charge easier than trying to blend colours.

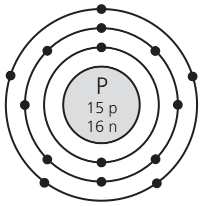


Figure 3 The Bohr diagram for a phosphorous atom

Atomic Structure and Electric Charge

Recall from Chapter 7 that according to modern atomic theory, all matter is made of atoms, and atoms are made of smaller particles (Figure 3). These particles are

protons: have a positive charge and a large mass (about 2000 times larger than an electron)

electrons: have a negative charge and a very tiny mass

neutrons: have no charge and are similar in mass to a proton

Protons and neutrons are in the nucleus of an atom and do not move from the nucleus when an atom becomes charged. Electrons move around the outside of the nucleus and can be more easily added or removed from an atom. If an atom has the same number of protons and electrons, the positive and negative charges cancel each other and the atom is neutral. If an atom does not have the same number of protons and electrons, it has an electric charge. An atom that has an electric charge is called an *ion*. A negative ion is an atom that has picked up extra electrons. A positive ion is an atom that has lost electrons. Although neutrons make up a substantial portion of an atom's mass, they do not make the atom neutral.

Table 1 The Electrostatic Series

Increasing tendency to gain electrons (↑)

plastic wrap
hard rubber
ebonite
vinyl
sulfur
rubber balloon
polyethylene
amber
sealing wax
Lucite
wood
cotton
paper
silk
cat fur
wool
nylon
human hair
glass
acetate
rabbit fur

Increasing tendency to lose electrons (↓)

Positive, Negative, and Neutral Objects

Objects are made of vast numbers of atoms. Neutral objects have equal quantities of positive and negative charges. Objects become negatively charged when they have a greater negative charge (more electrons) than positive charge (fewer protons). Objects become positively charged when they lose electrons. Remember that only electrons can move. Protons remain in the nucleus of an atom.

Electrons can be transferred from one object to another object. For example, when two objects rub against each other, one object loses electrons and the other object gains electrons. Both objects become charged.

The Electrostatic Series

Some materials are more likely than others to gain or lose electrons. Table 1 lists several materials in order of increasing attraction for electrons. For example, materials that are more likely to gain electrons are listed above materials that are less likely to gain electrons. This list is known as the electrostatic series. Paper is below vinyl, which means that if the two are rubbed together, the vinyl gains electrons from the paper and becomes negatively charged. The paper loses electrons to the vinyl and becomes positively charged. Remember that one object gains electrons from another object that loses the electrons.

TRY THIS: *Attracting Neutral Objects*

Skills Focus: creating models, observing

Try this activity to see if neutral objects can be attracted to charged objects.

Materials: round object such as a watch glass, 2 plastic rulers, paper towels

1. Balance a neutral plastic ruler on top of a round object, such as a watch glass (Figure 4).
2. Charge another plastic ruler by rubbing it with a paper towel.
3. Observe what happens when you bring the charged ruler toward the neutral ruler.
4. Observe what happens if you stop moving the charged ruler toward the neutral ruler.
5. Observe what happens when you move the charged ruler away from the neutral ruler.

A. What happened to the neutral (uncharged) ruler in steps 3, 4, and 5? Why do you think this happened?

B. Write a general rule about the interaction of a charged object and a neutral object.

Figure 4

Attraction of Neutral Objects to Charged Objects

A neutral object has an equal number of positive and negative charges. Neutral objects are not attracted or repelled from each other. But what happens when a charged object is brought toward a neutral object? As you saw in the Try This activity, when a positively charged ruler is brought toward a neutral ruler, the nearest end of the neutral ruler moved toward the positively charged ruler. This is because the positively charged ruler causes the electrons in the neutral ruler to shift slightly toward the positive ruler. Figure 5 shows an exaggeration of this effect. As a result of the slight shift of electrons, the end of the neutral ruler is attracted to the charged ruler. Although there is a slight shift of charges within the ruler, the ruler does not gain or lose electrons and is still neutral. This charging effect is known as an **induced charge separation**.

Did You KNOW?

Thales and Amber

In 600 BCE, Thales, one of the seven sages (wise men) of Greece, discovered that when he rubbed amber, a hard tree resin, with fur, it attracted objects such as feathers and pieces of straw. The Greek word for amber is *elektron*, from which we get the word "electricity."

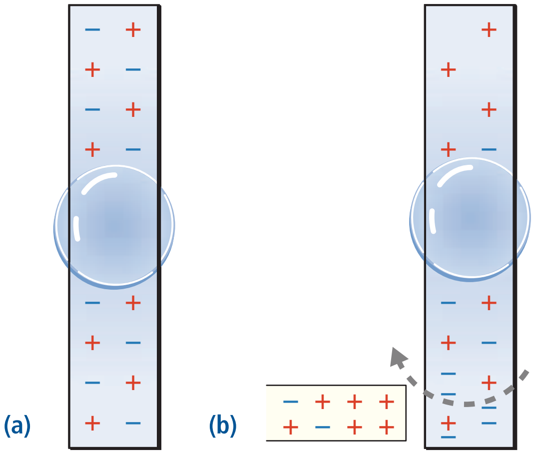


Figure 5 (a) A neutral ruler (b) The neutral ruler is attracted to a positively charged ruler.

9.1 CHECK YOUR Understanding

1. Write a definition, in your own words, of the term "static charge."
2. Give three examples of static electricity.
3. What type of charge does amber (Figure 6) acquire when it is rubbed with a nylon cloth? What type of charge does the nylon cloth acquire? How does the size of the charge on the amber compare with the size of the charge on the nylon cloth? (Hint: Refer to the electrostatic series on page 276.)

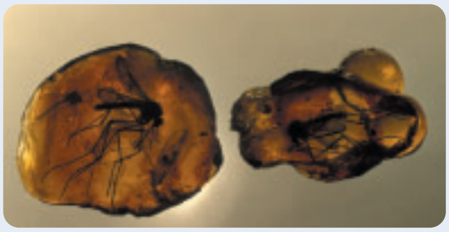


Figure 6

4. When an object is charged, does it remain charged forever? Explain your answer.
5. Is it possible to negatively charge a rod by rubbing it with a fabric without also giving the fabric a positive charge? Explain your answer.
6. If an electron is removed from a sodium atom, the atom becomes a sodium ion. What type of charge does a sodium ion have?
7. State the law of electric charges in your own words.
8. A plastic comb is used to brush the fur of a cat. The comb is then brought near some confetti lying on a table. The pieces of confetti are first attracted to the comb and then repelled. Draw diagrams to explain what happens. Make sure that you show the charges on the objects.
9. Suppose that you are given a metal sphere, a positively charged acetate strip, and a negatively charged vinyl strip. How could you determine the charge on the sphere using both strips? Why would you not be able to determine the charge using only one of the strips?
10. A student walks across a rug and notices a spark when she reaches for a metal doorknob. How could she determine whether she was positively charged or negatively charged?
11. A vinyl comb is rubbed on a wool sweater. The comb is brought toward some salt and pepper sprinkled on a countertop. The salt crystals are attracted to the comb and stick to the comb. The pepper is attracted to the comb at first, but then some of the pepper flies off. Explain the difference between salt and pepper, with respect to charges.
12. In a television, electrons travel between oppositely charged plates to the screen, as shown in Figure 7.
    (a) Would an electron move toward the negatively charged plate or toward the positively charged plate? Explain your answer.
    (b) A neutron travelling through the parallel plates is not attracted to either plate. Why?

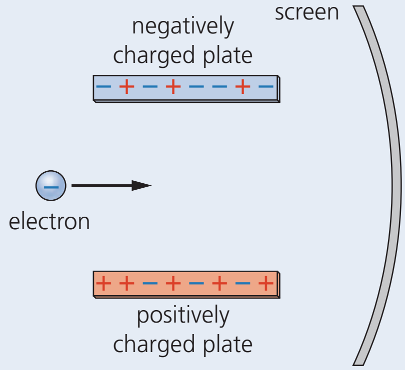


Figure 7

13. A student rubs a wooden stick with a cloth of unknown material and then brings the wooden stick near a suspended neutral pith ball. The pith ball does not respond.
    (a) What is the charge on the wooden stick?
    (b) If the material was one of the materials listed in the electrostatic series on page 276, which would it most likely be? Explain your answer.
14. If quartz is rubbed with a rubber cloth, the quartz becomes positively charged. Explain how the quartz becomes charged in terms of electron movement.

9.2 Charging by Friction, Conduction, and Induction

There are three ways in which objects become electrically charged: by friction, by conduction (contact), and by induction. **Charging by friction** occurs when two objects are rubbed together. For example, large amounts of electric charge build up on clothes as they tumble against each other in a dryer. Friction causes electric charges to be transferred from one object to another. 9A Investigation

For example, in Figure 1(a), the hair and the comb have equal numbers of protons and electrons, and are both neutral. When they are rubbed together, the polyethylene atoms that make up the comb have a stronger attraction for electrons than the atoms that make up the hair. The rubbing brings more of the hair in contact with the comb, allowing the transfer of significantly more electrons. The excess negative charge builds up on the comb, while the hair becomes positively charged because it loses some electrons (Figure 1(b)).

9A Investigation

Charging by Friction

To perform this investigation, turn to page 292.

In this investigation, you will use friction to charge objects, and then determine if there is a positive or negative charge.

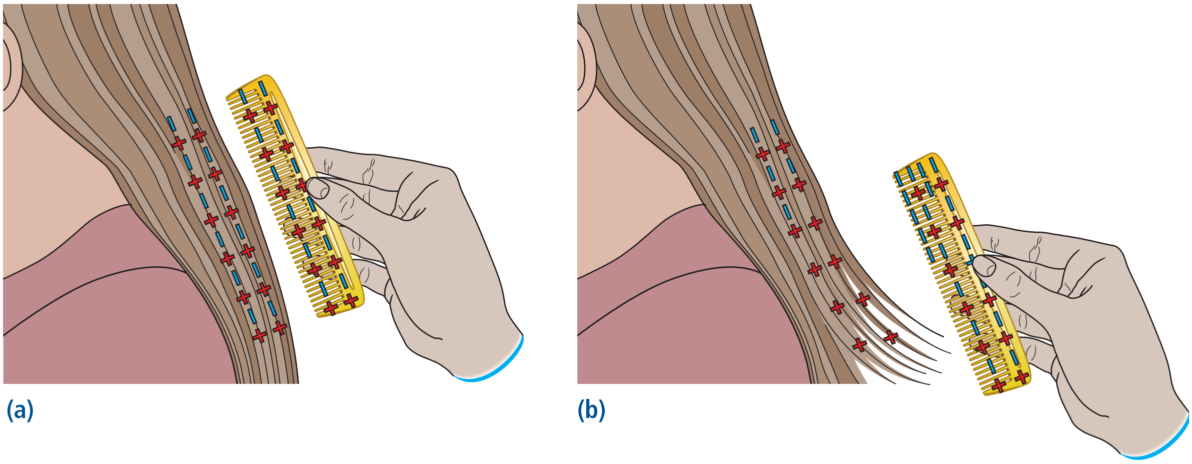


Figure 1 (a) The comb and the hair are both neutral (b) After being rubbed together, the comb is negatively charged and the hair is positively charged. Only the electrons move during the transfer of electric charge.

Objects also become charged through conduction, or contact. **Charging by conduction** occurs when objects touch and an electric charge is transferred from one object to the other. For example, if you walk across a carpet and get a spark by touching a metal doorknob, you are transferring some of your charge to the doorknob by conduction. Figure 2 shows a metal sphere being charged by conduction. GO

If you would like to learn more about charging by conduction, go to **www.science.nelson.com** GO

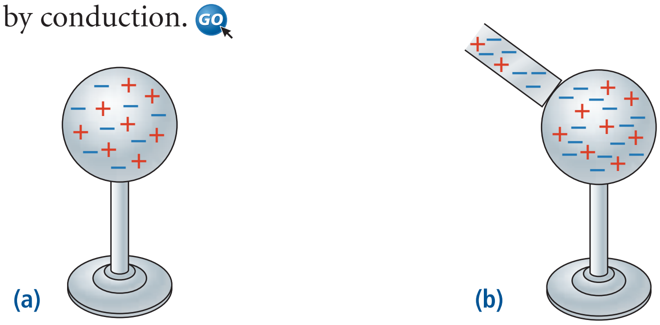


Figure 2 (a) A neutral metal sphere (b) When a negatively charged bar contacts the sphere, some of the extra electrons move to the sphere, giving it a negative charge.

TRY THIS: *Induced Charges*

Skills Focus: creating models, observing

In this activity, you will determine if an object can be charged without direct contact.

Materials: 2 aluminum spheres on stands, vinyl strip, paper towels, pith ball on a thread

1. Position the 2 aluminum spheres so they are touching each other.
2. Rub a vinyl strip with a paper towel. The vinyl strip is now negatively charged. (Refer to the electrostatic series on page 276.) Bring the negatively charged vinyl strip close to one of the spheres (Figure 3).

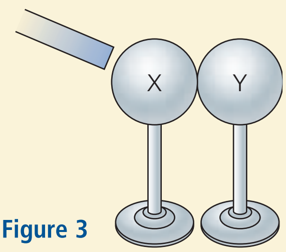


Figure 3

3. Move the two spheres apart, and then take the vinyl strip away.
4. Rub the vinyl strip with a paper towel to charge it negatively. Use the strip to give a hanging pith ball a negative charge. Bring the negatively charged pith ball close to sphere X (Figure 4). Record what happens to the pith ball.

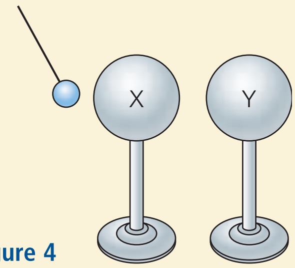


Figure 4

5. Now bring the negatively charged pith ball near sphere Y. Record what happens to the pith ball.

A. What happened when you moved the charged pith ball toward sphere X and toward sphere Y? Explain your observations.

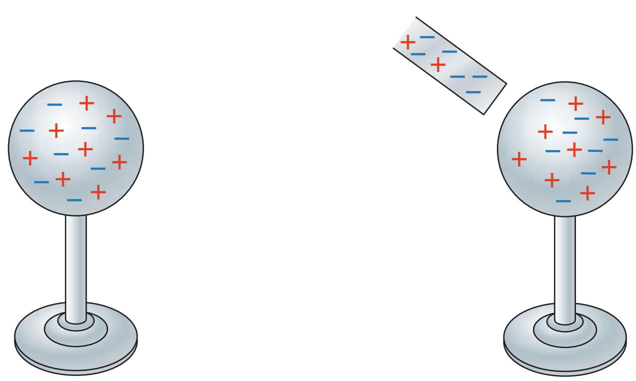
B. Draw a series of diagrams to show the movement of charge on the spheres in steps 2, 4, and 5.

LEARNING TIP

If you find yourself reading without understanding, stop and ask why. Do you understand the key terms? Slowly reread the part that you did not understand.

If you would like to learn more about charging by induction, go to **www.science.nelson.com** GO

When objects are charged without touching or making any direct contact, the process is called **charging by induction**. An example of this process is the buildup of dust on the screen of a television or computer monitor. When a screen is turned on, it begins to build up a charge. When a neutral dust particle comes near the screen, the screen induces an opposite charge on the near side of the dust particle and a similar charge on the far side. The dust is attracted to the screen. Figure 5 shows a metal sphere being charged by induction. GO



(a) **(b)**

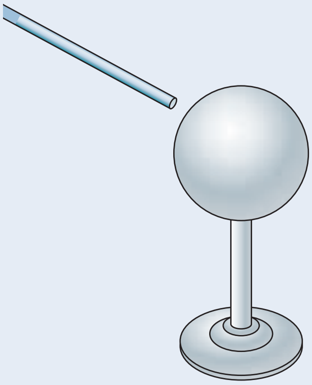
Figure 5 (a) A neutral metal sphere (b) When a negatively charged bar comes near the sphere, the charge on the bar causes, or induces, the electrons on the sphere to change their position.

9.2 CHECK YOUR Understanding

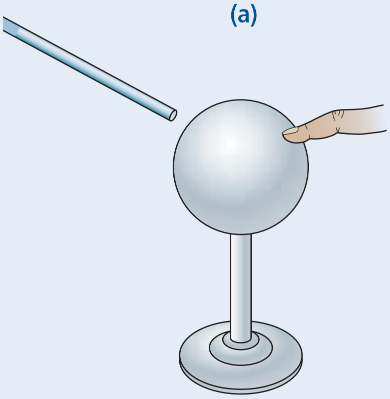
1. Explain how an object becomes charged by friction. Use diagrams in your answer.
2. Write your own definition of charging by conduction.
3. Write your own definition of charging by induction.
4. When an object is charged by contact, what kind of charge does the object have compared with the charge on the object giving the charge?
5. Use a diagram to show the result when a negatively charged object touches an uncharged pith ball.
6. What are the differences between charging objects by conduction and by induction? Give an example of each method.
7. Can a positive object be used to give a second object a negative charge by conduction? Can induction be used to make the second object negative? Explain your answers using words or diagrams.
8. When you are in bed at night in the dark and rub your feet on the sheets, you may observe tiny flashes of light. Give an explanation for this observation. You may also see this effect if you pull clear tape from a roll in the dark. How are these two effects the same?
9. Describe how you could determine whether the static charge on a sock from a clothes dryer is positive or negative (Figure 6).

Figure 6

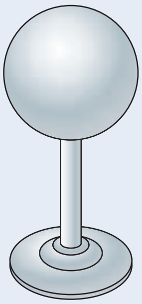
10. Figure 7(a) shows a metal sphere being charged by induction using a positively charged rod. Figure 7(b) shows a finger touching the metal sphere to discharge it. In Figure 7(c), both the rod and the finger have been taken away. Copy the three diagrams into your notebook. Using red positive signs and blue negative signs, show how the sphere becomes charged in each diagram.



(a)



(b)



(c)

Figure 7

9.3 Insulators and Conductors

LEARNING TIP

The writer uses clues to help you understand new vocabulary words. How can you tell the meaning of the words in bold from the sentences that contain them?

As you saw in Investigation 9A: Charging by Friction, some materials, such as acetate and vinyl, are able to acquire electric charges that stay on them for some time. These materials are called insulators. An **insulator** is a substance in which the electrons are so tightly bound to the atoms making up the material that they are not free to move to a neighbouring atom. Plastic is a good insulator. It is used to coat wires and extension cords to protect us from electric shock.

Other materials, such as aluminum and copper, are called conductors. A **conductor** allows electrons to flow freely from one atom to another. Metals are good conductors. Some materials, such as carbon, silicon, and germanium, are semiconductors because they allow electrons to move although there is some resistance. Pure water is an insulator, but tap water has enough substances dissolved in it to make it a good conductor. Dry air is an insulator, and moist air is a poorer insulator than dry air. Table 1 lists some insulators, conductors, and semiconductors. GO

If you would like to find out more about conductors and insulators, go to **www.science.nelson.com** GO

Table 1 Examples of Insulators, Conductors, and Semiconductors

Good insulators	Good conductors	Semiconductors
oil	silver	carbon
fur	copper	germanium
wool	gold	silicon
rubber	aluminum	selenium
glass	tungsten	polyacetylene
plastic	nickel	silicon carbide

9B Investigation

The Electroscope

To perform this investigation, turn to page 294.

In this investigation, you will use an electroscope to investigate objects that have been charged by conduction and induction.

A Metal-Leaf Electroscope

We can use a metal-leaf electroscope (Figure 1) to determine the presence of electric charges. **9B Investigation**

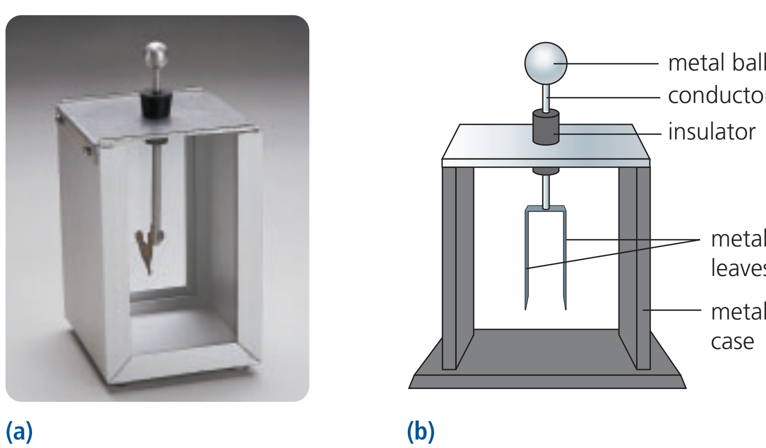
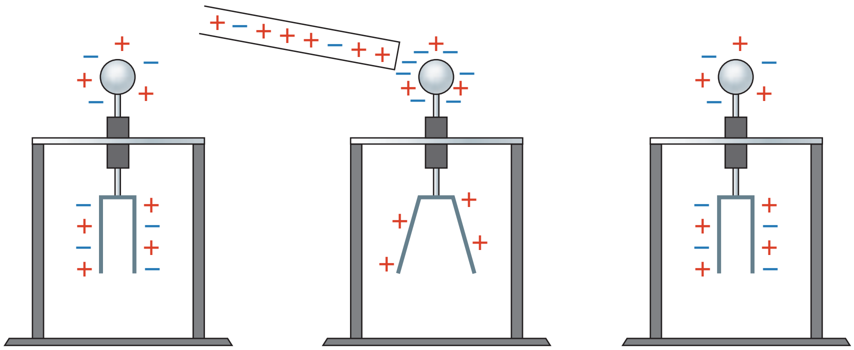


Figure 1 (a) A metal-leaf electroscope (b) The basic parts of the electroscope: the insulator shields the metal leaves from any static charges on the metal case, and the conductor connects the metal ball to the metal leaves.

When a positively charged strip is brought near the electroscope, it induces a separation of charge (Figure 2). The ball on the top of the electroscope becomes negatively charged and the two leaves become positively charged. Since the two leaves have the same charge, they repel each other and spread out. When the charged object is taken away, there is no longer an induced separation of charge and the leaves return to their original position.

LEARNING TIP

Make connections to your prior knowledge. Use what you know about the meaning of the word "isolated" to help you understand isolated conductors.



(a) **(b)** **(c)**

Figure 2 (a) The vertical leaves indicate that there is no charge.
(b) The leaves spread apart indicating that there is a charge near the metal ball.
(c) The vertical leaves indicate that there is no charge.

To ensure that the electroscope is neutral, it needs to have all the excess charges removed, or discharged. The simplest way to discharge any object, is to ground the object. An object is **grounded** if it is connected to Earth by a conductor, such as a copper wire. Earth is so immense that it removes excess static charge from an object. When you touch the ball of the electroscope briefly, you ground the electroscope by removing any excess charge from it.

The metal of an electroscope is a conducting material. However, it can hold a static charge because it is not in direct contact with its surroundings. This is known as being *isolated*. When an isolated conductor, such as a metal ball, is given a charge, the charge spreads out evenly over the surface of the ball because of the repulsion of like charges. In fact, if a person were to get inside a metal ball, the person would be perfectly safe from the static charge on the surface of the ball (Figure 3). A Faraday cage is named after British scientist Michael Faraday, who built the first one in 1836 and explained how it operated. Faraday showed that when discharges from an electrostatic generator struck the outside of a room that he had coated with metal foil, an electroscope inside the room did not react. This proved that there was no excess charge on the inside of the room. Automobiles and airplanes behave like a Faraday cage; if lightning hits a car, it does not affect the people sitting in the car. Cell phones and radios do not work in elevators and buildings made of metal because the building acts like a Faraday cage. GO

Figure 3 Michael Faraday showed that the charge stayed on the outside of a charged conductor, and did not affect anything enclosed within the conductor. Inside a Faraday cage, a person is safe from the static charge.

If a conductor has a sharp point, that area receives a greater concentration of charge. This is why a lightning rod that is placed on the top of a building has a pointed end. The lightning rod gets a concentrated positive charge if a negatively charged cloud is above the building. A conductor goes from the rod into the ground. The lightning passes through the rod and down the conductor into the ground below the building instead of going through the building.

To learn more about the Faraday cage, go to
www.science.nelson.com GO

9.3 CHECK YOUR Understanding

1. What is the difference between a conductor and an insulator? Give an example of each.
2. Which of the following materials are conductors?
   - copper
   - sulfur
   - glass
   - aluminum
   - gold
   - phosphorous
   - sodium
3. Explain why grounding an object makes the object neutral.
4. A positively charged rod is brought near, without touching, a metal sphere. A ground wire connects the opposite side of the sphere to the ground (Earth) (Figure 4). The ground wire is disconnected and the rod is taken away. What charge is left on the sphere? Use diagrams to explain your answer.

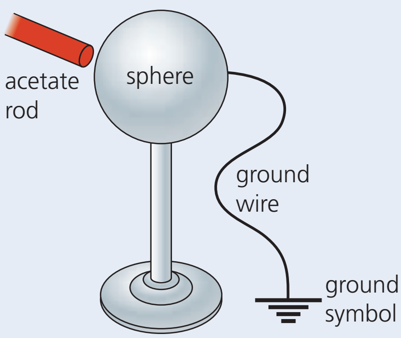


Figure 4

5. Figure 5 shows a lightning rod on the top of a building being struck by lightning. What are two characteristics of an effective lightning rod?

Figure 5

6. A student gives an electroscope a negative charge by touching it with a negatively charged vinyl strip (Figure 6). The student then brings a positively charged acetate strip near the electroscope. What happens to the leaves of the electroscope? Explain in terms of the movement of electrons.

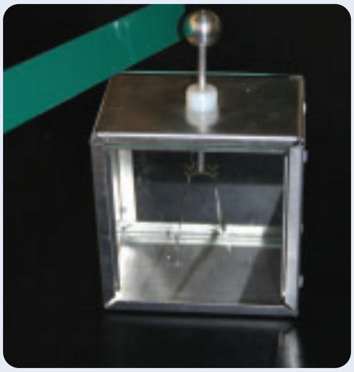


Figure 6

7. When you walk across a carpet, a static charge may build up on you such that when you touch a metal doorknob, you may feel a shock.
   (a) The effect is more noticeable on cold winter days than on warm summer days. Why do you think this happens?
   (b) Explain why you would not feel a shock if you touched the wooden part of a door.
8. Using a paper towel and an acetate strip, you can give an electroscope a positive charge two different ways. Describe both ways of charging the electroscope.
9. Two objects, X and Y, are neutral. When they are rubbed together, object X loses electrons to object Y. What type of charge is on object X and on object Y? What would happen if object X was brought close to a negatively charged electroscope? Explain your answer.
10. A scientist rubs a stick of sulfur with a wool cloth, and then moves the sulfur near the ball at the top of an electroscope. The leaves spread apart. What is the charge on the leaves of the electroscope? Explain your answer.

9.4 Electric Force

The **Van de Graaff generator** (Figure 1), developed in 1930 by Robert J. Van de Graaff at Princeton University, is a device that separates large quantities of electric charge. It is used to research static electricity and to make static charges available for experimentation. It is also used for educational and entertainment purposes (Figure 2).

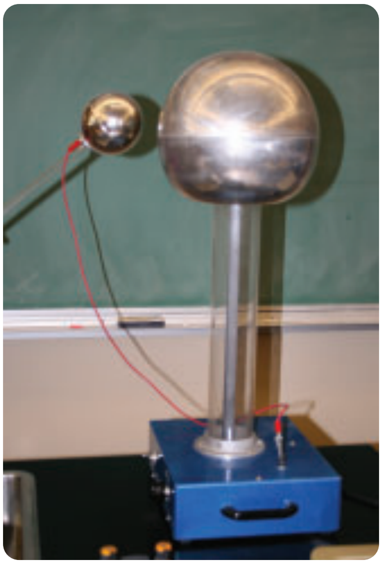


Figure 1 A Van de Graaff generator

Figure 2 Touching a Van de Graaff generator can be a hair-raising experience!

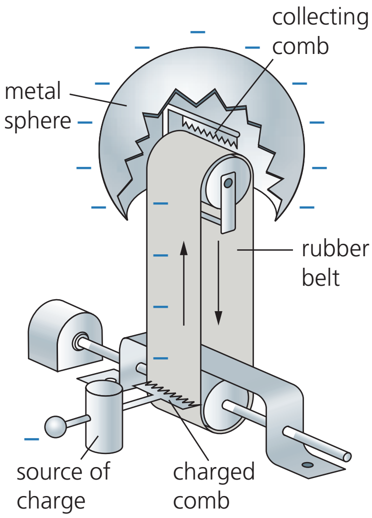


Figure 3 Charges in a Van de Graaff generator

Figure 3 shows the basic design of a Van de Graaff generator. An electric motor turns a rubber belt on a roller past a negatively charged comb. As the belt goes past the charged comb, it picks up the negative charges and carries them up to the collecting comb. The negative charges leave the belt at the collecting comb. They are conducted to the large hollow metal sphere where they spread across the outside surface of the sphere.

A Van de Graaff generator is able to produce very large electric charges, which can be used to investigate electric forces. A force is a push or pull acting on an object and is usually measured in newtons (N). If the force on an object is unbalanced, it can cause a change in the motion, or acceleration, of the object. The **electric force**, which is also called the electrostatic force, is the force that exists between static charges. The electric force can either pull the static charges together (force of attraction) or push the static charges apart (force of repulsion).

LEARNING TIP

As you read Figure 3, look closely at the labels and then read the information beside the figure. Begin with the label "source of charge." What does this tell you? Do the same for the rest of the labels.

TRY THIS: Van de Graaff Electric Charges

Skills Focus: creating models, observing

Figure 4

Materials: safety goggles, Van de Graaff generator and discharge ball, bubble solution and wand, plastic rod, thread, lightweight aluminum ball

1. Put on your safety goggles. Blow bubbles at a charged Van de Graaff dome. Draw a diagram of the Van de Graaff generator and bubbles, showing the behaviour of the bubbles.
2. Slowly bring the discharge ball near the Van de Graaff dome. Describe how the electric force between the dome and the discharge ball changes as the ball is brought closer to the dome.
3. Discharge the generator by grounding it with the discharge ball. Hold the discharge ball near the dome. Turn on the motor. Allow the charge to build up on the dome, keeping the discharge ball in the same place. Describe what happens to the electric force between the discharge ball and the dome as the charge builds up on the dome.
4. Tie a lightweight aluminum ball by a thread to the end of a plastic rod. Hang the ball near a charged generator dome (Figure 4). Describe the electric force between the ball and the generator dome.

A. Explain your observations of the behaviour of the bubbles by describing the movement of the charges.

B. Describe how the electric force varies with the distance between the ball and the dome.

C. Describe how the electric force varies with the size of the charge on the dome.

D. Explain how the movement of the aluminum ball around the dome of the generator is similar to the movement of the planets around the Sun.

In the Try This activity, you used a Van de Graaff generator to see how like charges repel and opposite charges attract. You also used the generator to investigate the factors that affected the strength of the electric force. You saw that the amount of charge on the Van de Graaff dome and the distance between the dome and the discharge ball both affect the strength of the electric force.

As the charge builds up on the dome, the electric force between the dome and the discharge ball increases. Therefore, the electric force increases as the charge increases. This is called a direct relationship because as one value increases, the other value also increases.

However, as the distance between the dome and the discharge ball decreases, the electric force increases. This is called an inverse relationship because as one value decreases, the other value increases.

In 1795, Charles Coulomb, a French physicist, was the first person to recognize the relationships between electric force, size of charge, and distance. These relationships form the basis for **Coulomb's law** and may be simplified as follows: *The strength of the electric force increases with increasing electric charges and decreases with increasing distance.* The SI unit for size of the electric charge is called the **coulomb** (C) in his honour.

Did You KNOW?

Coulomb

One coulomb is the amount of charge in 6.25×10^{18} electrons, or 625×10^{16} electrons, or the number 625 with 16 zeroes after it. No matter how you write it, it is a really big number!

9.4

CHECK YOUR Understanding

1. Look at Figure 2 on page 285. Explain why the girl's hair is standing on end.
2. Define "electric force" in your own words.
3. Figure 5 shows a discharge ball near a charged Van de Graaff dome. If the discharge ball is moved to the left, what will happen to the electric force between the dome and the discharge ball? Explain your answer.

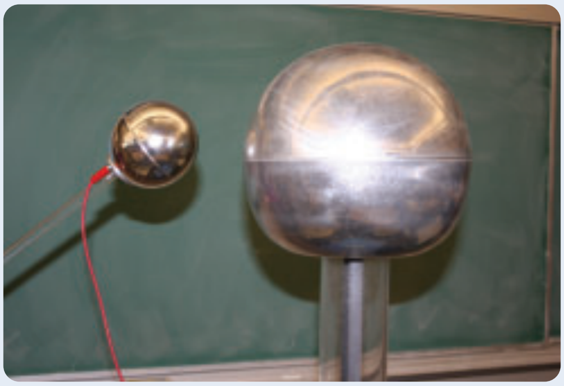


Figure 5

4. How does the electric force between two charged objects depend on the charges of the objects?
5. A student brings a pith ball on a string near a charged electroscope ball. The pith ball is repelled from the electroscope ball. What does this imply about the pith ball? If a second pith ball is brought near and is attracted to the electroscope ball, what can be said about the charge of the second pith ball?
6. In electroscope experiments, you ground the electroscope by touching it. Is it possible for your body to neutralize the electroscope totally so that there is absolutely no static charge? Explain why or why not.
7. If you put your hand near a Van de Graaff generator, a spark may jump to your hand from the generator. Is air a conductor or an insulator? Explain your answer.
8. A student rubs two rubber balloons with a wool sweater. The balloons are suspended by strings (Figure 6). Over time, the balloons slowly get closer together until they are touching each other. Explain why this happens.

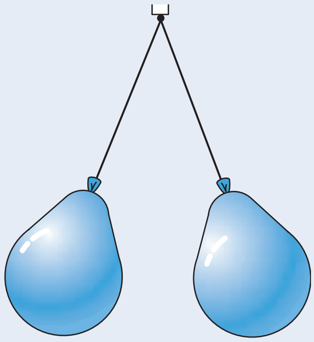


Figure 6

9. A student rubs one acetate strip with wool and another acetate strip with plastic wrap. The strip rubbed with plastic wrap interacts strongly with a suspended pith ball. However, the strip rubbed with wool does not seem to interact at all with the suspended pith ball. Explain why this happened.
10. Copy Figure 7 into your notebook, and indicate the charges on the dome and the soap bubbles. Explain what will happen to the soap bubbles.

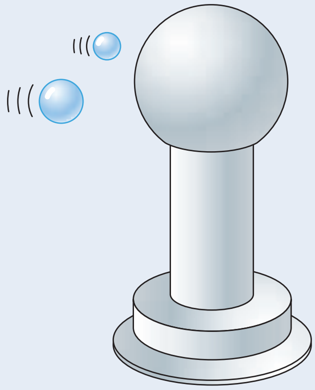


Figure 7

9.5 Applications of Static Electricity

Figure 1 Scientists do not completely understand how thunderclouds become charged.

Static electricity has applications that can be useful. However, it can also be a nuisance when it causes clothes to cling to you or lint to stick to your clothes. Static electricity can even be harmful.

Lightning

Lightning is a form of static electricity that can be harmful (Figure 1). As you previously learned, during the water cycle, moisture evaporates and condenses to form clouds in the atmosphere. Clouds contain millions of water droplets that collide with other droplets as they rise and fall. During these collisions, electrons are transferred from the rising water droplets to the falling water droplets. The negatively charged water droplets collect in the lower part of the cloud, giving it a negative charge. The positively charged water droplets continue to rise, carrying the positive charge to the top of the cloud. This causes the cloud to acquire a separation of charge.

As the collisions between droplets continue to occur, and the charges at the top and bottom of the cloud increase, the separation of charge in the cloud becomes more intense. Eventually, the electrons at the surface of Earth are repelled by the strong negative charge at the lower part of the cloud. This causes Earth's surface to acquire a strong positive charge. GO

In a complicated procedure, the air around the cloud forms a pathway from the cloud to the surface of Earth. This pathway is about 5 cm wide and usually lasts less than a second. Once the pathway is complete, moving electrons flow between Earth and the cloud in an attempt to neutralize the charge separation. The moving electrons excite the surrounding air, causing it to emit light—a lightning flash—and to heat to a temperature of about 3000 °C. The air rapidly expands, sending out a shock wave that we hear as the crack or rumble of thunder. The total energy produced in a large thunderstorm is equivalent to an atomic bomb being detonated!

To learn more about how lightning is formed, go to **www.science.nelson.com** GO

Did You KNOW?

How Far Away Is the Lightning?

You can determine the distance to lightning knowing that the speed of light is 300 000 km/s and the speed of sound is about 330 m/s. If you count the seconds between seeing the flash of lightning and hearing the sound of the thunder, and then divide the number by three, you can determine the approximate distance to the lightning in kilometres. For example, if you see a flash and then count 12 s before you hear thunder, you know that the lightning is about 4 km away.

Laser Printers

Static electricity is at the heart of the laser printing process (Figure 2). When you send a document from a computer to be printed, the computer translates the material into a language that the laser printer understands. The printer then sends the information to a laser device, which emits light that is reflected onto a drum. To begin, the entire drum is given a positive charge. The light from the laser causes negative electrostatic charges on the drum in the shapes of the letters and images. In this way, the laser "writes" the images on the drum. The drum is rolled onto a reservoir of toner, which is a fine powdery mixture of black pigment and plastic. The toner is given a positive charge so that it sticks to the negative areas of the drum and is repelled from the positive areas. This is similar to putting glue on some areas of a soda can and rolling the can over flour. The flour only sticks to the glue-coated areas of the can.

While the toner is stuck on the drum, the paper, which has been given a strong negative charge, rolls under the rotating drum. Since the paper is more negative than the drum, the force of attraction between the toner and the paper is greater, and the paper picks up the black toner from the drum.

The negative charge is removed from the paper to stop it from sticking to the drum, and then the paper passes through a fuser. The fuser heats the toner and melts it onto the page. The completed page is sent to the output tray, and your print job is finished. The remaining toner is removed from the drum, and the printer is ready for another page.

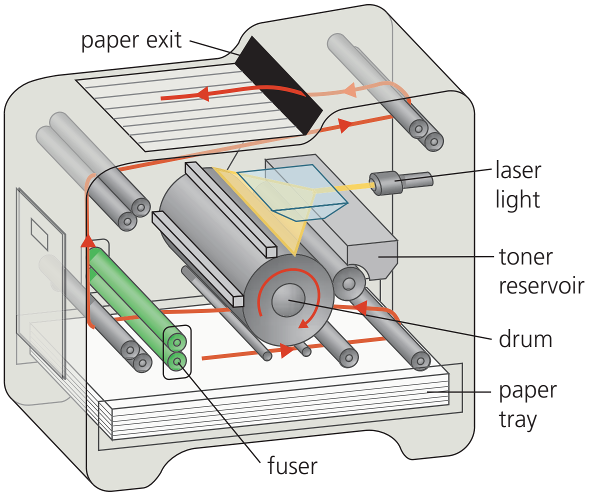


Figure 2 A laser printer

Fabric Softener Sheets and Static Cling

The tumbling of clothes in a dryer presents the perfect conditions for charging by friction. The clothes are made of different insulating materials, which rub against each other (friction) in a very dry air (non-conducting) environment as they tumble around. Wool socks might end up negatively charged, while a cotton shirt might become positively charged. The socks will then be attracted to the shirt.

Fabric sheets contain a chemical that is attracted to negatively charged clothes. The chemical is slightly oily and coats the surface of the clothes, leaving them feeling soft. Thus, the fabric sheet not only neutralizes the negative charges, but also reduces friction between clothes by making the surfaces slightly oily. GO

If you would like to learn more about how fabric softener sheets work, go to **www.science.nelson.com** GO

Electrostatic Precipitators

British Columbia generates most of its electrical energy using hydroelectricity and natural gas thermal power plants. However, almost half of the world's electrical energy is generated by burning coal. Burning coal produces pollutants and ash particles that contribute to global warming, acid rain, and pollution. Electrostatic precipitators are used to remove the ash particles from the smoke. Electrostatic precipitators can also be used to remove wood dust in industrial plants and pulp mills.

Figure 3 shows how an electrostatic precipitator works. The exhaust from burning coal passes through negatively charged plates, where the ash particles become negatively charged. The negatively charged ash particles then pass between positively charged plates, which attract the ash. The ash is then shaken or scraped off the plates and removed.

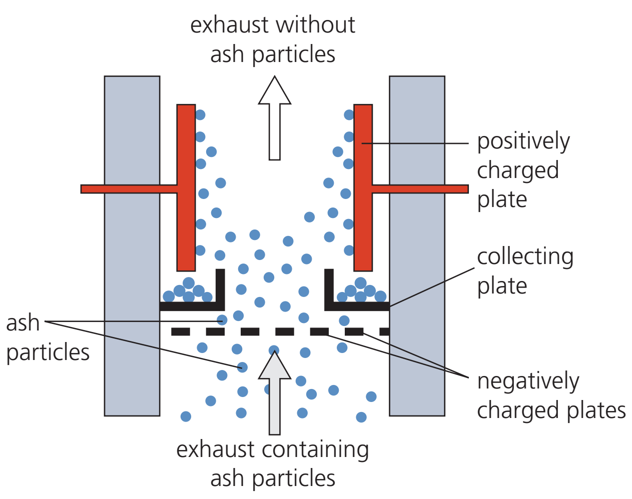


Figure 3 An electrostatic precipitator

9.5 CHECK YOUR Understanding

1. Copy the sketch of the thunderclouds shown in Figure 4. Use positive (+) and negative (−) signs to indicate the locations of the charges within the clouds and on the ground.

Figure 4

2. Is it safe to take cover under a large tree during a thunderstorm? Provide reasons for your answer.
3. Look at Figure 5. Is it possible for lightning to strike the same place twice? Explain why or why not.

Figure 5

4. Explain, in your own words, why lightning occurs.
5. (a) Explain why a person is safe from lightning inside a car that has a metal body.
   (b) Fibreglass is an insulator. Why is a person not safe inside a car that has a fibreglass body?
6. Is the paper that is used in a laser printer a conductor or an insulator? Explain your answer.
7. If the toner in a laser printer were accidentally given a negative charge, what would happen to the image?
8. Why is a clothes dryer an ideal place for static charges to build up?
9. How do fabric softener sheets help to reduce static cling?
10. Could a fabric softener sheet be used indefinitely? Explain why or why not.
11. Clothes dried outdoors on a clothesline do not build up static charges. Explain why.
12. In an electrostatic precipitator, the particles are given a negative charge. Would an electrostatic precipitator still work without charging the particles negatively? What is the advantage of charging the particles?
13. Can an electrostatic precipitator remove the polluting gases from the exhaust that is created when coal is burned? Explain your answer.

ELECTRIFYING FISH

Some fish use electric charges to defend against predators, to detect prey, and to stun or kill prey.

Zap! You have probably seen cartoons in which a person grabs onto an electric fish and gets an electric jolt.

Fish that are able to produce electric shocks are *electrogenic*. Their bodies contain an electric organ, which is made of specialized cells that can produce electric charges. Essentially, the stacked cells act as a battery. The charge that is generated in an electric organ is released into the body of another animal to stun or kill it, or the charge is released into the surrounding water to locate prey.

An electric eel can make, store, and discharge electricity (Figure 1). The electric eel lives in freshwater rivers, such as the Amazon in South America. It can produce low intensity charges for navigating in muddy streams and for communicating with other eels. It uses high-intensity charges to stun and kill other fish and amphibians, and to defend itself. The electric discharges are strong enough to knock a horse off its feet and to even kill a person!

The electric ray, or torpedo fish, (Figure 2) was the first electric fish to be discovered. The electric ray is found in all tropical or temperate seas. It likes to remain stationary on the bottom of the sea waiting for prey to swim by. It can produce two types of electric charges: moderate pulses to warn away predators and powerful blasts to stun prey. The result is a jolt of electricity that ranges from moderately tingly to lethal. To capture prey, the ray sneaks up on another animal and envelopes it within its large wing-like fins. Once it has folded itself around its prey, it discharges a strong electric charge to kill it.

Some fish can receive and interpret electric signals. Fish that can detect electric signals are *electroreceptive*. Electric signals are detected by special receptors located on the skin of the fish. Sharks, including the great white shark (Figure 3), can detect electric signals generated by prey. This ability allows sharks to accurately locate and attack prey. Sharks have such sensitive electroreceptors that they can sense electricity generated by a muscle twitch in a fish buried under sand at the bottom of the sea.

Figure 1 After delivering a strong shock, an electric eel must allow its electric organ to recharge.

Figure 3 The great white shark is a highly adapted predator: its mouth is lined with rows of serrated teeth; it has an exceptional sense of smell; and its electroreceptors help it detect small electrical discharges in the water.

Figure 2 Electric rays were used in medicine in Ancient Greece and Rome. Ancient Greeks even used electric rays to numb the pain of operations and childbirth.

9A

Investigation

Charging by Friction

Objects with like charges repel each other, and objects with opposite charges attract each other. If two objects are rubbed together, friction causes one object to become positively charged and the other object to become negatively charged. For example, if a paper towel is used to rub an acetate strip or glass rod, they both become electrically charged. The charge on the paper towel is negative, and the charge on the acetate strip or glass rod is positive. In this Investigation, you will look at the charges acquired by different materials because of friction.

Question

When two materials are rubbed together, what charge does each material acquire?

Experimental Design

In this investigation, you will rub different materials together and determine what, if any, charge the objects have (Figure 1).

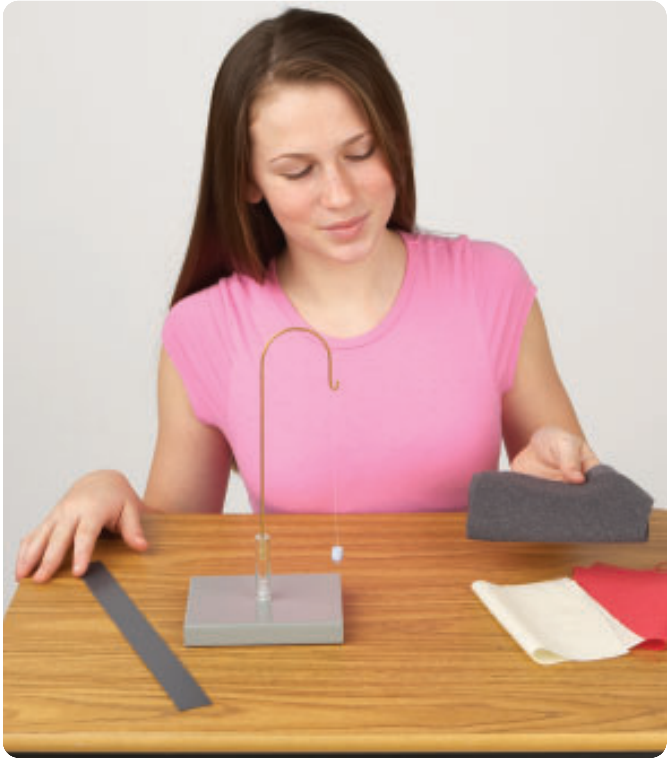


Figure 1

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ○ Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ○ Synthesizing
- ● Communicating

Materials

- pith ball electroscope or pith ball on a thread
- ring stand or tape
- vinyl strip
- paper towel
- acetate strip
- selection of materials to rub the test materials (such as paper, wool, cotton, silk, and plastic)
- selection of materials to test (such as glass, wood, aluminum, and ebonite)

Handle the pith ball carefully.

Procedure

1. Copy Table 1 into your notebook. Add other materials to the table that you would like to test.

Table 1

		Rubbing materials					
		paper	wool	cotton	silk	plastic	
Materials to test	vinyl						
	acetate						
	glass						
	wood						
	aluminum						
	ebonite						

2. Use a pith ball electroscope or hang a pith ball by taping it to the lab bench or ring stand. Ensure that the pith ball is not charged by holding it in your hand.
3. Rub a vinyl strip with a paper towel. Bring the vinyl strip near the pith ball and allow the strip to touch the ball (Figure 2). Refer to the electrostatic series to determine the type of charge on the vinyl strip. Record the charge that is on the vinyl strip in your table.

Figure 2 Step 3

4. Make sure that the pith ball is still negatively charged by recharging it with a charged strip. Rub the acetate strip with a paper towel, and bring the acetate strip near the pith ball. Determine the charge on the acetate strip. Record the charge that is on the acetate strip in Table 1.
5. In the same way, test the pairs of materials given in Table 1 (Figure 3), and record the type of charge that is on the testing material. Do not record the charge of the rubbing material.

Figure 3 Step 5

Analysis

(a) How did you make sure that the pith ball was negatively charged?

(b) What was the charge on the acetate strip? Why did you have to make sure that the pith ball was negatively charged before testing the acetate strip?

(c) Could you have determined the charge on the acetate strip using a positively charged pith ball? How?

(d) Compare the results of your experiment with the electrostatic series in Section 9.1, on page 276.

Evaluation

(e) Is it possible to use this experiment to create your own electrostatic series for the materials you investigated? Explain.

(f) If some of the materials did not show positive or negative charges, suggest another experiment that you could perform to investigate these materials.

(g) What would happen if you performed this experiment using the pith ball electroscope with two pith balls hanging side by side as shown in Figure 4? Explain your answer.

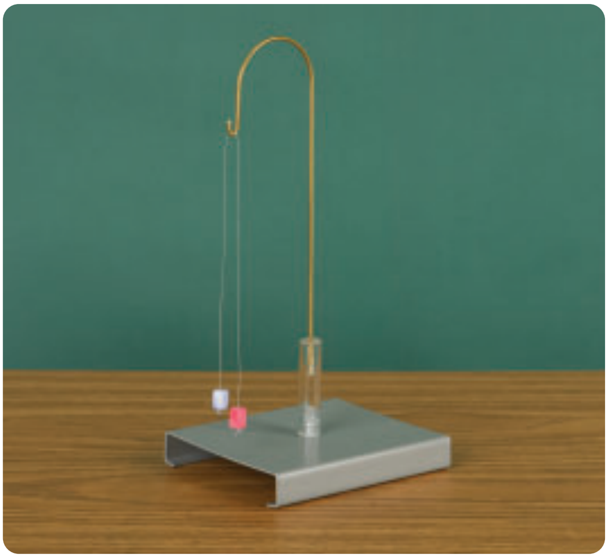


Figure 4

9B

Investigation

The Electroscope

William Gilbert, physician to Queen Elizabeth I, was the first person to create an electroscope around 1600. He was also the first person to use the term "electricity." Electroscopes have not significantly changed since the 1600s. For example, Figure 1 shows an electroscope from the late 1800s. Compare it with the electroscope that you will use in this Investigation.

Figure 1

In this Investigation, you will use an electroscope to investigate how different materials are charged by conduction and induction.

Question

How can an electroscope be charged by induction and by conduction?

Experimental Design

You will use an electroscope to determine the charges on different objects.

Materials

- metal-leaf electroscope
- vinyl strip
- paper towel
- acetate strip or glass rod
- piece of silk

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	● Synthesizing
○ Predicting	● Analyzing	● Communicating
○ Planning		

Procedure

1. Copy Figure 2, which shows a diagram of a neutral electroscope, into your notebook.

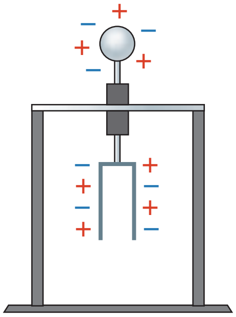


Figure 2 A neutral electroscope

2. Negatively charge a vinyl strip using a paper towel. Bring the strip near, without touching, the sides and then the ball on top of the electroscope (Figure 3). Draw a sketch of the electroscope and strip in the position where the leaves were spread out the most.

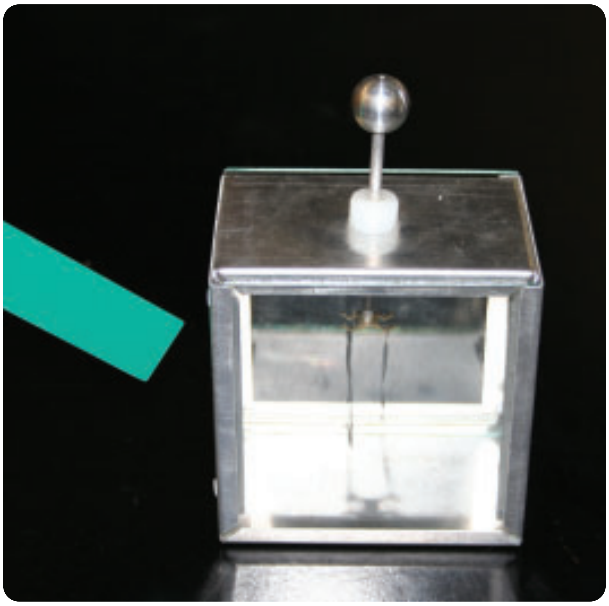


Figure 3 Step 2

3. Bring the negatively charged strip near the top of the electroscope and allow it to touch the metal ball of the electroscope.
4. Neutralize, or ground, the electroscope by touching it with your finger. Record your observations about what happens to the leaves of the electroscope.
5. Rub an acetate strip or a glass rod with silk to give it a positive charge. Bring the acetate strip or glass rod near, without touching, the metal ball. Record what happens to the leaves. Then touch the metal ball with the positively charged strip or rod. Record what happens to the leaves. Remove the positively charged strip or rod, and record what happens to the leaves.
6. Ground the electroscope by touching the ball with your finger. Bring a negatively charged vinyl strip rod near, without touching, the neutral electroscope. With the strip held near the electroscope, touch the top of the electroscope with your finger to ground it. Then take your finger off. After your finger is no longer touching the electroscope, move the negative strip away from the electroscope. Record your observations.

Analysis

(a) In step 2, when the leaves spread out indicating that they were charged, was this because of conduction or induction of electric charge? How do you know?

(b) Draw a diagram that shows what happens when a negative strip is brought near the metal ball. Show the position of the leaves, and the areas of negative and positive charges. What happened when the strip was taken away? How could you explain this in terms of electron movement?

(c) Draw diagrams to show what happens when the negative strip touches the metal ball, and what happens to the electroscope after the negative strip has been taken away.

(d) Is an electric force acting on the leaves in step 3? How do you know?

(e) Did the electroscope become charged in step 3? How do you know?

(f) Why was it necessary to ground the electroscope in step 4 before proceeding to step 5? What happened to the leaves of the electroscope when you grounded it? What does this indicate about the electroscope?

(g) Draw diagrams to show the position of the leaves of the electroscope and charges for steps 5 and 6.

(h) In steps 2 and 6, the electroscope is charged by induction. Explain what this means. How does charging the electroscope by induction compare with charging by conduction?

(i) Explain how you could use a positively charged acetate strip to give an electroscope a positive charge or a negative charge.

Evaluation

(j) Some electroscopes are made with gold leaves. Would this have been a benefit in your investigation?

(k) What is the advantage of using an electroscope, rather than simply using a hanging pith ball?

Synthesis

(l) Would it have made any difference to our understanding of electricity if electrons had been called positive and protons had been called negative? Explain your answer.

CHAPTER 9

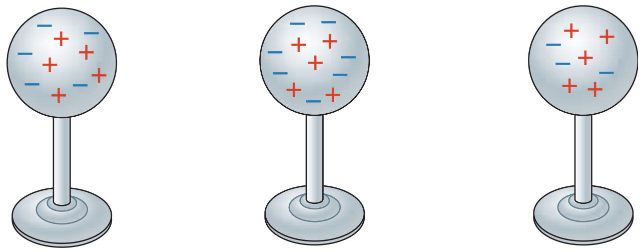
Review

Static Electricity

Key Ideas

Static electric charges can build up on objects.

- A static electric charge remains at rest until it is discharged.
- A neutral object has an equal number of positive and negative charges.
- Neutral objects can be given static charges that are either negative (by gaining electrons) or positive (by losing electrons).
- Neutral objects are attracted to charged objects because of separation of charges.



(a) a neutral sphere

(b) a sphere with a negative charge (more electrons than protons)

(c) a sphere with a positive charge (fewer electrons than protons)

Objects become charged by friction, conduction, and induction.

- Friction causes one object to gain electrons from another object.
- Some materials, such as metals, are conductors of electricity, while other materials are insulators.
- An object is charged by conduction when the excess charge on one object is transferred through contact to another object.
- Induction occurs when a charged object influences the charge distribution in another object.

Vocabulary

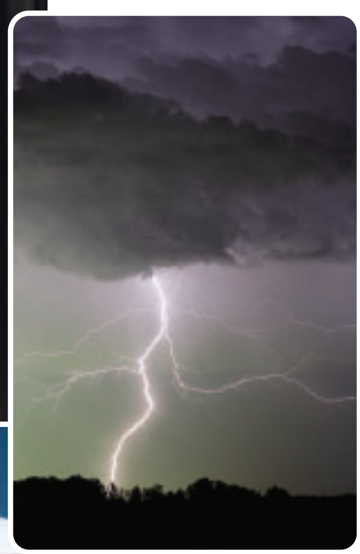
static charge, p. 274
discharge, p. 274
electrostatics, p. 274
law of electric charges, p. 275
induced charge separation, p. 277
charging by friction, p. 279
charging by conduction, p. 279
charging by induction, p. 280
insulator, p. 282
conductor, p. 282
grounded, p. 283
Van de Graaff generator, p. 285
electric force, p. 285
Coulomb's law, p. 286
coulomb (C), p. 286

An electric force between static charges can either attract or repel the charges.

- Like charges repel each other, and opposite charges attract each other.
- The size of the electric force between two charged objects increases with the sizes of the charges on the objects and decreases as the distance between the objects increases.

The discharge of static electricity in the form of lightning can be dangerous, but static electricity also has useful applications.

- Lightning is a spectacular example of static electric discharge.
- A metal-leaf electroscope is a device that can be given a known charge to determine the type and size of charge on an object.
- A Van de Graaff generator is a device that separates large quantities of static charge.
- Laser printers and electrostatic precipitators apply the principles of static electricity.



Review Key Ideas and Vocabulary

1. What happens when an atom gains or loses electrons? Use diagrams in your answer.
2. A student rubs a glass rod with a vinyl raincoat. What charge does the glass rod acquire? Explain your answer.
3. Is the change in mass significant when an object gains or loses electrons? Explain.
4. Figure 1 shows an acetate strip brought near, without touching, an aluminum sphere on an insulating stand. Which row of the table correctly indicates the charges on the sphere at positions X and Y?

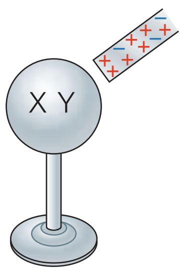


Figure 1

	Position X	Position Y
(a)	positive	positive
(b)	positive	negative
(c)	negative	positive
(d)	negative	negative

5. Which material is an insulator?
   (a) glass (c) mercury
   (b) copper (d) selenium
6. Draw each situation and indicate the charges on the objects.
   (a) A negatively charged pith ball is repelled from a negatively charged rod.
   (b) A positively charged pith ball is attracted to a negatively charged rod.
   (c) Two pith balls are positively charged and suspended from a common point.
7. Two socks and a shirt come out of a dryer stuck together. After the socks are pulled off the shirt, they are repelled by each other. Why did this happen?
8. Match each term on the left with the correct description on the right. Some terms may not be used.

Table 1

Term	Description
acetate	(a) a charge that stays put for some time
charging by friction	(b) a type of clear plastic
charging by induction	(c) a process in which an electric charge is transferred when objects rub together
conductor	(d) a material that allows electrons to flow
coulomb	(e) a machine that produces static charges
electric force	(f) a push or pull between two electrically charged objects
grounded	(g) a material in which electrons are tightly bound to atoms or molecules
insulator	(h) an amount of electrical charge
static charge	(i) a process in which an object is connected to a large neutral object
Van de Graaff generator	

Use What You've Learned

9. Is an electron attracted to a neutron? Explain your answer.
10. Figure 2 shows two neutral aluminum spheres touching each other. It is possible to charge the spheres by induction or by conduction with a negatively charged rod? Draw diagrams to show how this can be done. Include charge distributions in your diagrams to indicate static charges.

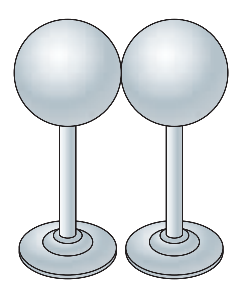


Figure 2

11. If you get caught in a thunderstorm in a large open field, as shown in Figure 3, should you lie flat and spread out, or crouch into a small ball? Explain your answer.

Figure 3

12. Electrostatics is used to spray-paint cars. Research to determine how and why this is done.

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13. When clear cellophane tape is pulled from a roll, it always seems to get tangled. Explain why this occurs.

14. In the summer, the moisture content of the air is higher than it is during winter, which makes it a better conductor. Would the spark from a Van de Graaff generator be longer in the summer or in the winter? Explain your answer.

15. St. Elmo's fire is a bright blue-white glow that can be seen on tall, pointed structures, such as church spires and ships' masts (Figure 4). Research this phenomenon. Is it related to static electricity? Explain your answer.

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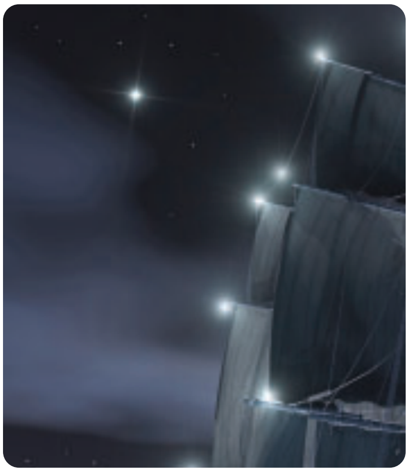

Figure 4

Think Critically

16. Why do birds not get sparks when flying near high voltage lines?

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17. Laser printers are named after the laser that is used to produce the light that writes the image. Does laser light have an electric charge? Explain your reasoning.

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18. James Wimshurst invented the Wimshurst machine, shown in Figure 5, in England in about 1880. The device produced electric charges using friction. Research to learn more about the Wimshurst machine, how it worked, and its uses. Use the information to write a report or create a poster about the Wimshurst machine that you can present to the class.

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Figure 5

19. A manufacturer claims that attaching a rubber strap to a car so that it hangs down and touches the road can help to prevent motion sickness. Research the idea behind this theory, and determine if using such a strap could prevent motion sickness.

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Reflect On Your Learning

20. Has your appreciation of static electricity changed as a result of studying this chapter? Explain how and why.

Visit the Quiz Centre at
www.science.nelson.com GO

CHAPTER

10

Current Electricity

KEY IDEAS

- In a circuit, electric charges flow from an energy source to a device that uses the energy.
- Current and voltage in a circuit can be measured by meters.
- Ohm's law relates resistance, voltage, and current in a circuit.
- Series and parallel circuits differ in terms of current, voltage, and total resistance.

Chapter Preview

What was life like before electricity was available from household outlets and batteries? What were the major sources of light in towns 100 or 1000 years ago? How many devices that depend on electrical energy do you use every day? How is electrical energy used to light up a city, such as Vancouver, at night? Why can't lightning be used to provide electricity?

All electrical devices depend on a circuit to get their energy. The circuit may be as small as an integrated circuit chip or as large as a provincial power grid. The basics of all circuits are the same and the goal is to control the flow of electricity.

TRY THIS: *Making an Electric Battery*

Skills Focus: observing, hypothesizing

In this activity, you will make a simple battery from a lemon.

Materials: lemons, zinc strip, copper strip, connecting wires, small speaker, miniature light bulb in holder, LED light

1. Squeeze the lemon to make it juicier. Be careful not to break the peel.
2. Insert the zinc strip and the copper strip into the lemon. Make sure that the metal strips do not touch each other.
3. Attach the connecting wires to the two metal strips.
4. Touch the wires to the speaker and see if you can produce a noise from the speaker.
5. Remove the speaker and replace it with a light bulb. If the bulb does not light up, add more lemons connected together until the bulb lights up.
6. Repeat step 5 using an LED light.

A. What does the noise that you hear in step 4 indicate about the lemon?

B. Why do you think the speaker only needed one lemon whereas the light bulb needed more?

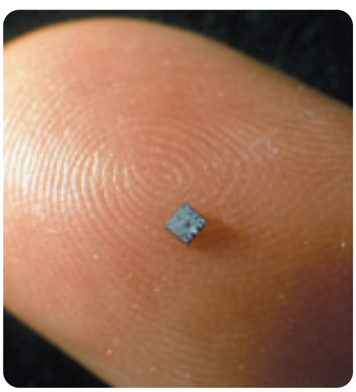
C. Make a hypothesis explaining why the lemon battery could light the LED light, but not the light bulb.

10.1 Electricity and Electric Circuits

Did You KNOW?

Integrated Circuit Chips

Some circuits contain elements such as capacitors (store energy) and transistors (control the flow of electricity). In the 1960s, capacitors and transistors were combined into a single integrated circuit chip. The invention of integrated circuit chips made advances in electronics possible. However, these chips are only part of the complete circuitry of devices. For example, your calculator uses one or more chips, but the chips need to be connected to energy sources, input keys, and output displays. The circuit of a small chip can easily include thousands of elements!



LEARNING TIP

Consider what you know about current electricity. As you read Chapter 10, confirm information that is accurate, and discard information that is inaccurate.

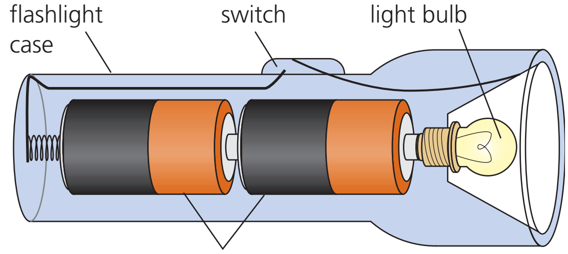
In Chapter 9, you learned that static electric charge can build up until it is discharged in the form of a spark jumping from your hand to a metal doorknob, or in the form of lightning going from cloud to cloud, or from cloud to Earth.

Unlike static electricity, **current electricity** refers to electric charges flowing in a circuit through a conductor in a controlled way. An electric circuit is a continuous path for electricity to flow through. Electricity flows along a conductor from an energy source, such as a battery, to a device that uses the energy.

The Parts of an Electric Circuit

A flashlight is an example of a very simple electric circuit. The flashlight shown in Figure 1 consists of wires that connect the parts together, a cylindrical holder that contains two D-cells, a light bulb, and a switch. The D-cells are the energy source, the bulb is the load, the switch controls the flow of electric charges, and the connecting wires provide a complete path that joins all the parts together.

(a)



(b)

Figure 1 (a) A flashlight (b) A diagram of a flashlight

Energy Sources of Circuits

The power lines that deliver electricity to your home are delivering electrical energy. (You will study electrical energy in more detail in Chapter 11.) Electrical energy can be converted into other forms of energy, including light energy from LED lights, heat energy from heating or cooking devices, or sound energy from stereo speakers. The **joule (J)** is the SI unit for measuring energy. For example, a light bulb in a table lamp needs about 4000 J of electrical energy each minute that it is on. Heating 1 L of water from room temperature to near boiling requires about 300 kJ (or 300 000 J) of energy.

The electrical energy in an electric circuit is actually provided by electrons. The amount of energy that is available from each electron is called the electric potential energy of the electron.

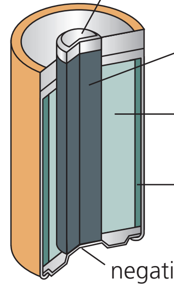


Figure 2 A common primary cell is the zinc–carbon cell. When the electrodes are connected to a light bulb, electrons flow through the bulb from the negative zinc electrode to the positive carbon electrode and complete the circuit.

Sources of Electrical Energy

There are different sources of electrical energy. For example, an electric cell is a device that converts chemical energy into electrical energy. There are two types of electric cells: primary and secondary. Both types of electric cells contain an electrolyte and a positive and negative electrode. A primary cell (Figure 2) cannot be recharged because the chemical reactions are irreversible. A secondary cell can be recharged using electrical energy to reverse the chemical reactions. In science, a **battery** is defined as a combination of two or more electric cells. However, the word "battery" is generally used in everyday language to refer to all electric cells, including a single electric cell. Thus, when you buy an electronic device and the label says, "batteries not included," it means "electric cells not included." In this chapter, we will use the term "electric cell" to refer to one cell and the term "battery" to refer to a combination of two or more electric cells. GO

If you would like to learn more about electric cells, go to **www.science.nelson.com** GO

Most cars use a lead–acid battery. Many electronic devices, such as digital cameras and hand-held gaming systems, use alkaline cells, a type of primary cell. Nickel–cadmium cells and lithium ion cells are used in portable computers.

Most of the electrical energy that we use in our homes and schools comes from generating stations, where rotating turbines produce electricity.

The Load in Circuits

The **load** in an electric circuit is any device that converts electrical energy into another form of energy. For example, in an electric toaster, the filaments of the toaster convert the electrical energy into heat energy, which toasts a piece of bread (Figure 3). The filaments are the load of the circuit. In the electric motor of a circular saw, electrical energy is converted into mechanical energy. The motor is the load.

Some loads convert electrical energy into more than one form of energy. For example, an incandescent light bulb converts some electrical energy into useful light energy. However, an incandescent light bulb is not an efficient light source. Most of the electrical energy that is used by an incandescent light bulb is converted into heat energy.

Figure 3 The filaments in a toaster are the load in the circuit. They convert electrical energy into heat energy and light energy.

The Pathway in a Circuit

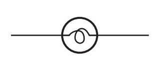
Conducting wires connect the energy source to the load in a circuit to create a controlled path through which the electric charge can flow. Because most metals are good conductors that let electric charge flow through them easily, metals are used to make conducting wires. Copper is the most commonly used metal in conducting wires. The diameter of a conducting wire depends on its use. For example, the conducting wire in a microchip is only a few atoms in a diameter. A transmission line is about 2 cm in diameter.

Electric Circuit Diagrams and Symbols

We can simplify the drawing of an electric circuit by using a special set of symbols. Using symbols makes it more convenient to draw an electric circuit because we only need to draw one symbol for a switch, rather than draw different pictures of all the different types of switches that exist. A **circuit diagram** (schematic diagram) is a representation of an electric circuit using standard symbols to represent the elements of the circuit. Table 1 shows some of the standard symbols that are commonly used in circuit diagrams. Since the symbols are standard, circuit diagrams can be interpreted by anyone in the world.

To see more circuit diagram symbols, go to **www.science.nelson.com**

Table 1 Circuit Diagram Symbols

Part of circuit	Symbol
electric cell	
two-cell battery	
switch	
light bulb (lamp)	

LEARNING TIP

Symbols help to simplify circuit diagrams. Check your understanding of the components of a circuit diagram by using Table 1 to explain Figure 4 to a partner.

The symbol for an electric cell is two parallel lines: the longer line represents the positive terminal and the shorter line represents the negative terminal. One way to remember this is that the thicker shorter line looks more like a minus sign and is the negative terminal.

Many circuits require two or more electric cells combined to provide the electrical energy. The symbol for a two-cell battery has two symbols of an electric cell side by side. To represent a three-cell battery, just add another electric cell symbol.

Figure 4 shows a circuit diagram for a simple circuit that contains an energy source (an electric cell), a switch, and a light bulb. When the switch is closed, the electrons flow and the light is lit. For this circuit, electrons flow in a counterclockwise direction from the negative terminal of the electric cell, through the bulb, and back to the positive terminal.

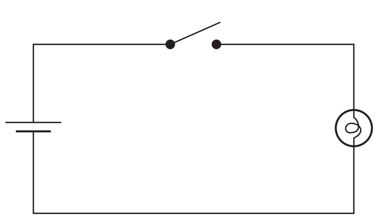


Figure 4 A circuit diagram uses symbols to represent the components in a circuit.

10.1 CHECK YOUR Understanding

1. Describe the major difference between static electricity and current electricity.
2. List the three parts of a circuit. Explain the function of each part and provide an example.
3. Why are circuit diagrams used rather than pictorial diagrams?
4. Draw a circuit diagram for a circuit that has two electric cells, a switch, and a light bulb.
5. Copy Figure 5 into your notebook. Label the components of the circuit. Label the positive and negative terminals of the two-cell battery on your diagram. Indicate the direction that the electrons flow.

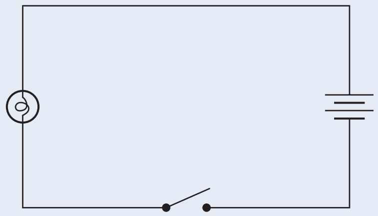


Figure 5

6. (a) Draw a circuit diagram of the circuit shown in Figure 6.
   (b) Explain the direction that the electrons flow in this circuit.

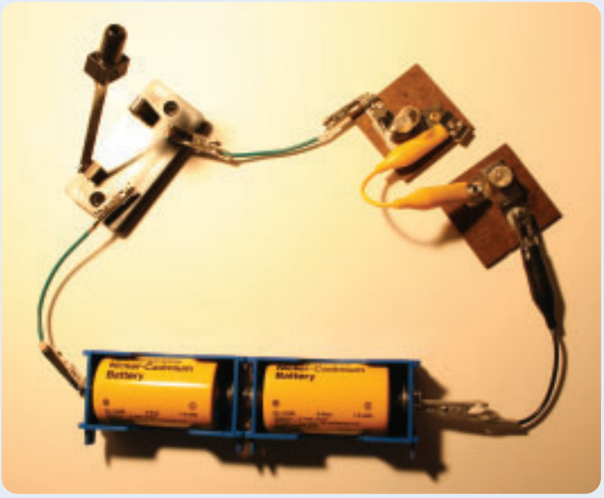


Figure 6

7. Draw a circuit diagram of the circuit shown in Figure 7.

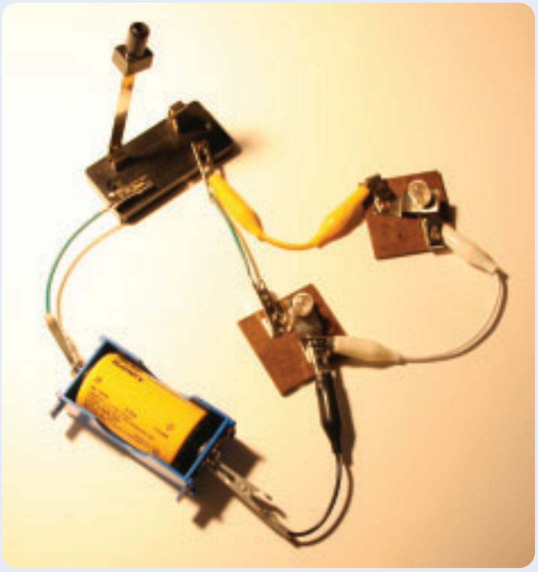


Figure 7

8. (a) What is the difference between a primary cell and a secondary cell?
   (b) What is the difference between an electric cell and a battery?
9. What are the three parts of a primary cell?
10. A smoke detector may use a rectangular 9 V battery that is composed of several electric cells. Is it correct to call it a battery or should it be called an electric cell?
11. Which part of a circuit converts electrical energy into another form of energy?
12. Give an example of an electrical load that converts electrical energy to light energy and an example of a load that converts electrical energy to heat energy. Which load do you think uses the most energy?

10.2 Electric Current

LEARNING TIP
In preparation for reading Section 10.2, skim the headings and read the first sentence in each paragraph. Ask yourself, "What do they let me know I will be reading about?"

Current electricity refers to electric charges flowing through a conductor. The flow of electric charges is called **electric current** (***I***). In reality, only the electrons (negative charges) move through a circuit.

Electric current can be compared with the current in a river. The current in a river is the amount of water that passes a point in a given time. Similarly, electric current is the amount of charge that passes a point in a circuit in a given time. The unit of measurement for electric current is the **ampere** (**A**). The ampere is named after the French physicist André Marie Ampère. The typical amount of current flowing through a light bulb is 1 A; through a toaster is 13 A; through a TV set is 4 A; and through a car starter motor is 500 A.

We can use the following equation to calculate current:

$$I = \frac{Q}{t}$$

where I is the current (in amperes), Q is the quantity of electric charge (in coulombs), and t is the time (in seconds). The quantity of charge (Q) is the amount of charge carried by the electrons. One coulomb is equal to the charge of 6.25×10^{18} electrons ($1\ C = 6.25 \times 10^{18}$ electrons). One ampere represents the current of one coulomb of charge per second.

When you touch a source of electricity and there is a complete circuit, you can get an electric shock. The severity of the shock depends on the current. At 0.001 A (1 mA), you will feel a tingling sensation. At 0.015 A (15 mA), your muscles will contract so that you cannot let go. At 1.0 A (1000 mA), the current is lethal. GO

To learn more about the human response to electric shock, go to **www.science.nelson.com** GO

Direction of Electric Current

In the early 19th century, scientists assumed that when an electric current flowed in a circuit, it was the positive charges that were moving. Current was defined as the direction that a positive charge would take. The direction of the electric current was from the positive terminal to the negative terminal of the energy source (Figure 1). The direction that a positive charge would take in a circuit is called **conventional current**.

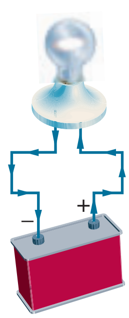


Figure 1 The flow of conventional current is from the positive terminal, through the light bulb, to the negative terminal.

The discovery of the electron changed how scientists looked at the flow of electric charges. Scientists determined that, in a metal wire, it is the negatively charged electrons that flow from the negative terminal to the positive terminal of the energy source. This is referred to as **electron flow**, which is opposite to the direction of conventional current (Figure 2).

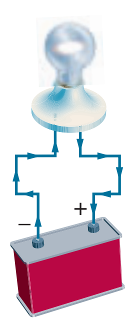


Figure 2 Electron flow is from the negative terminal, through the light bulb, to the positive terminal.

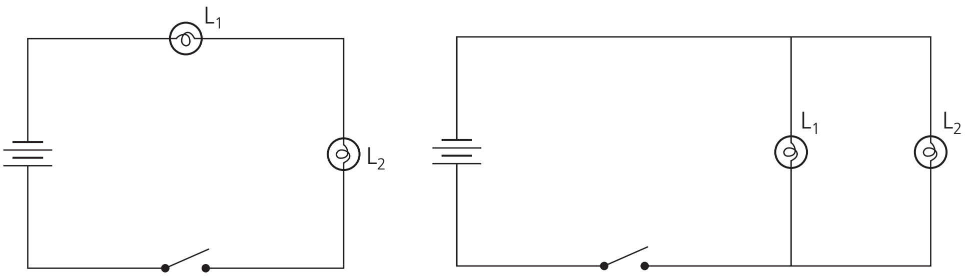
The electric current supplied from an electric cell flows in a single direction. This is called **direct current** (**DC**). Battery-operated watches and devices use direct current. Wall outlets in a house supply **alternating current** (**AC**). Alternating current results when the electrons periodically reverse direction. In an AC circuit in North America, the current reverses its direction 60 times a second.

Series and Parallel Circuits

Circuits, or devices within a circuit, can be connected in series or in parallel. When devices, such as light bulbs, are connected in a **series circuit**, the current goes through each device in sequence (Figure 3(a)). When devices are connected in a **parallel circuit**, the current splits up and some of the current goes through each device (Figure 3(b)). However, none of the current goes through more than one device.

LEARNING TIP

Use the caption and circuit symbols to explain Figure 3(a) and (b) to a partner. Refer to Table 1 on page 304 if you need to review the circuit diagram symbols.



(a) **(b)**

Figure 3 (a) Two lamps in series (b) Two lamps in parallel. Note that we use subscripts (1 and 2) to differentiate the lamps.

Measuring Electric Current

We can use an **ammeter** to measure the amount of electric current at a point in a circuit. The circuit diagram symbol for an ammeter is shown in Figure 4. An ammeter should be connected directly in the path of the moving electric charges. It is connected in series in the circuit. For example, to measure the current through a light bulb, an ammeter should be placed in series with, or in the same path as, the light bulb. The ammeter and the bulb are in series because all the charges that go through the ammeter also go through the light bulb (Figure 5).

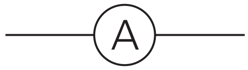


Figure 4 The circuit diagram symbol for an ammeter

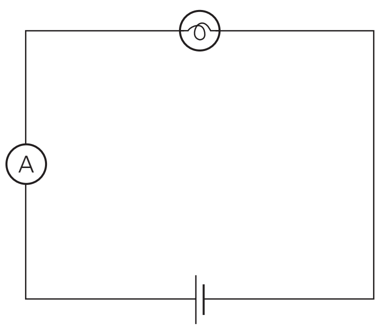


Figure 5 An ammeter in a circuit is placed in series with the light bulb.

Ammeters can be either analog or digital; we can also use a multimeter to measure current (Figure 6). A multimeter not only measures current, but also measures other electrical quantities. Since many currents are often less than 1 A, ammeters measure current in both amperes and in milliamperes (mA).

Figure 6 (From left to right) An analog ammeter, digital multimeter, and analog multimeter

We can use the measured value of current (as determined by an ammeter) to calculate how many electrons go past a point in a circuit, as shown in the following sample problem.

SAMPLE PROBLEM

Determine the Number of Electrons Going Past a Point Using Current and Time

An ammeter indicates that a current of 1.2 A flows through a lamp. How many electrons will go through the lamp in 45 s?

Solution

First, change the form of the equation for electric current to solve for Q (charge in coulombs).

$$I = \frac{Q}{t}$$

$$Q = It$$

$$= (1.2\ \text{A})(45\ \text{s})$$

$$Q = 54\ \text{C}$$

We know that $1\ \text{C} = 6.25 \times 10^{18}$ electrons. We can use this value to convert from coulombs to the number of electrons (N).

$$N = 54\ \text{C}\left(\frac{6.25 \times 10^{18}\ \text{electrons}}{1\ \text{C}}\right) = 3.4 \times 10^{20}\ \text{electrons}$$

Therefore, 3.4×10^{20} electrons will go through the lamp in 45 s.

Practice

A light bulb has a current of 0.073 A flowing through it. How many electrons pass through the light bulb in 45 s? Recall that $1\ \text{C} = 6.25 \times 10^{18}$ electrons.

TRY THIS: Measuring Currents

Skills Focus: observing, predicting, measuring

In this activity, you will measure currents in a simple circuit using an ammeter.

Materials: small light bulb in a holder, electric cells in holders, switch, connecting wires, ammeter

1. Connect the light bulb to the electric cells with a switch in series. Insert an ammeter into the circuit between the switch and the light bulb (Figure 7).
2. Draw a circuit diagram of your circuit. Draw an arrow on your diagram to indicate the direction of electron flow.
3. Close the switch. Measure the current entering the light bulb.
4. Open the switch. Remove the ammeter and place it on the other side of the light bulb, between the light bulb and the positive terminal. Make a prediction about how the current on this side of the light bulb will compare with the current on the other side.
5. Close the switch and measure the current leaving the light bulb.

A. How does the current entering the light bulb compare with the current leaving the light bulb?

B. Based on your observations, draw a conclusion about how the electrons entering the light bulb compare with the electrons leaving the light bulb.

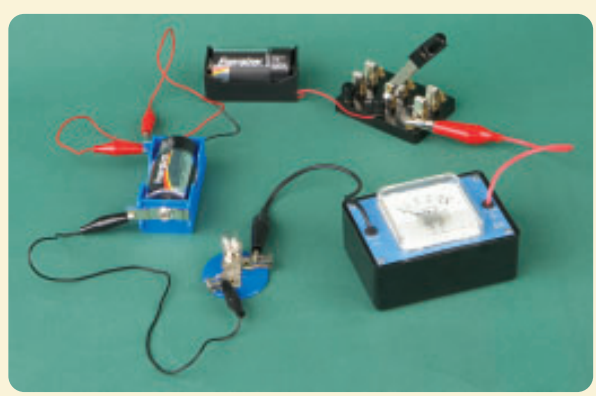


Figure 7

10.2 CHECK YOUR Understanding

1. What is electric current? State the symbol and SI unit that are used for electric current.
2. What kind of electric charges move through metals to form an electric current?
3. Define "conventional current" and "electron flow" in your own words.
4. Does a car battery produce alternating current or direct current?
5. Draw a circuit diagram for each of the following situations.
   (a) A lamp is added in series with the lamp shown in Figure 8. Label your diagram.
   (b) A lamp is added in parallel with the lamp shown in Figure 8. Label your diagram.

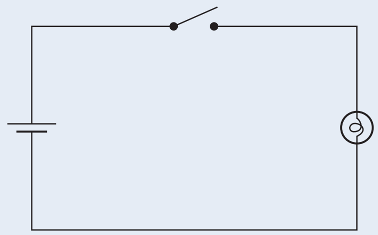


Figure 8

6. How is an ammeter connected in a circuit to measure the current? Draw a circuit diagram to help you explain your answer.
7. Figure 9 shows five ammeters connected to an electric circuit. Which ammeter(s) would measure the current going through the light bulb?

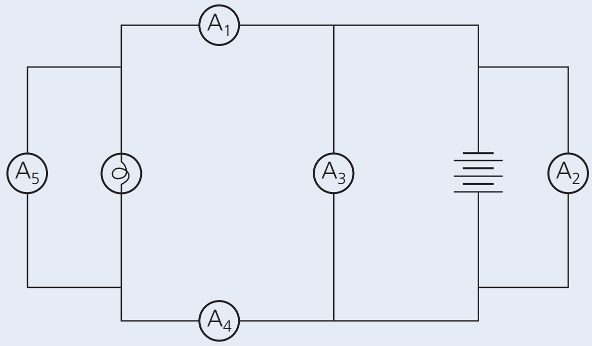


Figure 9

8. Convert the following values from mA to A. (Refer to page 522 in the Skills Handbook for information about converting units.)
   (a) 489 mA
   (b) 8.5 mA
   (c) 2300 mA
9. Convert the following values from A to mA. (Refer to page 522 in the Skills Handbook for information about converting units.)
   (a) 0.055 A
   (b) 2.2 A
   (c) 0.625 A
10. Determine the value of current indicated by the ammeter in Figure 10.

Figure 10

11. A current of 140 mA enters a light bulb. What is the current leaving the light bulb? Explain your answer.
12. A light bulb has 1100 C of electric charge flow through it in 8 min. What is the electric current, in amperes, flowing through the light bulb?
13. A current of 350 mA flows through an electric motor. How long will 185 C of electric charge take to pass through the motor?
14. A balloon is given a static electric charge of $-89\ \mu C$ (8.9×10^{-5} C). How many electrons does this represent?
15. A current of 120 mA flows past a point in a circuit for 25 s.
    (a) How much charge passes the point in this time?
    (b) How many electrons pass the point in this time?

10.3 Electric Potential Difference (Voltage)

To learn more about voltage, go to **www.science.nelson.com** GO

You have learned that electrical energy is carried through a circuit by electrons. The type of energy that each electron has is called electric potential energy. However, we can only measure the change in electric potential energy per coulomb of charge. This change is called electric potential difference, and is measured in volts (V). Because the differences are measured in volts, electric potential difference is often simply called **voltage** (***V***). GO

In mathematical terms, voltage is equal to the amount of electrical energy, in joules, for each coulomb of charge:

$$V = \frac{\Delta E}{Q}$$

where V is voltage (in volts), ΔE is the change in energy (in joules), and Q is the amount of charge (in coulombs). The symbol Δ is the Greek letter *delta*, and represents change. We can read the expression ΔE as "delta *E*," or "change in energy."

The **volt** (**V**) is defined as one joule per coulomb:

$$\text{one volt} = \frac{\text{one joule}}{\text{coulomb}}$$

The letter V is used as a symbol for both voltage (the electrical property) and volt (the SI unit of measurement for voltage). However, they can be distinguished easily: the symbol for the variable voltage is V (italicized), while the symbol for the unit volt is V (not italicized).

The voltage in a flashlight circuit is usually provided by two electric cells, which together give 3.0 V. In comparison, North American household outlets are 120 V, cross-country transmission lines are about 250 kV (250 000 V) (Figure 1), and the Van de Graaff generator produces about 2 MV (2 000 000 V).

Figure 1 These electricians are working on high-voltage transmission lines.

Measuring Voltage

A **voltmeter** is a device that measures the electric potential difference, or voltage. The circuit diagram symbol for a voltmeter is shown in Figure 2. The voltmeter can be connected to the energy source or it can be connected to the load. When you connect a voltmeter to the positive and negative terminals of a battery, the voltmeter measures the difference in volts between the positive and negative terminals (Figure 3).

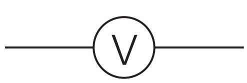


Figure 2 The circuit diagram symbol for a voltmeter

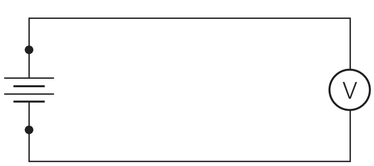


Figure 3 Measuring the voltage of a battery

A voltmeter measures the difference in voltage, which can be increasing (such as in a battery) or decreasing (such as in a load). A battery raises the voltage in a circuit the same way that a water pump raises water to the top of a waterwheel. Figure 4 shows a water pump raising water from a lake to a trough, and then letting the water pour onto a waterwheel to turn the wheel.

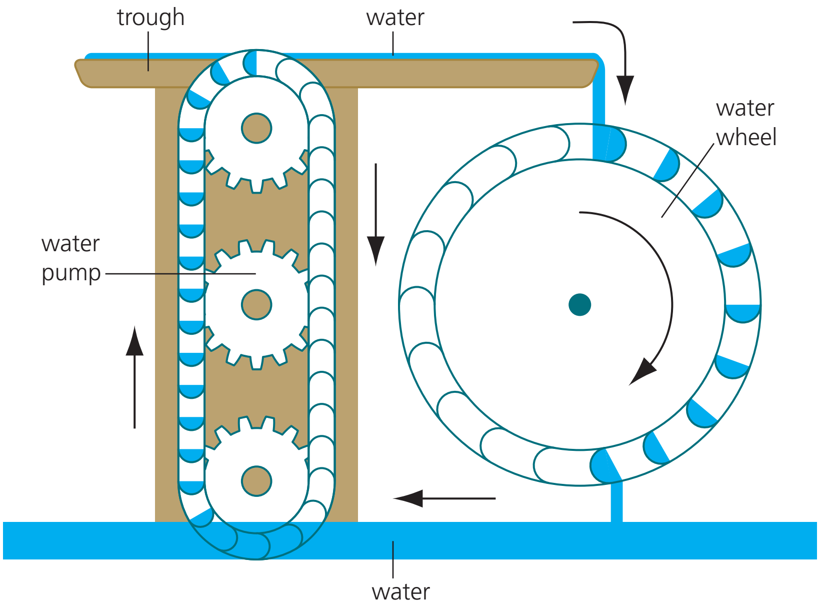


Figure 4 A water pump circuit

When a voltmeter is connected across a light bulb in a circuit, as shown in Figure 5, the voltage decreases the same way that the raised water flows down over the waterwheel. Note that the voltmeter is connected in parallel to the light bulb so that a small amount of current goes through the voltmeter and the rest of the current goes through the light bulb.

Voltmeters can be either analog or digital. A multimeter can also be used to measure voltage. Figure 6 shows a voltmeter and two multimeters.

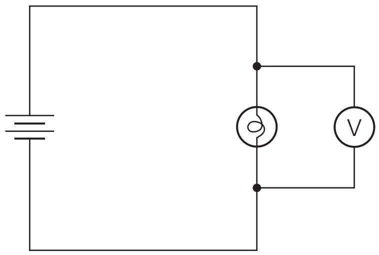


Figure 5 Measuring the voltage of a light bulb

Figure 6 (From left to right) An analog voltmeter, digital multimeter, and analog multimeter

Series and Parallel Combinations of Cells

In a circuit, an electric cell provides the electrons with electric potential energy. An electric cell functions in a circuit the same way that a water pump functions in the water pump circuit shown in Figure 4. The water pump gives the water gravitational potential energy, which is released as kinetic energy (motion) as the wheel turns, and sound energy. **10A** *Investigation*

10A *Investigation*

Voltage of Cells in Series and Parallel Circuits

To perform this investigation, turn to page 327.

In this investigation, you will determine the voltages of electric cells arranged in series and parallel batteries.

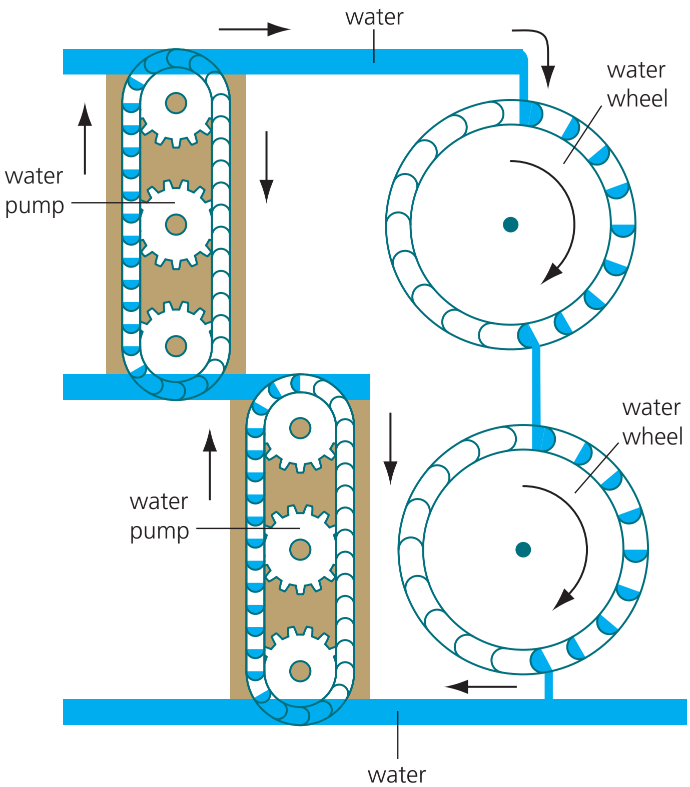


Figure 7 Two water pumps connected in series give the water twice as much gravitational potential energy as a single pump so they can turn two water wheels.

What would happen if there were two water pumps? There are two possible ways that the pumps could be arranged: stacked one on top of the other or side by side. If the pumps were stacked on top of each other in a series, as shown in Figure 7, the two pumps could lift the water twice as high as one pump, but they could not lift more water. On the other hand, if the pumps were parallel, as shown in Figure 8, the two pumps could lift twice as much water, but only to the same height as one pump.

Note that when the pumps are connected in series, water that goes through the first pump also goes through the second pump. When two pumps are connected in series, there is only one path—through both pumps. However, when the pumps are connected in parallel, the water only goes through one pump. When two pumps are connected in parallel, there are two paths—each path goes through one of the pumps.

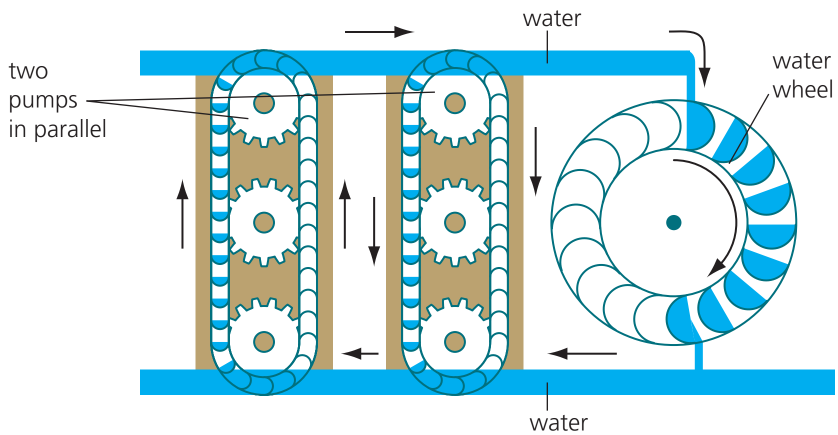


Figure 8 Two water pumps connected in parallel give the water the same amount of gravitational potential energy as a single water pump, but they can lift twice as much water.

Cells in Series

A common electric cell produces about 1.5 V. This means that the electric cell gives the current a voltage of 1.5 V. However, many circuits require more than a few volts. Just as water pumps in series provide the water with twice the gravitational potential energy, connecting two electric cells in series gives the current twice the voltage. Thus, when cells are connected in series, the voltage of the combined electric cells equals the sum of the individual cells (Figure 9). For example, the 12 V lead–acid battery of a car is composed of six 1.5 V cells connected in series. (Recall that we use the term "battery" to refer to a combination of two or more electric cells.)

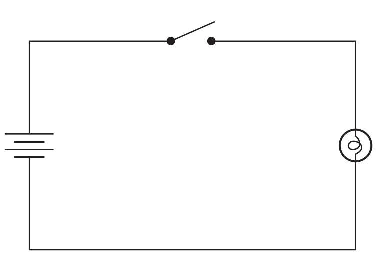


Figure 9 Two electric cells in series: the voltage of cells in series equals the sum of the voltage of the individual cells.

SAMPLE PROBLEM

Determine the Voltage of Electric Cells in Series

Four 1.5 V electric cells are connected in series to form a battery. What is the total voltage, V_T, of the battery?

Solution

$V_T = 4(1.5\ V) = 6.0\ V$

The total voltage is 6.0 V.

Practice

What is the total voltage of a battery made of six 1.2 V electric cells connected in series?

Cells in Parallel

When electric cells are connected in parallel, they do not provide more voltage. However, they do provide a greater amount of charge. This is similar to the water pumps in parallel that can pump twice as much water as a single pump. No matter how many 1.5 V cells you connect in parallel, the voltage of the combination is only 1.5 V. Batteries made with parallel cells can either provide more charge in a given time (greater current) or provide a given charge for a longer time (longer battery life). Figure 10 shows two electric cells connected in parallel.

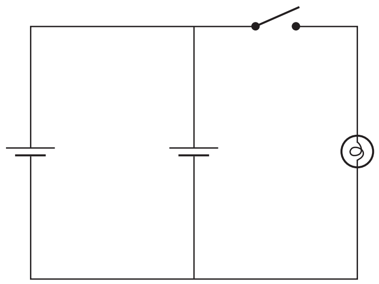


Figure 10 Two electric cells in parallel

Cells in Combination

Some batteries contain electric cells in both parallel and series combinations. For example, Figure 11 shows a circuit diagram of a battery made of six electric cells in two sets of three. Each set has the three cells connected in series. The two sets are connected in parallel. Point A represents the positive terminal, and point B represents the negative terminal of the battery. If each cell has a voltage of 1.2 V, then the battery has a total voltage of 3.6 V. We could measure this voltage using a voltmeter connected to points A and B.

Remember that voltages, as measured by voltmeters, are always the difference in voltage between two points. This is why voltmeters are always connected in parallel with devices.

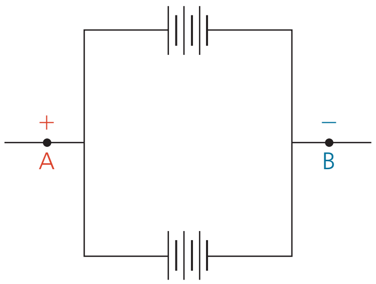


Figure 11 Battery made of six cells

10.3 CHECK YOUR Understanding

1. Define the term "voltage" (electric potential difference) in your own words. State the symbol and SI unit that are used for voltage.
2. When you connect a voltmeter to the terminals of a battery, the voltmeter indicates the voltage of the battery. Are electrons flowing through the voltmeter? What evidence supports your answer?
3. How should a voltmeter be connected to a battery to measure the voltage of the battery? Draw a circuit diagram to explain your answer.
4. Compare the way that an ammeter is connected in a circuit with the way that a voltmeter is connected in a circuit. Explain the difference.
5. Figure 12 shows a circuit that consists of a 1.5 V electric cell, a switch, a light bulb, and a voltmeter. When the switch is closed, what reading will the voltmeter indicate?

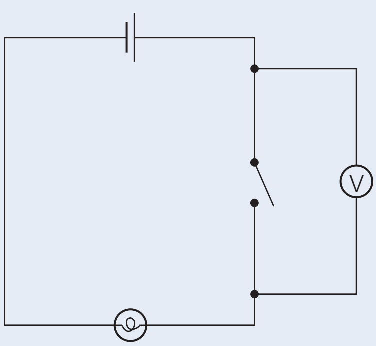
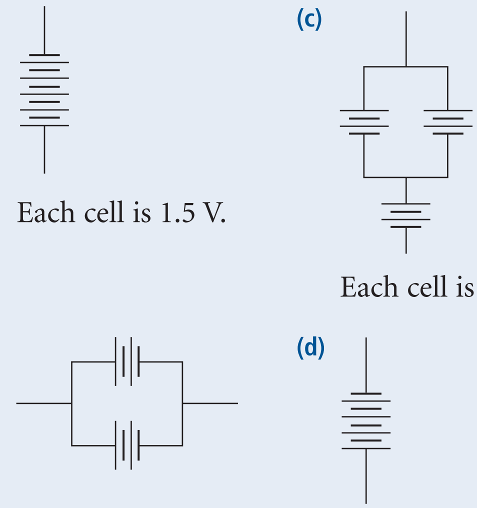


Figure 12

6. Draw a circuit diagram that shows three cells connected in parallel.
7. What is the voltage of three 1.5 V cells connected in series to form a battery? What is the general rule for the voltage of a battery made from cells connected in series?
8. What is the voltage of three 1.5 V cells connected in parallel to form a battery? What is the general rule for the voltage of a battery made from cells connected in parallel?
9. The circuit diagrams in Figure 13 show electric cells connected to make batteries. Copy the circuit diagrams into your notebook, and label the positive (+) and negative (−) terminals of the batteries. Determine the voltage of each battery.



(a) Each cell is 1.5 V.

(c) Each cell is 2.0 V.

(b) Each cell is 1.2 V.

(d) Each cell is 1.5 V.

Figure 13

10. (a) What is the advantage of making a battery using cells connected in series?
    (b) What is the advantage of making a battery using cells connected in parallel?
11. A car battery produces 12 V from electric cells that each produce 2.0 V. What is the minimum number of electric cells in a car battery?
12. A battery, composed of six 1.2 V cells, is connected to a light bulb (Figure 14). What is the voltage of the filament of the light bulb?

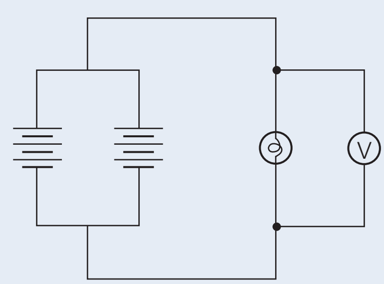


Figure 14

10.4 Resistors and Ohm's Law

A **resistor** (Figure 1) is a component of an electrical circuit that resists, or opposes, the flow of electrical current. The resistor is the load in a circuit and converts electrical energy to another form of energy, such as light energy or heat energy.

The unit of measurement for resistance is the **ohm**, which is denoted by the symbol Ω (the Greek letter "omega"). The amount of resistance offered by a resistor depends on the type of material that makes up the resistor. Many resistors are made of carbon, a semiconductor. Other resistors are made of a metal wire wrapped around ceramic or plastic tubing, and provide resistance at higher currents or voltages. In addition to the type of material, the resistance of a resistor depends on its length, diameter, and temperature. The resistance of a resistor increases with length and decreases with diameter. An increase in temperature generally causes an increase in resistance. The circuit diagram symbol for a resistor is shown in Figure 2.

Figure 1 Most electrical appliances have resistors in their circuits.

Figure 2 The circuit diagram symbol for a resistor

TRY THIS: *Voltage and Current in a Resistor*

Skills Focus: observing, measuring, interpreting data

In this activity, you will look at the relationship between voltage and current for carbon resistors.

Materials: 2 carbon resistors of different values, 5 D-cells in holders, switch, connecting wires, ammeter and voltmeter (or multimeter)

1. Copy Table 1 into your notebook.

Table 1 Voltage and Current in a Resistor

Number of cells	Voltage (V)	Current (mA)	Current (A)	Voltage / Current
1				
2				
3				
4				
5				

2. Record the value of the resistance of the resistor.
3. The cells should all have the same voltage. Use the voltmeter to check the voltage of the cells.
4. Use one of the resistors to construct a circuit like the circuit shown in Figure 3. Record the voltage and current in your table. Note that if the ammeter measures current in milliamperes, you will need to convert to amperes.

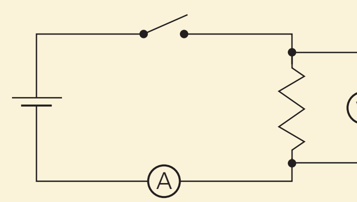


Figure 3

5. Modify your circuit using two, three, four, and five cells in series. Record the voltage and current for each setup.
6. Create another table like Table 1, and repeat steps 2 and 3 using another resistor with a different value.

A. On the same graph, plot voltage versus current for both resistors. Draw a line of best fit through each set of data.

B. In the last column of your tables, calculate and record the value of the voltage divided by the current (in A). What do you notice about the values for each resistor?

C. How does the value in the last column compare with the value of the resistor?

Did You KNOW?

The Colour of Resistance

Colour-coded bands on a resistor indicate the value of that resistor. Each colour represents a number as shown. The first two bands represent the first two digits and the third band is the number of zeros to be added. For example, the colour bands on a 68 Ω resistor are blue, grey, and black; the bands on a 100 Ω resistor are brown, black, and brown; and the bands on a 150 Ω resistor are brown, green, and brown.

black	0
brown	1
red	2
orange	3
yellow	4
green	5
blue	6
violet	7
grey	8
white	9

LEARNING TIP

Use Table 2 and Figure 4 to explain to a partner why the relationship between voltage and current in a resistor is called linear (relating to a straight line).

Voltage, Current, and Resistors

In Section 10.3, we looked at a water circuit that contained a pump and a water wheel (refer to Figure 4 on page 311). If there was a load on the water wheel, such as a millstone to grind corn, the water wheel would turn more slowly and less water would flow through the circuit. In this case, the water pump is the energy source and it increases the voltage, the water wheel decreases the voltage, the current is similar to the rate of water flow, and the resistance is the load, or the millstone.

Consider a circuit that has a resistor, a switch, an electric cell, a voltmeter, and an ammeter. Figure 3 (on page 315) shows the circuit diagram for this circuit. An experiment is performed to determine how the voltage of an electric cell, the resistance of a resistor, and current are related in a circuit. The resistor has a value of 68 Ω and is connected to a 1.2 V electric cell. When the switch is closed, the voltmeter measures the voltage across the resistor as 1.2 V and the ammeter measures the current as 18 mA (or 0.018 A). We could add electric cells in series to increase the voltage. If we measured the voltage across the resistor using the voltmeter and measured the current in the resistor using the ammeter each time we added an electric cell, we would obtain the data given in Table 2. Note that, since an ammeter usually measures current in milliamperes, and amperes, the table contains current measurements in milliamperes and in amperes. Figure 4 shows a graph of the relationship between voltage and current. Since the relationship is linear, we can draw a straight line (line of best fit) through the data.

Table 2 Voltage and Current in a Resistor

Number of electric cells	Voltage (V)	Current (mA)	Current (A)
1	1.2	18	0.018
2	2.4	35	0.035
3	3.6	53	0.053
4	4.8	71	0.071
5	6.0	88	0.088

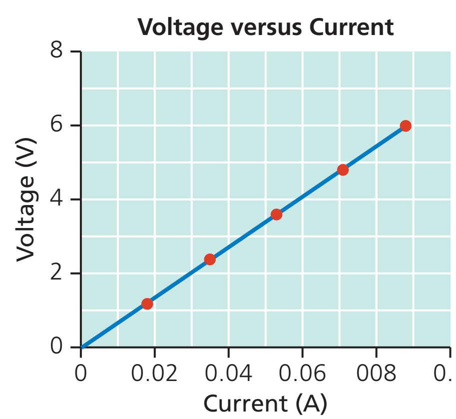


Figure 4 The straight line, or line of best fit, through the data from Table 2 shows that there is a positive correlation between voltage and current: as current increases, voltage increases.

Note that the variable that is controlled in an experiment is usually placed on the *x*-axis. However, for this experiment, the controlled variable, voltage, is placed on the *y*-axis and current is placed on the *x*-axis.

As you can see, there is a direct relationship between current and voltage: as the current increases, the voltage increases. In other words, voltage is directly related to current.

Ohm's Law

In 1827, German mathematician and physicist Georg Simon Ohm determined that the ratio of voltage to current was constant for a given conductor. He called this ratio the resistance of the conductor. The **resistance** (***R***) of a conductor is defined as the ratio of the voltage across a conductor to the current through the conductor. The relationship between voltage, current, and resistance of a conductor is known as **Ohm's Law** and can be written as the following equation:

$$R = \frac{V}{I}$$

where R is resistance (in ohms), V is the voltage (in volts), and I is the current (in amperes). This equation is usually written as:

$$V = IR$$

The resistance is a measure of how much the material of a conductor slows down, or resists, the flow of the current. Since the flow of current in a conductor is related to the movement of the electrons, the resistance is related to the collisions between the electrons and the atoms in the conductor. The collisions transform some of the electron's energy into heat energy in the conductor.

Almost all conductors exhibit some resistance. However, not all conductors obey Ohm's law. The resistance of a material depends on its temperature: resistance tends to increase with increasing temperature. So, although Ohm's law forms the basis for the definition of resistance, it is not a law in the usual scientific sense because it does not apply in all situations. You may assume that the conductors you will study in this course obey Ohm's law. GO

The following sample problems illustrate how we can use different forms of Ohm's law to determine resistance, voltage, and current.

SAMPLE PROBLEM 1

Determine Resistance

The starter motor of a car is connected to a 12 V battery. If the starter motor has 75 A of current going through it to start the car, what is the resistance of the starter motor?

Solution

Substitute the values into the equation for Ohm's law and solve.

$$\begin{aligned} R &= \frac{V}{I} \\ &= \frac{12\ \text{V}}{75\ \text{A}} \\ R &= 0.16\ \Omega \end{aligned}$$

The resistance of the starter motor is 0.16 Ω.

Practice

A flashlight uses two 1.5 V cells in series. The current in the bulb is 280 mA. What is the resistance of the bulb?

Did You KNOW?

Georg Ohm: The Man and His Work

Growing up in Germany, Georg Ohm (1787–1854) dreamed about working as a scientist at a German university. While teaching at a college, he experimentally showed the relationship between resistance, current, and voltage, and published his work in 1827. He received so much criticism that he was forced to resign his teaching position. After 15 years of living in poverty, Georg was recognized for his discovery by the Royal Society. In 1849, five years before his death, Georg's childhood dream was realized when he became a professor at the University of Munich.

To learn more about Ohm's law, go to **www.science.nelson.com** GO

Did You KNOW?

Superconductors

Superconductors are materials that have little or no resistance to electric current. The first superconducting materials displayed this effect only at temperatures near absolute zero (−273 °C). Scientists are researching materials that are superconducting at much higher temperatures. Superconductors are used to make extremely strong electromagnets, such as those used in magnetic resonance imaging (MRI) machines. Superconductors may one day be developed for use in motors, transformers, and transmission lines at normal temperatures.

LEARNING TIP

Your success in solving problems depends on your ability to understand what the problem is asking you to do. Ask yourself, "What are the key words? What equation needs to be applied to solve this problem?"

SAMPLE PROBLEM 2

Determine Voltage

A 92 Ω resistor has a current of 78 mA flowing through it. What is the voltage in the resistor?

Solution

First, convert the current into amperes.

$$78\ \text{mA} = 0.078\ \text{A}$$

Substitute the values into the Ohm's law equation and solve.

$$\begin{aligned} V &= IR \\ &= (0.078\ \text{A})(92\ \Omega) \\ V &= 7.2\ \text{V} \end{aligned}$$

The voltage across the resistor is 7.2 V.

Practice

A current of 150 mA flows through a 64 Ω resistor. What is the voltage across the resistor?

SAMPLE PROBLEM 3

Determine Current

A flashlight has a filament with a resistance of 10.7 Ω. The batteries provide 2.8 V. What is the current through the filament?

Solution

Change the form of Ohm's law equation to solve for I. Then substitute the values into the equation and solve.

$$\begin{aligned} V &= IR \\ I &= \frac{V}{R} \\ &= \frac{2.8\ \text{V}}{10.7\ \Omega} \\ I &= 0.26\ \text{A} \end{aligned}$$

The current through the filament is 0.26 A.

Practice

A 22 Ω resistor has a voltage of 3.5 V. What is the current in the resistor? Give your answer in mA.

10.4 CHECK YOUR Understanding

1. Write definitions of "resistance" and "resistor" in your own words.
2. An electric hot plate in a science lab uses a current of 8.5 A when it is plugged into a 120 V outlet. What is the resistance of the hot plate?
3. The 2.4 Ω headlight of an automobile uses a current of 5 A. What is the voltage in the headlight?
4. (a) The resistance of dry skin is about 500 000 Ω. How much current would go through you if you touched the terminals of a 9 V battery with dry hands?
   (b) The resistance of wet skin is about 1000 Ω. How much current would go through you if you touched the terminals of a 9 V battery with wet hands? (Remember that electric currents can be dangerous, and it is possible to cause heart fibrillation with a current of less than 100 mA.)
5. A toaster uses a current of 4 A. If the resistance of the toaster is 27 Ω, what is the voltage in the toaster?
6. Figure 5 shows a light bulb connected to two 1.2 V cells. When the switch is closed, an ammeter measures the current as 252 mA. What is the resistance of the bulb?

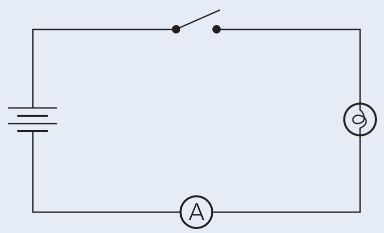


Figure 5

7. If resistance is doubled and voltage is halved, what is the effect on the current?
8. (a) A student varied the voltage through a resistor and measured the current through the resistor. She recorded the information in Table 3. Draw a voltage–current graph of the data. Use the data to calculate the resistance of the resistor. (Hint: Remember to convert mA to A first.)

Table 3 Voltage and Current in a Resistor

Voltage (V)	1	2	3	4	5	6
Current (mA)	7	13	20	27	33	40

   (b) Using Ohm's law, calculate the current through the resistor if she raised the voltage to 1000 V. What do you think would happen to the resistor with this current?
9. Many avoidable electrical fires (Figure 6) can be traced to improper use of extension cords. If you operate too many devices from an extension cord, the wire in the extension cord may become hot. Why does this happen?

Figure 6

10. (a) A 100 W light bulb is designed for use in North America where the voltage is 120 V. The resistance of the filament of the bulb is 144 Ω. Calculate the current in the bulb.
    (b) If the bulb is taken to Europe where the voltage is 240 V, what do you think will happen to the brightness of the bulb? Explain your answer.
11. Using Ohm's law as an example, describe the difference between a theory and a law.

10.5 Resistors in Series and Parallel Circuits

Most circuits contain many loads, or resistors (Figure 1). What happens in an electric circuit that has more than one resistor in series? Does the same thing happen when the resistors are in parallel?

Figure 1 Do you think that the lights in this circuit are connected in series or in parallel?

When resistors are arranged in a series circuit, the current passes through each resistor, in turn, down a single path. However, in a parallel circuit, the path branches to the resistors and some current goes down each branch. You will explore series and parallel circuits in Investigation 10B. **10B** *Investigation*

10B *Investigation*

Resistors in Series and Parallel Circuits

To perform this investigation, turn to page 328.

In this investigation, you will look at how the current and voltage vary in series and parallel circuits.

We can use a waterslide analogy to understand the differences between an electric circuit with two resistors in series and an electric circuit with two resistors in parallel. Imagine that each circuit is a waterslide made of two slides and that the electrons moving through the circuit are people at the waterslide. One waterslide (Figure 2) has the two slides connected in series. The people going down this slide all follow the same path. The other waterslide (Figure 3) has the two slides connected in parallel. The people going down this slide can choose which slide to go down. Let's look at some other differences between the waterslides.

We need to understand that the people going down the series slides have twice as much gravitational potential energy at the top of the slide as the people at the top of either of the parallel slides. A person on the series slides takes a longer time to reach the bottom than a person on one of the parallel slides.

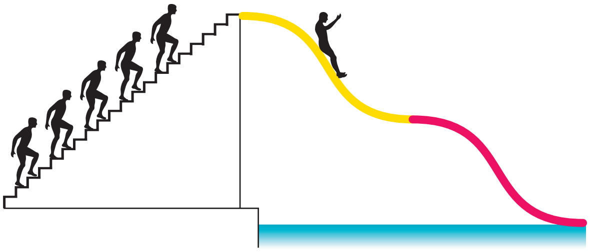


Figure 2 Waterslide with two slides connected in series

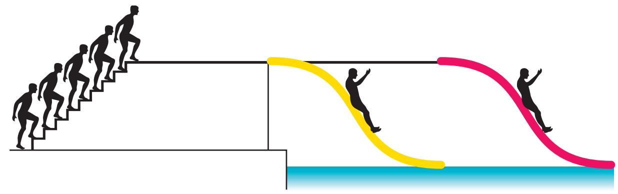


Figure 3 Waterslide with two slides connected in parallel

How does the number of people who go down each slide compare? If we built a people counter into each slide, we could record how many people go down each slide in a day. To determine the number of people on the series slide, we could take the reading from either slide. However, to determine the number of people on the parallel slides, we would have to add the counts from both slide sections. Since two people can go down the parallel slides at the same time, and people take longer to go down the series slide, more people would go down the parallel slides than down the series slide in a day, assuming that people come to both slides at the same rate.

What would happen if we added more slides to the series waterslide and to the parallel waterslide? On the series slide, not only would people take longer to reach the bottom, but there would also be fewer people going down the waterslide each day. However, if more slides were added in parallel, more people would be able to go down the parallel slides each day. If the slides were identical, two parallel slides would have twice as many people per day as one slide, and three parallel slides would have three times as many people.

We can use the waterslide analogy to understand resistors in series and parallel circuits. In a series circuit, for example, the charge from the two-cell battery must go through the first resistor (R_1), then the second resistor (R_2), and then return to the battery (Figure 4). The number of electrons remains the same.

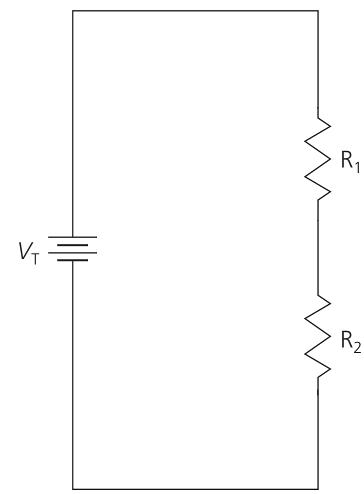


Figure 4 In a series circuit, the current is constant throughout the entire circuit. The current at R_1, which we can call I_1, is the same as the current I_2 at R_2.

However, in a parallel circuit (Figure 5), the current is split so that some goes through each resistor. The amount of current leaving the battery is equal to the sum of the current going through each resistor.

In series resistors, the total voltage of all the resistors is the same size as the voltage of the battery. That is, the sum of all the voltages of the resistors is equal to the voltage of the battery. In parallel resistors, the voltage of all the resistors is the same as the voltage of the battery. That is, the voltage is the same across all the resistors connected in parallel.

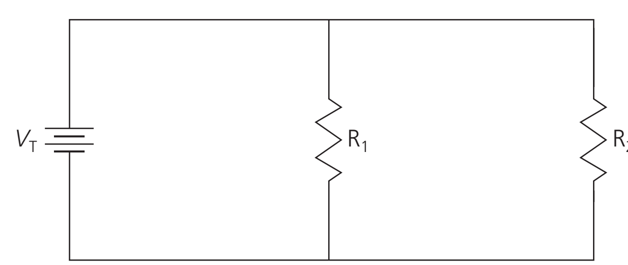


Figure 5 In a parallel circuit, the total current equals the sum of the individual currents. The total current for the circuit equals the sum of the current at R_1, which we can call I_1, and the current I_2 at R_2.

LEARNING TIP

Can you identify the differences between a series and a parallel circuit? If not, reread pages 320 and 321 and re-examine Figures 2–5.

The resistance of a circuit is a measure of how much the circuit resists the flow of charge. What happens when resistors are added to a series circuit? Just as adding slides to the series waterslide reduced the number of people going down the slide each day, adding resistors in series decreases the amount of current that can pass through. In other words, adding resistors in series increases the total resistance. In general, for resistors in series, the total resistance is equal to the sum of the individual resistances. If the resistors are identical, then the total resistance is equal to the individual resistance multiplied by the number of resistors.

However, adding resistors in parallel creates more paths for the charge to take. Just as adding slides in parallel means that more people can go down the slides, adding resistors in parallel decreases the total resistance. For identical resistors in parallel, the total resistance is equal to the individual resistance divided by the number of resistors.

Table 1 summarizes the rules for currents, voltages, and resistance in circuits with series or parallel resistors.

LEARNING TIP

Make a copy of Table 1 on a study card. This way, you will not have to flip back and forth to Table 1 when solving the practice problems.

Table 1 Characteristics of Series and Parallel Circuits

Type of circuit	Series circuit	Parallel circuit
total current (I_T)	$I_T = I_1 = I_2 = I_3$	$I_T = I_1 + I_2 + I_3$
total voltage (V_T)	$V_T = V_1 + V_2 + V_3$	$V_T = V_1 = V_2 = V_3$
total resistance (R_T)	$R_T = R_1 + R_2 + R_3$ $R_T = nR$; for n identical resistors	$R_T = \frac{R}{n}$; for n identical resistors

We can use these rules to determine the current, voltage, and resistance for circuits with series or parallel resistors, as shown in the following sample problems.

SAMPLE PROBLEM 1

Determine Total Resistance

Three resistors are connected in series. If the resistors have values of 22 Ω, 68 Ω, and 100 Ω, what is the total resistance (R_T) of the three resistors?

Solution

$$R_T = 22\ \Omega + 68\ \Omega + 100\ \Omega$$
$$= 190\ \Omega$$

The total resistance is 190 Ω.

Practice

What is the total resistance (R_T) of a 47 Ω resistor connected in series with a 150 Ω resistor?

SAMPLE PROBLEM 2

Determine Voltage, Current, and Resistance

Figure 6 shows three identical resistors connected in series to a 120 V source. Note that the circuit symbol for the electric cell can be used to represent any source of voltage.

(a) What is the voltage of each resistor?

(b) An ammeter measures the current leaving the voltage source as 0.06 A. What is the current going through the middle resistor (R_2)?

(c) What is the resistance of each resistor?

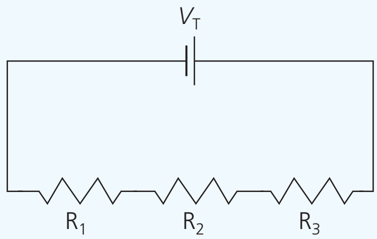


Figure 6

Solutions

(a) Since the three resistors are in series, the total voltage of all three resistors is equal to 120 V.

$$V = \frac{120\text{ V}}{3} = 40\text{ V}$$

Since they are identical, each resistor has a voltage of 40 V.

(b) Since the resistors are in series, the current is the same throughout the circuit. The current in R_2 is 0.06 A.

(c) There are two possible methods for determining the resistance of each resistor:

Method A

Use Ohm's law equation to calculate the resistance.

$$R = \frac{V}{I}$$

Substitute the voltage and the current that goes through R_1 into the equation.

$$V_1 = 40\text{ V}$$

$$I_1 = 0.06\text{ A}$$

$$R_1 = \frac{40\text{ V}}{0.06\text{ A}}$$

$$R_1 = 667\ \Omega$$

The resistance of each resistor is 667 Ω.

Method B

Use Ohm's law equation to calculate the total resistance of the circuit. Substitute the total voltage and the total current into the equation.

$$V_T = 120\text{ V}$$

$$I_T = 0.06\text{ A}$$

$$R = \frac{V}{I}$$

$$R_T = \frac{120\text{ V}}{0.06\text{ A}}$$

$$R_T = 2000\ \Omega$$

Since the total resistance equals the sum of the individual resistances, we can calculate the individual resistances by dividing.

$$R_1 = \frac{2000\ \Omega}{3} = 667\ \Omega$$

Practice

A voltage source applies 60 V to two identical resistors, as shown in Figure 7.

(a) What is the voltage of each resistor?

(b) If the current leaving the voltage source is 400 mA, what is the resistance of each resistor?

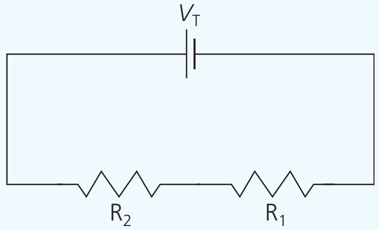


Figure 7

Did You KNOW?

The Shocking Truth about High Voltage

Van de Graaff generators produce very high voltages—about 300 000 V—and yet are safe to touch. This is because the generator produces a high voltage with a very tiny current. It is the amount of current that determines the effect.

So why doesn't the sign say "Danger High Currents"? Sources of high voltage, such as transmission lines, are also sources of high currents. Although air is an insulator, if you get too close to a high voltage source, the electricity can arc to you. It is important to follow safety procedures when working with or around electrical equipment.

SAMPLE PROBLEM 3

Determine Voltage and Resistance

Three identical resistors are connected in parallel to an electric cell (Figure 8). In the third resistor (R_3) the resistance is 63 Ω and the current is 23 mA.

(a) What is the voltage (V_T) of the electric cell?

(b) What is the total resistance (R_T) of the parallel group of resistors?

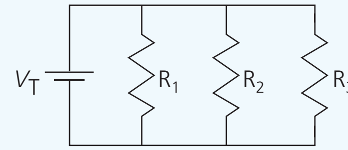


Figure 8

Solutions

(a) First, convert the current into amperes.

23 mA = 0.023 A

Use Ohm's law equation to calculate the voltage, V_3, of the third resistor.

$$V_3 = IR$$
$$= (0.023\ \text{A})(63\ \Omega)$$
$$V_3 = 1.449\ \text{V}$$

Rounded to two significant digits, the voltage of the third resistor is 1.4 V.

Since the voltage of the electric cell is the same as the voltage of all the resistors, $V_T = 1.4$ V.

The voltage of the dry cell is 1.4 V.

(b) There are two possible methods for determining the total resistance:

Method A

Each resistor has a current of 0.023 A. The total current, I_T, equals the sum of the current in the three resistors.

$$I_T = I_1 + I_2 + I_3$$
$$= 0.023\ \text{A} + 0.023\ \text{A} + 0.023\ \text{A}$$
$$I_T = 0.069\ \text{A}$$

Use Ohm's law equation to calculate the total resistance, R_T.

$$R_T = \frac{V_T}{I_T}$$
$$= \frac{1.449\ \text{V}}{0.069\ \text{A}}$$
$$R_T = 21\ \Omega$$

Method B

Since the resistors are identical, we can use

$$R_T = \frac{R}{n}$$
$$= \frac{63\ \Omega}{3}$$
$$R_T = 21\ \Omega$$

The total resistance of the parallel group of resistors is 21 Ω.

Practice

Two identical resistors are connected in parallel to an electric cell (Figure 9). In the first resistor (R_1) the resistance is 80 Ω and the current is 1.5 A.

(a) What is the voltage (V_T) of the electric cell?

(b) What is the total resistance (R_T) of the circuit?

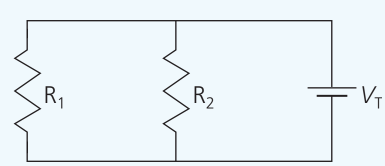


Figure 9

LEARNING TIP

If you are having difficulty completing the practice problems, look back through the sample problems and solutions.

10.5 CHECK YOUR Understanding

1. Write the rules for determining the total voltage of resistors connected in series and in parallel in your own words.
2. Four identical 22 Ω resistors are connected in series to a 9 V battery.
   (a) Draw a circuit diagram for this circuit.
   (b) What is the current going through each resistor?
   (c) What is the total resistance of this circuit?
3. Two identical resistors are connected to a 120 V energy source in a parallel circuit. The energy source delivers 1.2 A, in total, to both resistors.
   (a) What is the voltage of each resistor?
   (b) What is the current in each resistor?
   (c) What is the resistance of each resistor?
   (d) What is the total resistance of the circuit?
4. Two light bulbs are connected, with switches, to a 3 V energy source (Figure 10). When the switches are closed, both bulbs are lit. The current delivered by the voltage source to the circuit is 440 mA.

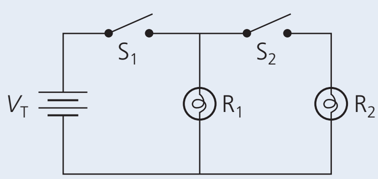


Figure 10

   (a) The current in the first light bulb (R_1) is 160 mA. What is the current in the other light bulb?
   (b) Are the two light bulbs identical?
   (c) Determine the resistance of each light bulb and the total resistance.
   (d) If the second switch (S_2) is opened, what is the voltage across the second light bulb (R_2)? Explain your answer.
   (e) What is the voltage across the first light bulb? Explain your answer.
   (f) What current is delivered by the battery to the circuit?
5. Three resistors, with values of 30 Ω, 60 Ω, and 90 Ω, are connected in series. What is the total resistance of the three resistors?
6. Copy Figure 11 into your notebook. Add the symbol for an ammeter or a voltmeter in the correct position to measure:
   (a) the voltage across R_2
   (b) the voltage across R_1 plus R_2
   (c) the total voltage (V_T) for the circuit
   (d) the current through R_3 only

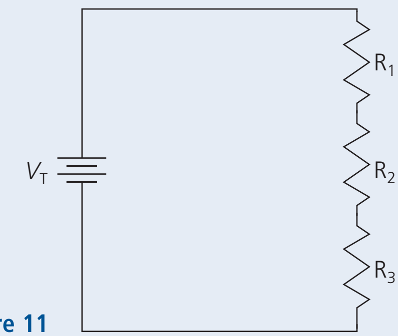


Figure 11

7. Copy Figure 12 into your notebook. Add the symbol for an ammeter in the correct position to measure:
   (a) the current through R_1
   (b) the current through R_3
   (c) the current through R_2 and R_3

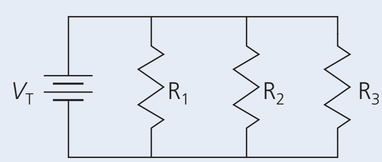


Figure 12

8. Figure 13 shows a circuit that consists of three identical resistors. The total voltage (V_T) is 12 V.
   (a) What is the voltage of each resistor?
   (b) The current in the third resistor (R_3) is 500 mA. Determine the current in the first resistor (R_1).
   (c) What is the combined (total) resistance of the three resistors?

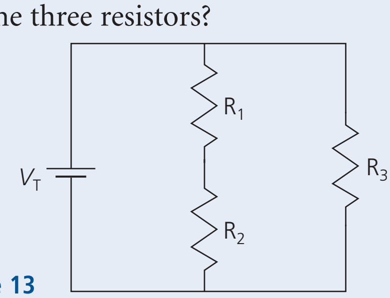


Figure 13

Science
WORKS

HEART DEFIBRILLATORS

Using a defibrillator to deliver a shock to the heart can restore normal heart rhythms to a victim of cardiac arrest.

Figure 1

You may have seen TV doctors yell, "Clear!" as they jolt a patient's chest with electricity. While the scenario on TV may not exactly be true to life, defibrillators can be used to restore a normal heart rhythm by delivering an electric shock to the heart.

Between 35 000 and 45 000 cases of cardiac arrest occur each year in Canada. Cardiac arrest occurs when the heart stops beating regularly and blood stops going to the brain. Unlike a heart attack, in which blood flow to the heart is temporarily blocked, sudden cardiac arrest is an electrical malfunction of the heart. For example, in ventricular fibrillation, the heart begins to fibrillate, or rapidly, but ineffectively, contract in an unsynchronized way.

Anyone at any age can suffer cardiac arrest and, unless normal heart rhythm is restored, the person dies within minutes. Cardiopulmonary resuscitation (CPR) keeps blood and oxygen flowing to the heart and brain until defibrillation can be administered.

An external defibrillator (Figure 1), which consists of a central unit and two electrodes, produces an electric current that stops the heart so that it can restart with a normal rhythm. The electrodes are placed in positions on the chest that maximize current flow through the heart. The operator of the device selects the shock energy, which is usually 200 J. The appropriate energy level for further shocks is 200 J to 300 J.

Some people are at risk of repeated cardiac arrest. Their heartbeat can be maintained at a normal rhythm using an implanted defibrillator. The device, which is similar to a pacemaker, consists of a battery and a pulse generator connected to one or more insulated wires. It is implanted under the skin in the shoulder, and the wires are threaded through blood vessels from the defibrillator to the heart muscle. Unlike a pacemaker, which stimulates the heart to beat normally, an implantable defibrillator delivers an electric shock to return an abnormal or disorganized heartbeat to normal.

External defibrillators are typically used in hospitals or ambulances, but are becoming more common in shopping centres, arenas, airplanes, and schools. There are even some models that are designed for home use (Figure 2). These models are smaller than this textbook. Not only can these home devices deliver a shock to restore a regular heartbeat, but they can also determine whether a shock is even needed, making it possible for people without medical training to use them.

Figure 2

10A Investigation

Voltage of Cells in Series and Parallel Circuits

Individual electric cells produce only a few volts at most. However, when we need a greater voltage, we can combine cells to make batteries. In this Investigation, you will look at using cells in series and in parallel.

INQUIRY SKILLS		
○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	● Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

Question

What are the effects of combining electric cells in series and in parallel?

Predictions

Predict about what will happen to the voltage in a circuit as cells are added in series. Predict what will happen to the voltage in a circuit as cells are added in parallel.

Experimental Design

In this Investigation, you will combine electric cells in series and in parallel.

Materials

- 4 D-cells with holders
- connecting wires
- switch
- voltmeter

Procedure

1. Read through the procedure and create a table in which to record your data.
2. Build a circuit based on the circuit diagram in Figure 1. Close the switch and read the voltmeter. Record the measurement in your table.

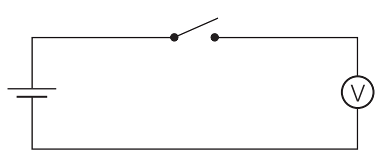


Figure 1

3. Open the switch and add another cell in series to the single cell (Figure 2). Close the switch and read the voltmeter. Record the measurement in your table.

Figure 2

4. Repeat step 3 two more times. You should have four cells in series.
5. Replace the four cells in series with two cells in parallel. Close the switch and read the voltmeter. Record the measurement in your table.
6. Add another cell in parallel. Read the voltmeter. Record the measurement in your table.
7. Repeat step 6. You now have four cells in parallel.

Analysis

(a) Compare the voltage produced by one cell with the voltage produced by four cells in series.

(b) Compare the voltage produced by two cells in parallel with the voltage produced by four cells in parallel.

(c) Describe any trends you observed in the voltages of the various series and parallel circuits.

(d) Write a general rule for determining the voltage produced by cells in series and cells in parallel.

Evaluation

(e) Were your predictions accurate? Explain why or why not.

Synthesis

(f) If different types of electric cells, for example D-cells and AA-cells, were combined, would this change your results? How could you determine this?

10B Investigation

Resistors in Series and Parallel Circuits

Resistors can be connected to a voltage source in series, in parallel, or in a combination of the two. In this Investigation, you will see how current and voltage vary in series and parallel circuits.

Question

How do current and voltage vary in series and parallel circuits?

Predictions

Predict how current and voltage in a circuit will vary as resistors are combined in series.
Predict how current and voltage in a circuit will vary as resistors are combined in parallel.

Experimental Design

In this Investigation, you will construct series and parallel circuits with resistors. You will measure currents and voltages in different parts of each circuit and determine rules to explain their behaviour.

Materials

- 3 resistors of different values
- 2 D-cells in holders
- connecting wires
- ammeter (or multimeter set to amperes)
- voltmeter (or multimeter set to volts)

Procedure

Part A: Resistors in Series

1. Copy Figure 1 and Table 1 into your notebook.

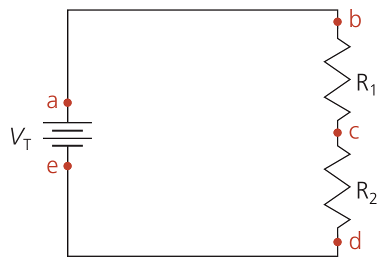


Figure 1

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	● Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

Table 1

Position	a	b	c	d	e
current (A)					

2. Connect two of the resistors to two cells connected in series as shown in Figure 1. Note that the letters *a* to *e* represent positions in the circuit.
3. Insert an ammeter at position *a* to measure the current. Record the current (in amperes) in Table 1.
4. Insert an ammeter at each of the other positions (*b* to *e*). Record the current (in amperes) in Table 1.
5. Copy Table 2 into your notebook.

Table 2

	V_T	V_1	V_2	$V_1 + V_2$
voltage (V)				

6. Connect a voltmeter to points *a* and *e*. Measure the voltage of the battery (V_T) and record the voltage in Table 2.
7. Measure and record the voltage of the first resistor (V_1) and the second resistor (V_2). Record the sum of the two voltages in Table 2.

Part B: Resistors in Parallel

8. Copy Figure 2 and Table 3 into your notebook.

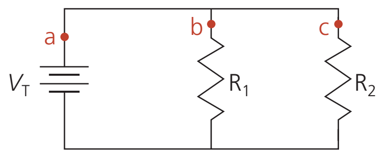


Figure 2

Table 3

Position	a = I_T	b = I_1	c = I_2	$I_1 + I_2$
current (A)				

9. Connect two of the resistors (labelled R_1 and R_2 in Figure 2) to two cells connected in series (labelled V_T for total voltage of the battery).

10. Insert an ammeter at position *a* to measure the total current from the battery (I_T). Record the current, in amperes, in Table 3.

11. Insert an ammeter at positions *b* and *c*. Record the current in Table 3.

12. Copy Table 4 into your notebook.

Table 4

	V_T	V_1	V_2
voltage (V)			

13. Connect a voltmeter to measure the voltage of the battery (V_T). Record the voltage of the battery in Table 4.

14. Measure and record the voltages in the first resistor (V_1) and the second resistor (V_2).

Analysis

(a) In a series circuit, how does the current at each position in the circuit compare?

(b) In a series circuit, how does the total voltage of the battery compare with the sum of the individual voltages?

(c) Using Ohm's law, calculate the total resistance of the series circuit (R_T) using the total voltage of the battery and the current in the battery.

(d) For the series circuit, calculate the resistance of each resistor using Ohm's law. How does each value compare with the value indicated by the coloured bands on each resistor?

(e) In a parallel circuit, how does the total current from the battery compare with the sum of the currents in the parallel branches?

(f) In a parallel circuit, how does the voltage across one resistor compare with the voltage across each of the other resistors?

(g) Using Ohm's law, calculate the total resistance of the circuit (R_T) using the total voltage of the battery and the total current in the battery. In a parallel circuit, how does the total resistance compare with the resistance of the smallest resistor?

Evaluation

(h) Were your predictions accurate? Explain why or why not.

(i) Identify and explain any possible sources of error in your investigation.

Synthesis

(j) Develop rules that explain the nature of current in series and parallel circuits.

(k) Develop a rule that explains what happens to the total resistance of a circuit when resistors are added in series.

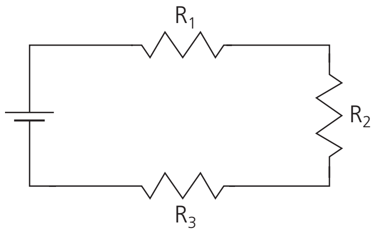
(l) Develop a rule that explains what happens to the total resistance of a circuit when resistors are added in parallel.

Current Electricity

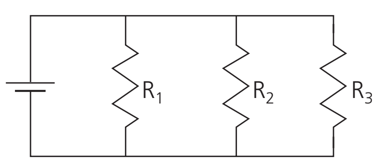
Key Ideas

In a circuit, electric charges flow from an energy source to a device that uses the energy.

- The components in a circuit can be represented using circuit diagram symbols.
- An electric cell is an energy source. A battery is a combination of two or more electric cells.
- Conventional current is the flow of positive charge. Electron flow is the flow of negative charge and goes from the negative terminal and returns to the positive terminal of a battery in a circuit.
- Circuits may contain resistors that are in series or in parallel.



(a) Three resistors in series



(b) Three resistors in parallel

Current and voltage in a circuit can be measured by meters.

- Electric current is the rate of flow of electric charge and is measured in amperes by ammeters placed in series.
- Voltage (electric potential difference) is the amount of energy per coulomb of charge and is measured in volts by voltmeters placed in parallel.
- When electric cells are added in series, the voltage increases.
- When electric cells are added in parallel, the voltage does not change.

Total voltage (V_T) in series circuits
$V_T = V_1 + V_2 + V_3$

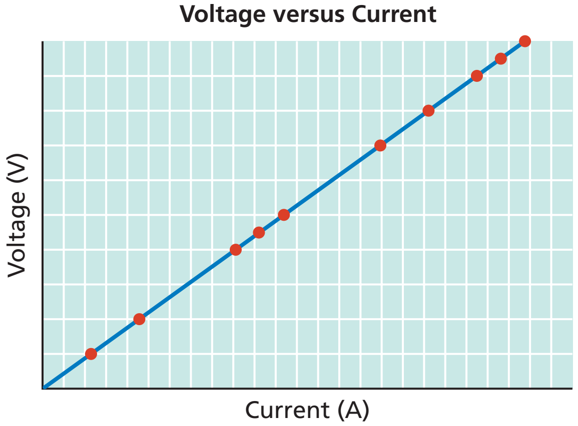
Total voltage (V_T) in parallel circuits
$V_T = V_1 = V_2 = V_3$

Vocabulary

current electricity, p. 302
joule (J), p. 303
battery, p. 303
load, p. 303
circuit diagram, p. 304
electric current (I), p. 306
ampere (A), p. 306
conventional current, p. 306
electron flow, p. 306
direct current (DC), p. 306
alternating current (AC), p. 306
series circuit, p. 307
parallel circuit, p. 307
ammeter, p. 307
voltage (V), p. 310
volt (V), p. 310
voltmeter, p. 310
resistor, p. 315
ohm (Ω), p. 315
resistance (R), p. 317
Ohm's law, p. 317

Ohm's law relates resistance, voltage, and current in a circuit.

- A resistor resists the flow of electric current and, thus, has resistance.
- Ohm's law states that the resistance of a material is equal to the ratio of voltage divided by current.
- The equation for Ohm's law is $R = \frac{V}{I}$ or $V = IR$.



Series and parallel circuits differ in terms of current, voltage, and total resistance.

- In a series circuit, the current remains the same, but the voltage changes.
- In a parallel circuit, the current changes, but the voltage remains the same.
- The total resistance of a circuit depends on the number of individual resistances.
- Increasing the number of resistors in series increases the total resistance.
- Increasing the number of resistors in parallel decreases the total resistance.

Total current (I_T) in series circuits	Total current (I_T) in parallel circuits
$I_T = I_1 = I_2 = I_3$	$I_T = I_1 + I_2 + I_3$

Total resistance (R_T) in series circuits	Total resistance (R_T) in parallel circuits
$R_T = R_1 + R_2 + R_3$	$R_T = \frac{R}{n}$ for n identical resistors

Review Key Ideas and Vocabulary

1. Figure 1 shows two circuits. Which circuit is connected so that the light bulbs will light?

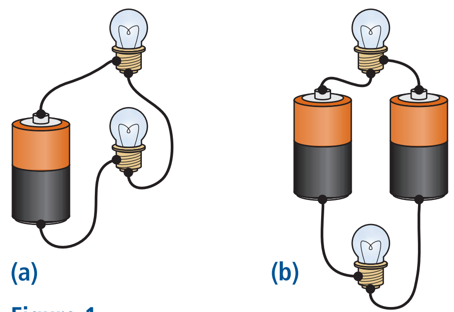


Figure 1

2. What total voltage is produced when four 1.5 V cells are connected as shown in Figure 2?

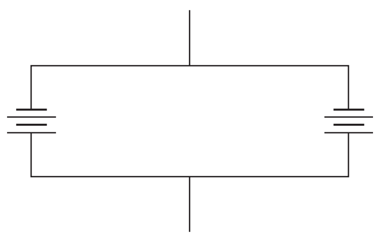


Figure 2

(a) 1.5 V (c) 4.5 V
(b) 3.0 V (d) 6.0 V

3. What is the measured voltage when three 1.3 V cells are connected as shown in Figure 3?

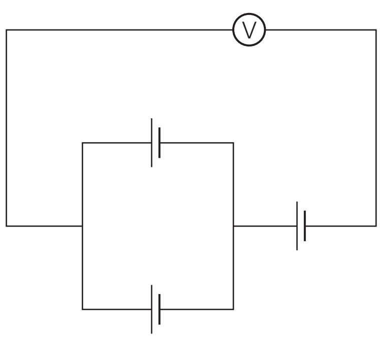


Figure 3

(a) 0.65 V (c) 2.6 V
(b) 1.3 V (d) 3.9 V

4. If one of the resistors in a series circuit "burned out" so that current could not get through it, would the current continue to flow through the circuit? Explain your answer.

5. If one of the resistors in a parallel circuit "burned out" so that current could not get through, would the current continue to flow through the circuit? Explain your answer.

6. Which statement describes how light bulbs A, B, and C are connected in Figure 4?
(a) A is in series with B and C.
(b) A is in series with B, but in parallel with C.
(c) A is in parallel with B, but in series with C.
(d) A is in parallel with B and C.

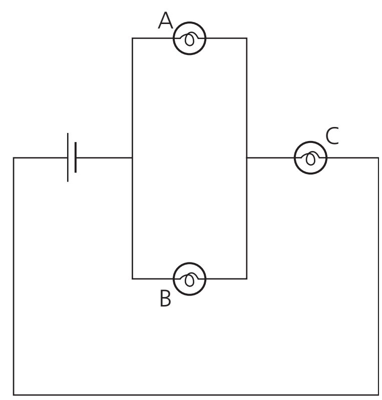


Figure 4

7. Ohm's law equation is $R = \frac{V}{I}$. What is the electrical unit for each variable in the equation?

8. A coulomb is to the amount of electric charge as a __?__ is to voltage.

9. Ammeters are always connected in __?__ in a circuit, and voltmeters are always connected in __?__ .

10. When resistors are added in series, the total resistance __?__. When resistors are added in parallel, the total resistance __?__.

Use What You've Learned

11. Draw a circuit diagram that shows how you could connect several resistors so that their total resistance is less than the sum of their individual resistances.

12. A battery is made from three 2 V cells connected in series. If one of the cells is "dead," what is the voltage of the battery? Note that a voltmeter connected to a dead cell reads 0 V.

13. A battery is made from three 2 V cells connected in parallel. If one of the cells is "dead," what is the voltage of the battery? Note that a voltmeter connected to a dead cell reads 0 V.

14. Draw a circuit diagram that shows a 120 V energy source, an electric toaster (shown as a resistor), and a device that will read the current through the toaster. If the current through the toaster is 2 A, what is the resistance of the toaster?

15. Are the voltmeter and the ammeter in series or in parallel with the resistor in Figure 5?

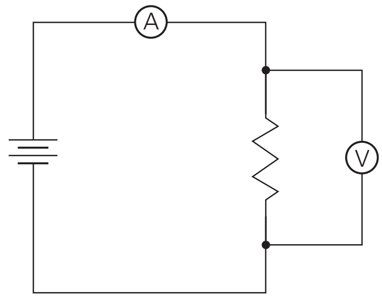


Figure 5

16. A student works with the circuit shown in Figure 5. She observes that the ammeter had a reading of 41 mA (0.041 A) and the voltmeter had a reading of 2.6 V. What is the resistance of the resistor?

17. How many cells (1.5 V each) are needed to cause a current of 500 mA to flow in a circuit with a resistance of 60 Ω?

18. A student makes a battery that has a voltage of 4.6 V. When the student attaches the battery to a resistor, the current is 180 mA. What is the resistance of the resistor?

Think Critically

19. Some words, such as "battery," "energy," and "terminal," have a specific meaning in the context of electricity. Can you think of other words that have different meanings in everyday speech and in science?

20. A calculator runs on two 6.0 V electric cells connected in parallel. If the calculator draws 0.001 A, how many milliamperes does it draw? What is the resistance of the calculator?

21. Are household electrical outlets connected in series or in parallel? What evidence could you provide to support your answer?

22. For the circuit shown in Figure 6, the current in R_1 is 250 mA and the current in R_2 is 200 mA. What is the current in R_3 and R_4?

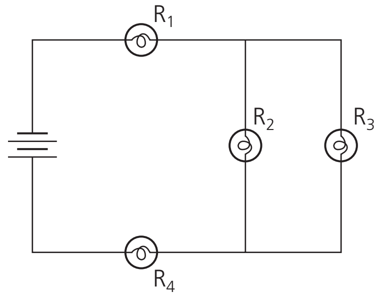


Figure 6

23. Three resistors (numbered 1, 2, and 3) are connected in a circuit to two two-cell batteries connected in series (Figure 7). Three voltmeters and three ammeters are attached to the circuit. The voltage of the battery, V_T, is 6 V. The current at A_1 is 140 mA. The voltage is 2 V in resistor 2. The current at A_3 in resistor 3 is 90 mA. What is the current at A_2 in resistor 2 and the voltage in resistor 3?

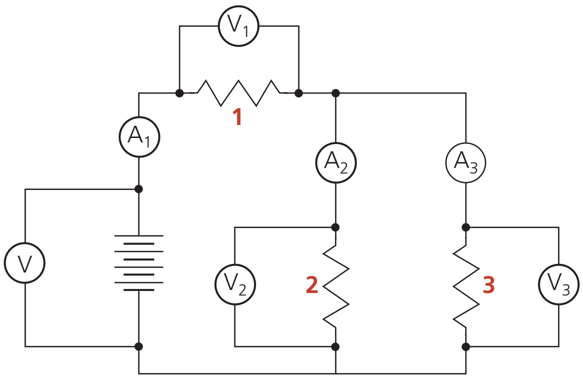


Figure 7

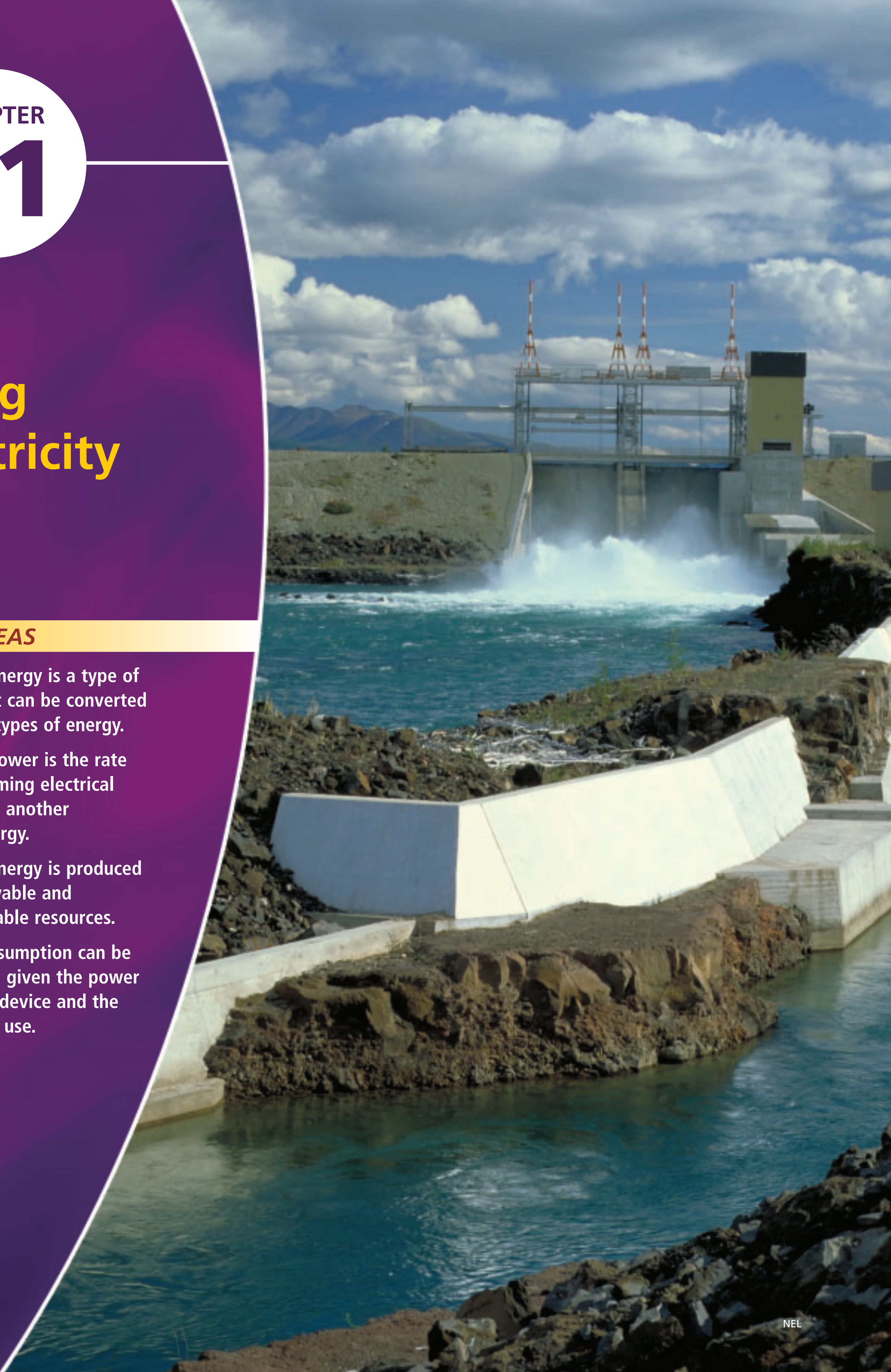
Reflect On Your Learning

24. How do you think your everyday life would be affected if electric circuits were not available? Give examples to support your answer.

Visit the Quiz Centre at
www.science.nelson.com GO

CHAPTER 11

Using Electricity



KEY IDEAS

- Electrical energy is a type of energy that can be converted into other types of energy.
- Electrical power is the rate of transforming electrical energy into another type of energy.
- Electrical energy is produced from renewable and non-renewable resources.
- Energy consumption can be determined given the power rating of a device and the duration of use.

Chapter Preview

Light bulbs are produced with different power ratings, such as 40 W, 60 W, and 100 W. We can measure the energy used in a home in kilowatt•hours. Hydroelectric plants produce thousands of watts of electricity. For example, the Whitehorse Rapids Plant (shown) in the Yukon produces 40 MW of electricity during the summer months and 24 MW during the winter months. What are watts and how do they relate to electricity? How much energy is in one kilowatt•hour?

TRY THIS: *The Power of Light*

Skills Focus: predicting, observing

In this activity, you will observe the brightness of light bulbs in series and parallel circuits.

Materials: 2 different light bulbs (such as 1 W and 2 W) in holders, connecting wires, 2 electric cells in holders

1. Copy Figure 1 into your notebook. Predict which light bulb will be brighter.

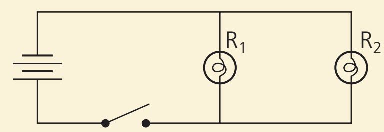


Figure 1

2. Connect the light bulbs in parallel, as shown in Figure 1. Close the switch and check your prediction.
3. Copy Figure 2 into your notebook. Predict which light bulb will be brighter.

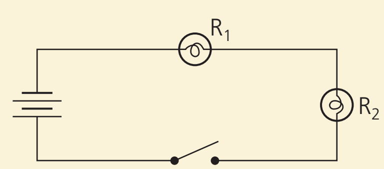


Figure 2

4. Connect the light bulbs in series, as shown in Figure 2. Close the switch and check your prediction.

A. What did you observe in step 2? Explain what you observed.

B. What did you observe in step 4? Explain what you observed.

11.1 Work, Energy, and Power

Some words that are associated with electricity, such as "work," "energy," and "power," are commonly used in everyday language. However, as you will learn, these terms have specific meanings in science that may differ from their everyday meanings.

What Is Work?

In science, work and energy are closely related concepts. Every time you flip a switch or plug something in, work is done to transform (change) electrical energy into another type of energy. **Work** is defined as the transforming or converting of energy. It is measured in joules. For example, when a battery in a flashlight produces an electric current, work is done as electrical energy is converted into light and heat energy. In a motor, work is done as electrical energy is converted into motion.

What Is Energy?

Energy is more difficult to define. It is easier to describe what energy does than what it is. There are many different types of energy including kinetic, thermal, light, sound, electrical, chemical, and nuclear. Some of these types of energy are described in Table 1. In general, an object has **energy** (***E***) if it has the ability to do work.

Although there are many types of energy, scientists classify energy into two major types: potential energy and kinetic energy. **Potential energy** (***PE***) is energy that can be stored in an object. There are different types of potential energy. Gravitational potential energy (Figure 1) is energy that is stored in an object because of the object's position relative to something else. Elastic potential energy is energy that is stored because an object is forced out of shape. Chemical potential energy is energy that is stored in the makeup of an object's molecules. **Kinetic energy** (***KE***) is the energy that an object has because of its motion. The different types of energy can be converted into each other. GO

Did You KNOW?

Capacitors

A capacitor is a device that stores electrical energy. It is made of parallel plates of metal. When a capacitor is connected to a battery, the plates acquire equal, but opposite, charges. These charges are stored and can be used to do work. For example, the capacitor in an electronic flash of a camera slowly stores electrical energy and then quickly discharges with the flash of the bulb. Capacitors come in a variety of sizes and shapes.

LEARNING TIP

When you come across information in brackets and quotation marks, think about how you can use this information to help you understand the material you are reading.

To learn more about the different types of energy, go to
www.science.nelson.com GO

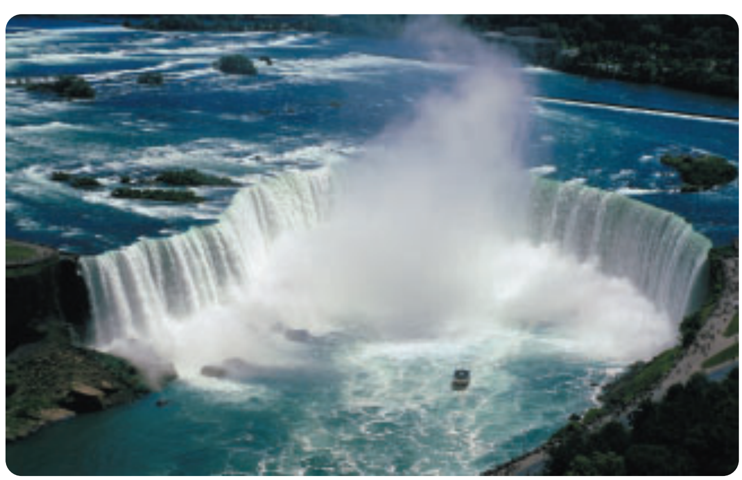


Figure 1 Some of the water above the Canadian (Horseshoe) Falls at Niagara Falls is diverted through generators that transform the gravitational potential energy of the water into electrical energy.

Table 1 Some Types of Energy

Type of energy	Description	Examples
electrical	energy from the movement of electrons	• electricity • lightning
gravitational potential	energy stored in an object because of its height or position	• waterfall • wrecking ball
chemical potential	energy stored in chemical bonds	• natural gas • petroleum
elastic potential	energy stored in objects that are stretched or compressed	• springs • rubber bands
nuclear	energy stored in the nucleus of an atom	• uranium atoms (fission) • hydrogen atoms (fusion)
kinetic	energy due to motion	• moving baseball • falling raindrop

For example, when you throw a ball up into the air, you give the ball kinetic energy, which is transformed into gravitational potential energy as the ball rises. At the ball's highest point, all the kinetic energy has been transformed into potential energy. As gravity pulls the ball back down, gravitational potential energy is transformed back into motion. In other words, work has been done as kinetic energy is transformed into potential energy, and then again as potential energy is transformed into kinetic energy.

Kinetic energy depends on the mass and speed of an object. The greater the mass or speed of an object, the greater the kinetic energy of the object. When an object's speed changes, work is done that is equal to the object's change in kinetic energy. We can write this as an equation:

$$W = KE_{\text{final}} - KE_{\text{initial}}$$

where W is work, KE_{final} is the final kinetic energy, and KE_{initial} is the initial kinetic energy. We can shorten this equation to

$$W = \Delta KE$$

where ΔKE represents the change in kinetic energy. (Remember that the symbol Δ is the Greek letter *delta*, which is used to indicate change.) We can read this equation as "work is equal to the change in kinetic energy." Since work is equal to the change in energy, we can write this equation as:

$$W = \Delta E$$

All types of energy can be converted from one type into another type of energy. When energy is converted from one type to another, there is no overall loss of energy. As one type of energy decreases, another type increases by the same amount. This is the basis for the **Law of Conservation of Energy**, *which states that in any closed system, the total amount of energy (including potential energy) remains constant*. This means that when the amounts of all the different types of energy are added up, the total never changes, no matter what you do to the system. GO

Did You KNOW?

Calculating KE

We can calculate the kinetic energy of an object using the equation

$$KE = \frac{1}{2}mv^2$$

where m is the object's mass (in kg) and v is the object's speed (in m/s). Kinetic energy is measured in joules (J).

LEARNING TIP

Check your understanding. Look at the bolded words in this section. Take turns explaining them to a partner. Try to use your own words.

If you would like to learn more about the law of conservation of energy, go to **www.science.nelson.com** GO

TRY THIS: *Electric Generator*

Skills Focus: predicting, observing

Figure 2

A direct current (DC) motor uses electric cells to convert electrical energy into kinetic energy. What happens if the motor is used backwards? Can it produce an electric current? Can it be used to transform kinetic energy into electrical energy?

In this activity, you will use a galvanometer, which is a sensitive ammeter that can measure small currents in either direction, to determine whether an electric motor can generate electrical energy when it is rotated by a force that causes it to run backward.

Materials: small DC motor (1 V to 6 V), galvanometer, connecting wires

1. Connect the terminals of a motor to a galvanometer, as shown in Figure 2.
2. Using your fingers, spin the shaft of the motor clockwise and watch the meter. Describe the relationship between how fast you spin the shaft with how much the galvanometer needle is deflected.
3. Spin the shaft counterclockwise and observe the meter.

A. Does the amount of current depend on how fast you spin the shaft in step 2?

B. How does the direction you spin the shaft of the motor affect the direction of deflection of the galvanometer needle?

C. Predict what would happen if you rapidly spin the shaft back and forth. Check your prediction.

What Is Power?

Whether you walk or run up a hill, you do the same amount of work. However, there is a difference in the time that you take to make each trip. When you run up a hill in a short amount of time, you require more power than when you walk up the hill in a longer amount of time. **Power (*P*)** is the rate at which energy is transformed or the rate at which work is done. It is measured in **watts (W)**. Note that one watt is equal to one joule per second (1 W = 1 J/s).

We can use the following equation to determine power:

$$P = \frac{\Delta E}{\Delta t}$$

where P is power (in watts), ΔE is the amount of energy transformed (in joules), and Δt is the time interval (in seconds).

Since we learned earlier that $W = \Delta E$, we can substitute W for ΔE:

$$P = \frac{W}{\Delta t}$$

where P is power (in watts), W is the amount of work done (in joules), and Δt is the time interval (in seconds). Note that the symbol for the variable work is W (italicized), while the symbol for the unit watt is W (not italicized).

Did You KNOW?

Horsepower and Watt

James Watt developed the steam engine and used the unit of horsepower (hp) to measure power. One horsepower is the same as 746 W, which is equal to doing 746 J of work every second. Although horsepower is still used, mostly for car engines, the watt is the SI unit for power in honour of James Watt.

11.1 CHECK YOUR Understanding

1. Define "potential energy" in your own words.
2. Define "kinetic energy" in your own words.
3. Compare the scientific definitions of "work" and "energy."
4. List three types of energy, and give two examples for each.
5. A newspaper ad describes a light bulb that uses only 88 J of electrical energy, but produces 100 J of light energy (Figure 3). Do you think this ad is true or false? Give reasons to support your answer.

Figure 3

6. Is it possible for a type of energy to be both potential energy and kinetic energy? Explain your answer. (You may use types of energy to illustrate your example.)
7. When a basketball is dropped, it does not bounce back to its original height (Figure 4). Gravitational potential energy is converted into kinetic energy going down, but less energy is converted back into potential energy on the way up. What happened to the "missing" energy?

Figure 4

8. A red car and a blue car accelerate from rest to 100 km/h. The red car takes 9.1 s to accelerate and the blue car takes 10.3 s. The cars have the same mass.
   (a) Which car has the most kinetic energy?
   (b) Which car had the most power?
   (c) What assumptions did you make when answering (a) and (b)?
9. A company claims that it has a new and improved electrical device that does twice as much work in half the time. Is the device really improved? By what factor has the power changed?

11.2 Electrical Energy and Power

Figure 1 A light bulb that has a 100 W power rating uses 100 J of electrical energy per second.

Light bulbs and other electric devices are labelled with a power rating. For example, some light bulbs are rated at 40 or 100 W (Figure 1), an electric kettle is rated at 1500 W, and a television set is rated at 80 W. What do these ratings mean?

Electrical Energy, Time, and Power

In Section 11.1, you learned that power is a measure of the rate at which energy is transformed. *Electrical power* is a measure of the rate at which electrical energy is transformed into other types of energy. The power rating of a device indicates the rate at which the device transforms electrical energy (Figure 1). For example, a 40 W incandescent light bulb uses 40 J of electrical energy to produce 38 J of heat energy and 2 J of light energy. A 10 W compact fluorescent lamp, which produces the same brightness as a 40 W incandescent bulb, uses 10 J of electrical energy to produce 8 J of heat energy and 2 J of light energy per second. Note that the power ratings of light bulbs indicate the amount of electrical energy used, not the amount of light produced. GO

We can calculate the electrical power of a device using the equation:

$$P = \frac{\Delta E}{\Delta t}$$

We will use this equation in the following sample problems to determine the power and electrical energy of various devices.

To find out more information about different kinds of light sources and power ratings, go to **www.science.nelson.com** GO

LEARNING TIP

It is a helpful strategy to "talk through" equations. For example, "power (in watts) is equal to the amount of energy transformed (in joules) divided by the time interval (in seconds)."

SAMPLE PROBLEM 1

Determine Power

A laser pointer used 0.045 J of electrical energy during 15 s of operation. What is the power of the laser pointer?

Solution

Solve for P.

$$P = \frac{\Delta E}{\Delta t}$$

$$= \frac{0.045\ \text{J}}{15\ \text{s}}$$

$$P = 0.003\ \text{W}$$

The power is 0.0030 W.

Practice

What is the power of a toaster that converts 24 000 J of electrical energy into heat energy in a time of 35 s?

SAMPLE PROBLEM 2

Determine Energy

A 100 W light bulb is left on for 3 h. How much electrical energy did it use? Express your answer in scientific notation.

Solution

First, convert hours to seconds.

$$3\text{ h}\left(\frac{3600\text{ s}}{\text{h}}\right) = 10\ 800\text{ s}$$

$$\Delta t = 10\ 800\text{ s}$$

Then change the form of the equation to solve for ΔE.

$$P = \frac{\Delta E}{\Delta t}$$

$$\Delta E = P\Delta t$$

$$= 100\text{ W }(10\ 800\text{ s})$$

$$\Delta E = 1\ 080\ 000\text{ J or } 1.1 \times 10^6\text{ J}$$

The lamp used 1.1×10^6 J of electrical energy in 3 h.

Practice

A car headlight has a power rating of 45 W. How much electrical energy does it require in 28 min?

SAMPLE PROBLEM 3

Determine Time

A laptop computer operates on 14 W of power. If the battery has 200 kJ of electrical energy stored, how many hours can you use the computer before you need to recharge the battery?

Solution

$$\Delta E = 200\text{ kJ} = 200\ 000\text{ J}$$

Change the equation to a form to solve for Δt.

$$P = \frac{\Delta E}{\Delta t}$$

$$\Delta t = \frac{\Delta E}{P}$$

$$= \frac{200\ 000\text{ J}}{14\text{ W}}$$

$$\Delta t = 14\ 300\text{ s}$$

We need to convert seconds to hours.

$$14\ 300\text{ s}\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 4.0\text{ h}$$

You can use the computer for 4.0 h before you need to recharge the battery.

Practice

A car battery can produce 4000 W of electrical power to start a car. If the car uses 3000 J of electrical energy to start, how long does it take to start the car?

LEARNING TIP

Your success when solving problems depends on your ability to understand what the problem is asking you to do. Ask yourself, "What are the key words? What equation needs to be applied?" It is a good strategy to draw a picture before attempting a difficult problem.

Although it is possible to determine the power of an electrical device using the equation $P = \frac{\Delta E}{\Delta t}$, it is difficult to measure the change in electrical energy. In Chapter 10, you learned how to measure voltage and current in circuits. You can use these quantities to solve for power using the equation:

$$P = VI$$

where P is the power (measured in watts), V is the voltage (measured in volts), and I is the current (measured in amperes).

The following sample problems illustrate how to use different forms of the equation $P = VI$ to determine the power, voltage, and current of an electrical device.

Did You KNOW?

Dimensional Analysis

You can use dimensional analysis to determine that an equation is correct by checking the units. For example, we can check the equation for electrical power as follows:

$P = VI$

watt = (volt)(ampere)

$\text{watt} = \left(\frac{\text{joule}}{\text{coulomb}}\right)\left(\frac{\text{coulomb}}{\text{second}}\right)$

$\text{watt} = \frac{\text{joule}}{\text{second}}$

This is a good way to check or to derive an equation.

SAMPLE PROBLEM 4

Determine Power

A light bulb has a current of 0.625 A when it is plugged into a 120 V outlet. What is the power of the light bulb?

Solution

Substitute the values into the equation.

$$P = VI$$
$$= 120\ \text{V} \times 0.625\ \text{A}$$
$$P = 75\ \text{W}$$

The light bulb has 75 W of power. In other words, the light bulb has a power rating of 75 W.

Practice

A solar cell produces 1.8 A of current at 0.42 V. What is the power of the solar cell?

SAMPLE PROBLEM 5

Determine Voltage

The power of the resistor shown in Figure 2 is 0.5 W.
If the current is 0.382 A, what is the voltage of the resistor?

Solution

Change the form of the equation to solve for V.

$$P = IV$$
$$V = \frac{P}{I}$$
$$= \frac{0.5\ \text{W}}{0.382\ \text{A}}$$
$$V = 1.3\ \text{V}$$

The voltage of the resistor is 1.3 V.

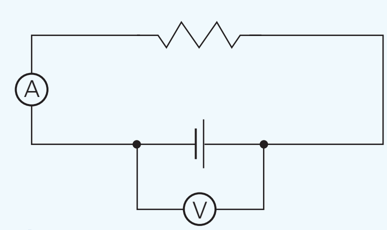


Figure 2

Practice

A 37 W cordless drill uses a current of 2.6 A. What is the voltage of the battery?

SAMPLE PROBLEM 6

Determine Current

An electronic gaming system is rated at 380 W (Figure 3). When a student plugs the system into a 120 V outlet, what is the current in the system?

Solution

Change the form of the equation to solve for I.

$$P = VI$$

$$I = \frac{P}{V}$$

$$= \frac{380\ \text{W}}{120\ \text{V}}$$

$$I = 3.2\ \text{A}$$

The gaming system has a current of 3.2 A.

Practice

What is the current in a 95 W television set that is connected to a 120 V household outlet?

Figure 3

Voltage, Current, Time, and Electrical Energy

We can solve for power using electrical energy and time, or using voltage and current using the following equations:

$$P = \frac{\Delta E}{\Delta t} \quad \text{or} \quad P = VI$$

Setting the two expressions for power equal to each other gives the following energy equation:

$$\frac{\Delta E}{\Delta t} = VI$$

$$\Delta E = VI\Delta t$$

We can use this equation in the following sample problems to solve for the electrical energy of an electrical device.

Did You KNOW?

Transforming Power

Transformers are used to convert one voltage to another voltage. Some transformers are attached to electronic gaming systems, printers, and portable computers. Transformers consume power because they are plugged into wall outlets, whether they are connected to a device or not. Although transformers are very efficient, a transformer consumes about 1 W to 5 W of power.

SAMPLE PROBLEM 7

Determine Electrical Energy

A resistor has a current of 0.28 A and a voltage of 4.5 V. If the current flows for 50 s, how much electrical energy is transformed into heat?

Solution

Substitute the values into the equation.

$$\Delta E = VI\Delta t$$

$$= (4.5\ \text{V})(0.28\ \text{A})(50\ \text{s})$$

$$\Delta E = 63\ \text{J}$$

63 J of electrical energy are transformed into heat.

Practice

A light bulb has a current of 0.5 A when it is connected to a 120 V household outlet. If the light is left on for 30 min, how much electrical energy is used by the light bulb?

11.2 CHECK YOUR Understanding

1. What is the difference between electrical energy and electrical power?
2. What is the current in a 75 W light bulb that is plugged into 120 V household outlet?
3. The aircraft carrier USS *Nimitz* (Figure 4) is powered by two nuclear reactors. In addition to propelling the carrier, the reactors drive eight turbines that generate 8 MW of electrical power for the carrier. How much energy do the eight turbines generate in 15 s?

Figure 4

4. A stun gun (Figure 5) can deliver a nonlethal current of 2 mA at 400 kV to subdue attackers. What is the power of a stun gun?

Figure 5

5. A 35 W bulb of an automobile headlight has a current of 2.82 A going through it. Determine the voltage of the bulb.
6. Figure 6 shows a circuit diagram of a light bulb connected to a 1.5 V cell. With the switch closed, the power of the light bulb is 0.4 W. What is the current in the light bulb?

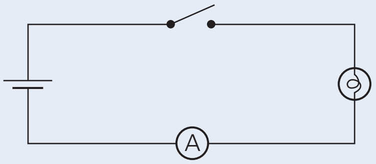


Figure 6

7. A microwave oven has a current of 4.6 A. How much electrical energy does it use in 45 s? (Hint: A microwave is plugged into a wall outlet.)
8. What are the units of each term in the right-hand side of the electrical energy equation, $\Delta E = VI\Delta t$?
9. The voltage (V_T) applied to the circuit shown in Figure 7 is 9 V. The ammeter reads 60 mA, and the voltmeter reads 6 V.
   (a) What is the power of R_2?
   (b) What is the power of R_3?

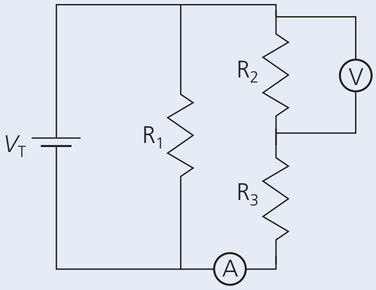


Figure 7

10. The power rating for R_1 in Figure 7 is 0.5 W, which means that the resistor cannot exceed this value without overheating. What is the maximum current that can go through R_1?
11. A 100 Ω resistor is connected to a 6 V energy source for three minutes.
    (a) How much energy did the power source deliver to the resistor?
    (b) How much electrical energy did the resistor convert into heat energy?

THE OSCILLOSCOPE

Oscilloscopes are used by many people, from electronic technicians to physicists to medical researchers. Oscilloscopes are used to draw graphs of electrical signals. The electrical signals are not restricted to circuits, but can include vibrations, sounds, and even brain waves.

An oscilloscope (Figure 1) is a device that measures voltage as a function of time. The information is displayed as a voltage–time graph. Oscilloscopes are very useful for displaying what is happening in a circuit when a traditional voltmeter would not react fast enough to changing information.

While the input for the oscilloscope is voltage, the origin of the signal does not have to be a variation in voltage. For example, a medical team can measure brain activity by converting the brain's signal into voltage. With the proper converter, many other physical properties can be the input for an oscilloscope. Some familiar examples are pressure, light intensity, vibrations, and earthquakes. Another familiar example is a microphone, which converts sound into an electrical signal that can be played through a stereo or observed with an oscilloscope.

An oscilloscope can have one or two input voltages. The oscilloscope in Figure 2 has one input connected to a 1.5 V cell and a second input is grounded (0 V). The vertical (*y*-axis) scale is 1 V per division. Figure 3 shows two 1.5 V cells in series. The currents produced by these cells are DC, and the display is a constant positive voltage.

Figure 4 shows the voltage produced by a household outlet. To display household voltage, the vertical scale has been changed to 75 V per division. The current produced is AC so the output varies between +170 V and −170 V as the current goes back and forth (this is equal to 120 V/ms). The horizontal scale (*x*-axis) is 5 ms. It takes a little over three divisions to complete one cycle. This is 15 ms or about 1/60th of a second, which is how household 60-cycle AC electricity is displayed on an oscilloscope.

Figure 1 An oscilloscope

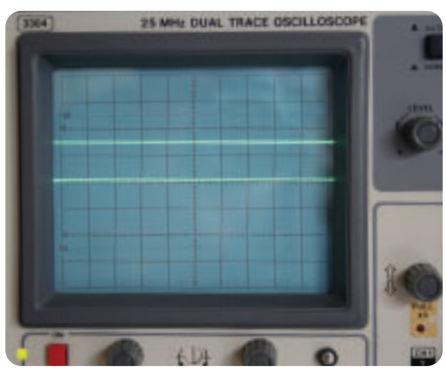


Figure 2 A display of a 1.5 V cell connected to an oscilloscope

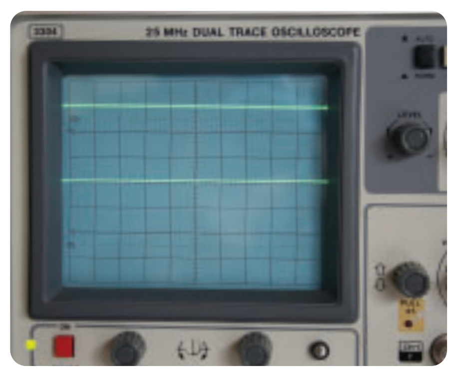


Figure 3 A display of two 1.5 V (3 V) cells in series connected to an oscilloscope

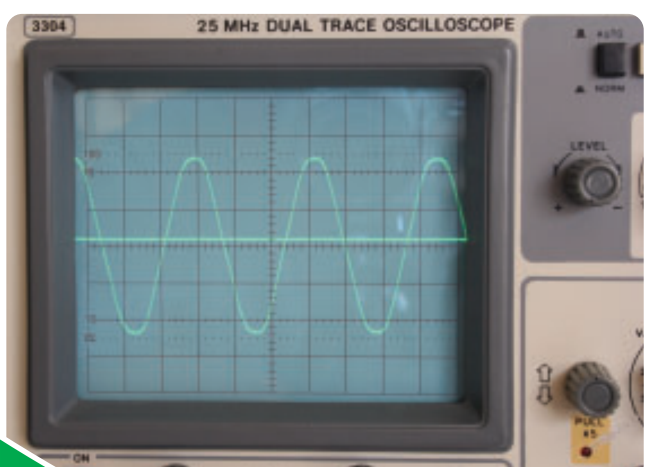


Figure 4 A display of a household outlet connected to an oscilloscope

11.3 Explore An Issue

DECISION MAKING SKILLS

- ○ Defining the Issue
- ● Researching
- ● Identifying Alternatives
- ● Analyzing the Issue
- ● Defending a Decision
- ● Communicating
- ● Evaluating

Producing Electrical Energy

We can safely predict that our society will continue to have an increasing need for electrical energy (Figure 1). How this electrical energy is produced will impact not only this generation, but also future generations. The decisions about how to produce electrical energy require careful consideration.

Figure 1 High voltage transmission lines carry electrical energy from power generating stations.

The Issue: Wise and Practical Use of Energy Resources

Manufacturers are continuously developing devices that are increasingly more efficient in their use of electricity. For example, computers today use only a fraction of the electrical energy that was required by early computers. However, our demand for electrical energy is increasing as the number of new electrical devices increases and as existing devices become more common. Our society must decide how best to meet this demand, without forgetting the need to produce and use electrical energy wisely and efficiently.

LEARNING TIP

As you read this activity, establish a purpose for reading each section. Ask yourself, "What does the heading tell me I will be reading and thinking about?"

Statement

Only renewable energy resources should be used to produce electrical energy.

Background to the Issue

A renewable resource is a source of energy that can be replaced or is so vast that it will not run out in a human lifetime. Hydroelectricity, wind, and solar power are renewable resources. A non-renewable resource is either used up or is naturally replaced at an extremely slow rate. Fossil fuels were formed over hundreds of millions of years, but are being used at rate much faster than they can be produced. For this reason, fossil fuels are considered to be a non-renewable resource. GO

If you would like to learn more about renewable and non-renewable resources, go to **www.science.nelson.com** GO

Renewable Resources

Hydroelectric power (Figure 2) uses the gravitational potential energy of falling water to turn turbines to produce electrical energy. It is the leading source of renewable energy. It does not produce pollution and it is relatively cheap. However, it is not a perfect energy resource because it requires a costly dam, which can flood the land and interfere with fish migration.

Solar power is energy that comes from the Sun. Photovoltaic cells (often called solar cells) convert the Sun's energy directly into electrical energy (Figure 3). However, since the cells require direct sunlight, their use can be interrupted.

Figure 2 Revelstoke Hydroelectric Dam in Revelstoke, B.C.

Figure 3 Panels of photovoltaic cells

Wind power has been used for centuries to do work. While a traditional windmill is very picturesque, modern wind turbines are much more efficient at producing electrical energy (Figure 4). Wind turbines work best in windy areas. Wind turbine farms can produce significant power, although they require large open spaces, and birds can be hurt or killed if they fly into the blades.

Biomass energy uses plant and animal materials to produce electrical energy. The most common material is wood waste from the forestry industry. The material is burned to create thermal energy, which is converted (in a series of steps) into electrical energy. Although wood waste is generally available in British Columbia, burning produces significant waste products. Rather than burning the fuel directly, the fuel can be fermented to produce alcohol, which burns more efficiently.

Geothermal energy uses the thermal energy in Earth's crust. Geothermal energy is most commonly used to heat buildings. While this does not directly produce electrical energy, it reduces the amount of electrical energy required. In areas where the molten rock of Earth's crust is close to the surface, the steam that is produced can be used to turn a turbine and produce electrical energy. However, only certain areas, such as the South Meager geothermal area, which is 170 km north of Vancouver, have access to geothermal energy.

Tidal power plants (Figure 5) use the kinetic and gravitational potential energy from ocean waves and tides to generate electrical energy. Although the use of tidal power is restricted to coastal communities, the amount of energy seems vast and inexhaustible because most of Earth's surface is covered with water. Unfortunately, tidal power plants can harm coastlines and affect marine life.

Figure 4 Under typical wind conditions, a 2 MW wind turbine can supply more than 500 homes with electricity.

Figure 5 The Annapolis tidal plant, in Nova Scotia, is North America's only tidal plant. It produces up to 20 MW of power daily.

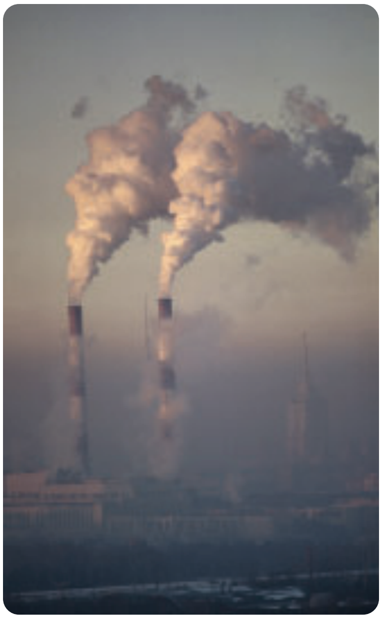


Figure 6 Burning fossil fuels creates air pollution.

Figure 7 The Pickering Nuclear Plant in Ontario is one of the world's largest nuclear generating facilities.

Landfill gas is mostly methane gas and is produced at landfill sites as waste decomposes. Usually the gas is simply burned at the landfill site. The gas can also be piped to a generating plant where the thermal energy is converted (in a series of steps) into electrical energy.

Non-renewable Resources

Coal, oil, and natural gas are fossil fuels made from the remains of ancient life forms. Coal is made from ancient swamp plants that were compressed and heated into solid rock. Coal is the most abundant and widespread fossil fuel. Oil and natural gas come from plant and animal remains that were deposited in ancient seas. Fossil fuels can be burned to produce steam, which turns a turbine to produce electricity. However, burning fossil fuels produces pollutants that contribute to acid rain and global warming (Figure 6). Coal mining damages the surrounding environment and oil spills can destroy ecosystems.

Nuclear power is the conversion of a small amount of mass into a large amount of energy. This conversion can be done by nuclear fission, a process in which large atoms, such as uranium, are broken into smaller atoms. Thermal energy from nuclear reactions is used to boil water to create steam, which is used to produce electricity. Although nuclear power does not create air pollution, the products of the reaction are highly radioactive and need to be stored safely for thousands of years. Nuclear power plants (Figure 7) are expensive, and safety is a major concern.

Make a Decision

1. Carefully read the statement and the background information.
2. Your class will be divided into two groups. One group will support the statement and the other group will oppose the statement.
3. Search for information about using energy resources to produce electrical energy. You may find information in newspapers, a library periodical index or a CD-ROM directory, or on the Internet. You may want to research one energy source and then combine your research with other groups that researched a different energy resource. Make sure that you include a cost–benefit analysis for each energy resource that you research.

   www.science.nelson.com GO

4. Gather relevant information, and prepare to defend your position in a class debate. You should also prepare to respond to challenges to your position.

Communicate Your Decision

Your teacher will organize a classroom debate for you to present your position and listen to the presentations for the opposing position. Each group should choose one of its members to be the group's spokesperson.

At the end of the debate, each member of the class will vote on the issue. Be open-minded and willing to change your position. You should vote for the position with the most convincing arguments. Your teacher will conduct the class vote and announce the results.

LEARNING TIP

Summarizing (condensing main points in your own words) helps you to stay focused. As you read the Explore An Issue activity, summarize each section in your head or on a piece of paper.

11.4 Household Electrical Energy

Energy has always been used in homes for heating, cooking, and lighting. The first lamps were probably nothing more than animal fat or oil burning in a shell or in torches made of reeds. In the early 1800s, natural gas and kerosene lamps became popular. Gaslights were used for street lighting in towns and cities.

The first electric light was the arc lamp (Figure 1). The arc lamp has two carbon electrodes that are touched together to allow current to flow at a low voltage and then pulled apart slowly. The current arcs between the electrodes producing light. Arc lamps were much safer than gaslights because they did not cause fires. However, the carbon electrodes needed constant adjustment as the carbon burned off the rods. In 1879, Thomas Edison revolutionized home lighting with his incandescent light bulb.

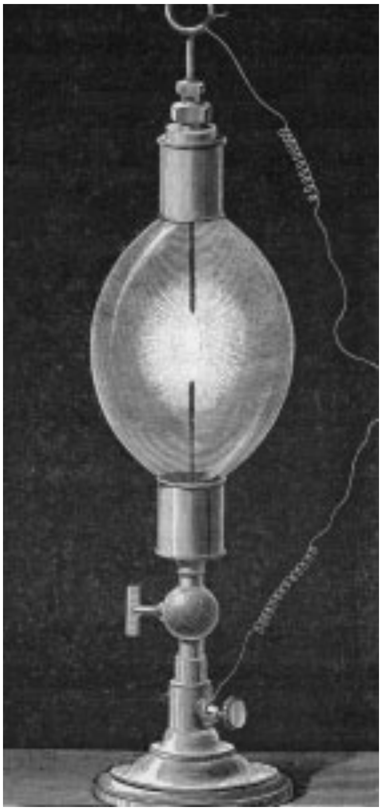


Figure 1 The arc lamp provided city street lighting in the 1800s.

The History of the Electrical Power Industry

During 1880, while Edison continued to refine his light bulb, he also began exploring ways to generate and transmit the electricity that his light bulb would need. Edison opened the first electrical power plant in 1882 in New York, which provided electricity to 59 customers. Edison's system used about 100 V of direct current (DC). Recall from Chapter 10, that direct current refers to electric current that flows only in one direction. The first motors used DC current.

Although Edison's direct current distribution system was spectacular at the time, it had two problems. First, because the voltages were so low (100 V), large currents were needed to supply even relatively small amounts of power. Large currents required large copper wires to carry them, as well as many generating stations. Second, the purpose in the system was to sell electrical energy for profit, but it was difficult to determine the amount of energy consumed.

George Westinghouse recognized the difficulties and knew the answer lay in using a higher voltage. At a higher voltage, the current would decrease. With the help of Nikola Tesla, Westinghouse developed a commercially usable electrical transformer. A transformer is a device that can raise or lower voltages. It requires alternating current and will not work with direct current. In alternating current (AC), the current flows back and forth. The electrons move in one direction, and then in the opposite direction. Edison fought Westinghouse in the courts and newspapers for control of the electrical distribution system. However, once Tesla pioneered the development of AC motors, Westinghouse's victory was assured over Edison. GO

In late 1896, electrical energy was produced using hydroelectric power and transmitted to Buffalo, New York. The first transmission line carried about 800 kW of power. Demand for electricity increased, and transmission lines were added to provide power to such places as New York City. Today, voltage is transmitted at hundreds of thousands of volts, which allows large amounts of power to be sent at relatively low currents.

Did You KNOW?

Swan's Light Bulb

In 1878, British scientist Sir Joseph Wilson Swan invented the modern light bulb. The invention of the light bulb is often associated with Edison, although he independently discovered the same device a year later than Swan.

For the complete story of the battle between Edison, and Westinghouse and Tesla, go to **www.science.nelson.com** GO

Figure 2 An induction meter

The Electric Meter

Even though Westinghouse had gained control of electrical distribution, he still had a significant problem. Since the current was alternating, there were no electric meters that could accurately measure how much electrical energy a customer used. In 1894, the Westinghouse Company produced the first induction watt•hour meter (Figure 2). This meter measured electrical energy consumption in watt•hours, and it was inexpensive, accurate, and simple. Use of this meter represented the final step in the battle between AC and DC electrical power distribution.

Energy is usually measured in joules. Since $\Delta E = P\Delta t$, or power (in watts or kilowatts) multiplied by time (in hours), the watt•hour can also be used as a unit of electrical energy. Today, electric meters, such as the one shown in Figure 3, are generally referred to as kilowatt•hour meters (or kilowatt-hour meters) because they measure the amount of electrical energy in **kilowatt•hours (kW•h)**.

LEARNING TIP

Check your understanding of the history of the electric age. Discuss the following statement with a partner: In the "war of the currents," Edison and Westinghouse were main rivals.

Figure 3 Electric meter

The average home in British Columbia uses about 800 kW•h of electricity per month. Individual electrical energy use depends on such factors as how the home is heated or cooled, how many people live in the home, and the season. How much electrical energy is 800 kW•h of electricity measured in joules?

$$800 \text{ kW•h} \times \frac{1000 \text{ W}}{1 \text{ kW}} \times \frac{3600 \text{ s}}{1 \text{ h}} = 2\ 880\ 000\ 000 \text{ J}$$

$$2\ 880\ 000\ 000 \text{ J} \times \frac{1 \text{ GJ}}{1\ 000\ 000\ 000} = 2.88 \text{ GJ}$$

The number 2.88 GJ (gigajoules) is very large, which is why electricity is sold by the kilowatt•hour and not by the joule.

Determining Electrical Energy Costs Using a Kilowatt•hour Meter

Electric meters are read using the rotating pointers on the dials. The dials rotate in alternating clockwise and counterclockwise directions. From left to right, the dials shown in Figure 4 represent ten thousands, thousands, hundreds, tens, and units of kilowatt•hours. GO

For more information on how to read an electrc meter, go to www.science.nelson.com GO

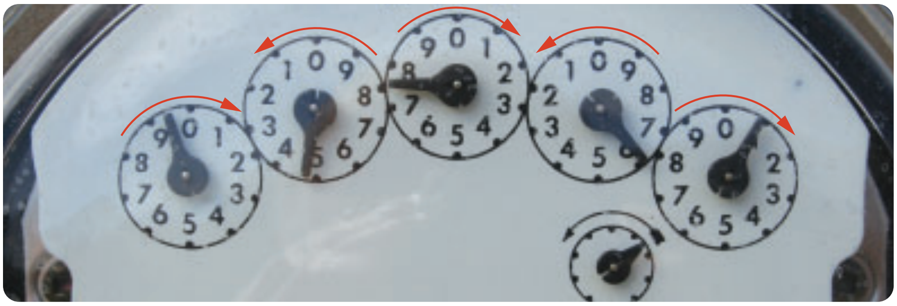


Figure 4 A close-up view of the dials of an electric meter. Note that the dials go clockwise, counterclockwise, clockwise, counterclockwise, and then clockwise when read from left to right.

The reading on an electric meter does not indicate the amount of electrical energy used in a month. It measures the amount of electrical energy used since the meter was installed. The meter is not reset to 0 every time it is read. To determine monthly usage, the reading at the start of the month is subtracted from the reading at the end of the month. The cost of the electrical energy used is determined by multiplying the difference in kilowatt•hours by the rate set by the electric utility company. 11A Investigation

11A Investigation

Household Electrical Energy Use

To perform this investigation, turn to page 355.

In this investigation, you will determine the amount of electricity that your household uses in a week.

SAMPLE PROBLEM 1

Reading a Kilowatt•Hour Meter and Determining the Cost of Electricity

(a) Determine the reading on the kilowatt•hour meter shown in Figure 5.

(b) The meter reading shown in Figure 5 was taken on the last day of the month. The meter reading on the last day of the previous month was 61 409 kW•h. How much electrical energy was used during the month?

(c) If the electric utility company charged \$0.065/kW•h, how much did the electricity for the month cost?

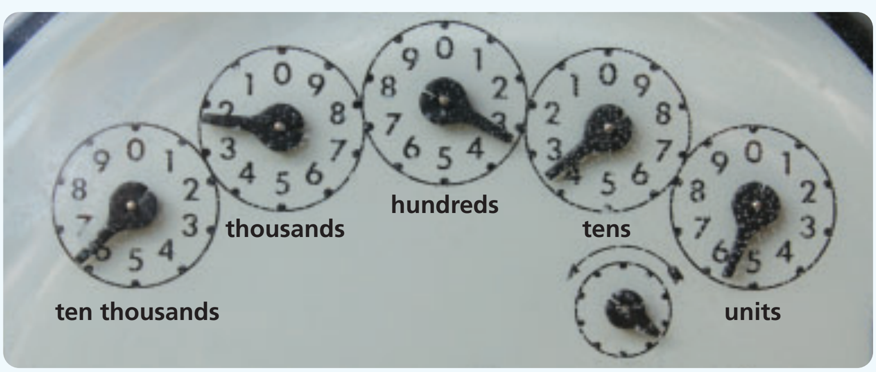


Figure 5
When the pointer is between two numbers, read the smaller number. For example, the units pointer is between 5 and 6, so the reading is 5.

Solutions

(a) To determine the meter reading, read the dials from right to left. The reading is 62 335 kW•h.

(b) The energy used was 62 335 − 61 409 = 926 kW•h.

LEARNING TIP

If you are having difficulty with determining the meter readings in Figure 6, reread the instructions in Figure 5.

(c) Multiply the amount of electrical energy used for one month by \$0.065/kW•h.

$$\text{Cost} = (926 \text{ kW•h})\left(\frac{\$0.065}{\text{kW•h}}\right) = \$60.19$$

The electricity cost \$60.19 for the month.

Practice

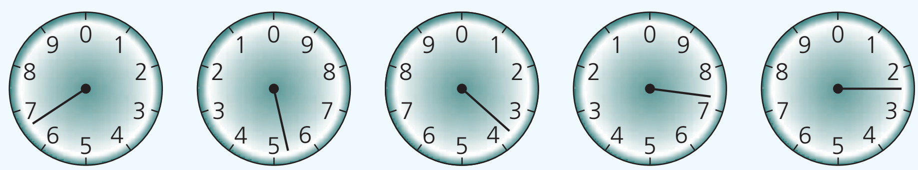
Figure 6 shows the dials of an electric meter.

(a) Determine the readings on the two meters shown in Figure 6.

(b) The meter readings were taken on the first day of each month. How much electrical energy was used during the month?

(c) If electrical energy costs \$0.065/kW•h, how much did the electricity for the month cost?

January 1 kilowatt•hour meter reading



February 1 kilowatt•hour meter reading

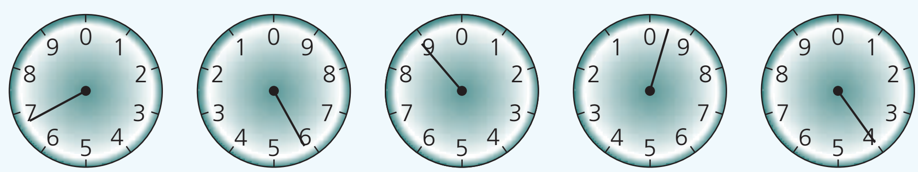


Figure 6

TRY THIS: *Reading an Electric Meter*

Skills Focus: observing, measuring, interpreting data

How much electrical energy, in kilowatt•hours, is required by a 100 W light bulb in one day (24 h)?

Materials: demonstration kilowatt•hour meter, lamp with a 100 W light bulb

1. Record the date and time. Record the reading on the electric meter.

2. Plug the demonstration meter into an outlet, and then plug the lamp into the electric meter outlet. Leave the light bulb on for 24 h.

3. Record the date and time. Record the reading on the electric meter.

4. If there is time, repeat the activity for another day or two.

A. Based on your meter readings, how much electrical energy was used (in kilowatt•hours)?

B. Calculate how much electrical energy is used by a 100 W bulb in 24 h using the equation $\Delta E = P\Delta t$. How does this value compare with your answer to A? Explain any differences.

C. Do you think that the difference between your answers in A and B will get smaller as the time gets longer? Why or why not?

Government of Canada EnerGuide Labels

All household appliances are sold with an EnerGuide label that provides consumers with information about the appliance's electrical energy consumption and efficiency. A sample label is shown in Figure 7. The information on an EnerGuide label is based on extensive testing. The label provides an estimate of how much electrical energy (measured in kilowatt•hours) the appliance should use in a typical year. The appliance is compared with similar models, and a bar graph indicates the appliance's ranking. Consumers can compare the EnerGuide labels of different appliances to help them make an energy-wise choice when buying a new appliance. As you can see from Table 1, appliances are becoming more efficient. As a result, the ratings are updated every few years. GO

To learn more about the EnerGuide program, go to
www.science.nelson.com GO

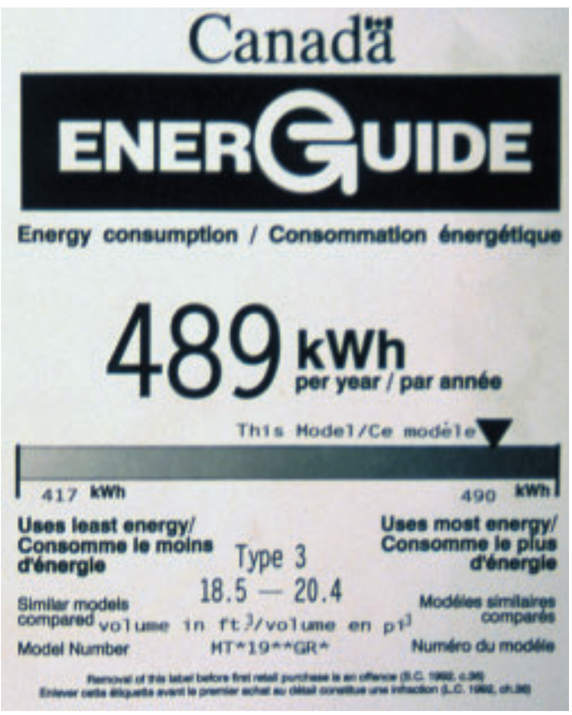


Figure 7 An EnerGuide label. This label indicates that the appliance uses approximately 489 kW h of electrical energy a year.

Table 1 Average Annual Electrical Energy Consumption of Major Appliances (in kW•h/year)

Appliance	1984	1990	1997	1999	2002
refrigerator	1457	1044	664	664	514
dishwasher	1213	1026	649	640	592
clothes washers (top loading)	1243	1218	930	860	779
clothes dryers	1214	1103	887	908	916
freezer	813	714	376	383	368
ranges (self-cleaning)	790	727	759	742	735
ranges (not self-cleaning)	–	786	780	770	784

Did You KNOW?

An Energy Star

Some energy-efficient appliances are labelled with an Energy Star® symbol, as well as an EnerGuide label. The Energy Star® is the international symbol that is used to identify products that have the highest levels of energy efficiency. The Energy Star® program was created in 1972 by the US Environmental Protection Agency.

11.4 CHECK YOUR Understanding

1. Electrical energy is transmitted through high voltage transmission lines. What is the advantage of using high voltage?
2. A small business uses 498 kW•h of electrical energy. How many joules of energy is this?
3. A clothes washer has a power rating of 350 W. A dryer has a rating of 4600 W.
   (a) What is the power rating of the washer in kilowatts?
   (b) If the washer runs for 30 min, how many kilowatt•hours of electrical energy has been used?
   (c) What is the power rating of the dryer in kilowatts?
   (d) If the dryer runs for 60 min, how many kilowatt•hours of energy will it use?
   (e) How much electrical energy do the washer and dryer use together?
   (f) If energy costs $0.062/kW•h, what is the cost to do a load of laundry?
4. What is the reading of the electric meter shown in Figure 8?

Figure 8

5. In an average week, a student uses a 1200 W hair dryer for 30 min. If electrical power costs $0.065/kW•h, what is the cost to use the hair dryer for a year?
6. What is the reading shown by the kilowatt•hour meter dials shown in Figure 9?

kilowatt•hour meter reading

Figure 9

7. The electric meter readings for a home are shown in Figure 10. Determine how much electrical energy was used during the month of March.

April 1 kilowatt•hour meter reading

March 1 kilowatt•hour meter reading

Figure 10

8. A family uses 988 kW•h of electricity in one month. If electricity costs $0.063/kW•h, what is the family's electricity bill for the month?
9. What information does the EnerGuide label provide? Determine the EnerGuide number for an appliance that you have at home or you have seen in a store. Explain what the number means.
10. An appliance has an EnerGuide rating of 630 kW•h/year. What is the cost per week to run the appliance if electricity costs $0.068/kW•h?
11. The monthly electricity bill for an apartment is $80.71. If the electricity rate is $0.072 kW•h, how many joules of energy are used?
12. The Smith household has their highest electricity bill in December. The Jones household has their highest electricity bill in August. Provide possible reasons for this difference.

11A Investigation

Household Electrical Energy Use

The amount of electrical energy that is used in a home depends on such factors as the number of people in the home, the type of heating used, and the season. In this Investigation, you will take a snapshot of your family's electrical energy use during one week.

Question

How much electrical energy does my family use in one week?

Experimental Design

In this Investigation, you will keep a record of your home electrical energy consumption.

Procedure

1. Copy Table 1 into your notebook.
2. Locate your family's kilowatt•hour meter, and record the reading in Table 1 for eight consecutive days. Try to take the reading about the same time each day.

Table 1 Daily Log

Day	Date : Time	Meter reading	Daily electrical energy (kW•h)	Total electrical energy (kW•h)
0	____ : ____			
1	:			
2	____ : ____			
3	:			
4	____ : ____			
5	:			
6	____ : ____			
7	:			

INQUIRY SKILLS

- ● Questioning
- ○ Hypothesizing
- ○ Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Analysis

(a) Why does the first meter reading start with day 0? Why does the meter need to be read for eight days?

(b) Calculate the electrical energy used each day and the total electrical energy used.

(c) How much electrical energy did your family use in one week? How does this compare with the amount used by your classmates' families?

(d) Using your total for the week, estimate how much electrical energy your family uses in a month. Determine the cost of electricity for a month using the cost per kilowatt•hour obtained from your family's last electricity bill or your teacher.

(e) How does the figure you calculated compare with your family's electricity bill last month?

Evaluation

(f) Do you think it is acceptable to estimate the monthly consumption based on the data from one week? Explain.

Synthesis

(g) Create a list of recommendations for how your family can conserve electrical energy.

(h) How could you accurately estimate the yearly electrical energy consumption of your home?

CHAPTER 11

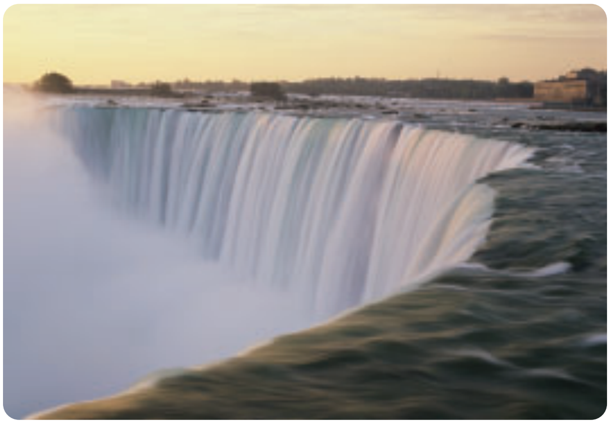
Review

Using Electricity

Key Ideas

Electrical energy is a type of energy that can be converted into other types of energy.

- Electrical energy can be potential energy, such as the energy stored in a battery, or it can be the energy of moving electrons in an electric current that can do work.
- Potential energy is energy that can be stored. Kinetic energy is the energy that is associated with motion.
- Work is done when energy is transformed. Energy is defined as the ability to do work. The metric unit for both work and energy is the joule (J).
- Energy comes in many types and is often only observed when it changes from one type to another. Energy is always conserved.
- We can use various equations to calculate the electrical energy of a device.



Electrical energy

$$\Delta E = P\Delta t$$

$$\Delta E = VI\Delta t$$

Electrical power is the rate of transforming electrical energy into another type of energy.

- Power is the rate of doing work or the rate of transforming energy. The metric unit for power is the watt (W).
- We can use various equations to calculate the electrical power of a device.

Electrical power

$$P = \frac{\Delta E}{\Delta t}$$

$$P = VI$$

Vocabulary

work (W), p. 336

energy (E), p. 336

potential energy (PE), p. 336

kinetic energy (KE), p. 336

law of conservation of energy, p. 337

power (P), p. 338

watt (W), p. 338

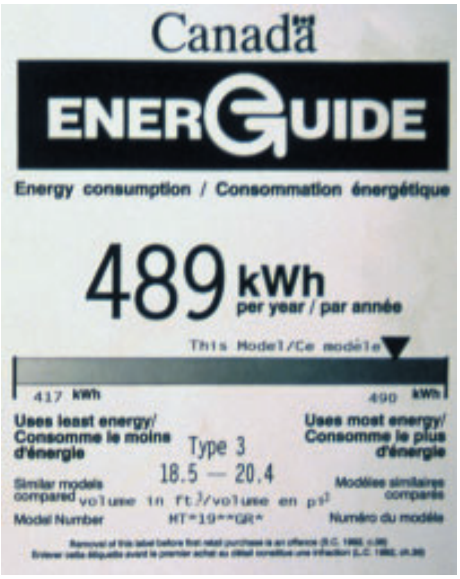
kilowatt•hour (kW•h), p. 350

Electrical energy is produced from renewable and non-renewable resources.

- Electricity can be generated from renewable resources including water (hydro), the Sun (solar), wind, biomass, tides, geothermal, and landfill gas.
- Electricity can be generated from non-renewable resources, including fossil fuels and nuclear reactions.

Energy consumption can be determined given the power rating of a device and the duration of use.

- Electrical energy is often measured in kilowatt•hours (kW•h).
- Household electrical energy is sold in units of kilowatt•hours (kW•h), not joules, and is measured by kilowatt•hour meters (electric meters).
- EnerGuide labels provide information about the energy consumption and efficiency of appliances in Canada.



Review Key Ideas and Vocabulary

1. Give an example of a device that converts electrical energy into each of the following types of energy:
   (a) heat
   (b) kinetic energy
   (c) light energy
2. A warm cup of coffee has 20 000 J of energy. After being heated in a microwave, the cup of coffee has 70 000 J of energy. How much work was done by the microwave to heat the coffee?
   (a) 20 000 J
   (b) 50 000 J
   (c) 70 000 J
   (d) 90 000 J
3. What is the reading shown by the kilowatt•hour meter dials in Figure 1?

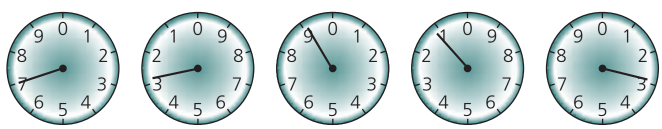


Figure 1

   (a) 72912
   (b) 72923
   (c) 83023
   (d) 73913
4. A family uses a 1200 W microwave oven for 30 min. If electrical power costs \$0.063/kW•h, what is the cost to use the microwave oven?
   (a) \$0.038
   (b) \$0.43
   (c) \$2.27
   (d) \$37.80
5. A watt is to power as a ____?____ is to work.
6. Is a kilowatt•hour a unit of electrical energy or a unit of power? Explain your answer.

Use What You've Learned

7. A hair dryer is rated at 1200 W. How much current flows through the hair dryer when it is plugged into a 120 V outlet?
8. Calculate the power rating of an electric toaster that uses 210 000 J while toasting bread for 140 s.
9. How much electrical energy does a 2 W clock use in one day?
10. A Segway® Personal Transporter (PT), shown in Figure 2, has two electric motors (one for each wheel) and one 72 V battery. If each motor consumes 180 W of power when travelling up a hill, how much current would the motors get from the battery?

Figure 2

11. An electric drill has a current of 0.55 A flowing through it for 48 s. If the drill is connected to a 120 V outlet, how much energy is used?
12. How much energy does a calculator use in two minutes if it draws 0.2 mA of current from a 2.8 V battery?
13. What is the power of a 1.2 kA lightning bolt with a voltage of 1.5 MV?

Figure 3

14. An electric utility company provides 250 kW of power over transmission lines at 240 kV. What is the current in the transmission lines (Figure 3)?
15. (a) What is the current in a 373 W motor using a 120 V outlet?
    (b) If the motor is plugged into a 240 V outlet, what happens to the current in the motor?
16. An electric heater, rated at 2600 W, is plugged into a household outlet. If the current from the outlet exceeds 15 A, a circuit breaker shuts off the circuit. Will the heater cause the breaker to stop the current flow? Show your calculations, and explain your reasoning.
17. A standard dishwasher has an EnerGuide rating of 592 kW•h. What is the cost per week to run the appliance if electricity costs $0.068/kW•h?
18. An electric refrigerator operates on 120 V and uses 2 A. To keep the refrigerator cool, the motor operates one-quarter of the time. What is the cost of operating the refrigerator for seven days if the cost of electrical power is $0.065/kW•h?
19. Find the EnerGuide rating of an appliance in your home and determine the cost of electrical energy in your area. Use this information to determine the weekly cost of the appliance.
20. Batteries are often rated in ampere•hours (A•h), which is a measure of how much electric charge the battery has. This can be shown as follows:

$$1 \text{ ampere•hour} = \frac{1 \text{ coulomb}}{\text{second}} \times 3600 \text{ seconds}$$
$$= 3600 \text{ coulombs}$$

How much energy is stored in each of the following batteries?
    (a) Two 1.5 V AA batteries, each rated at 2 A•h, are used in a CD player.
    (b) A 12 V truck battery rated at 100 A•h is used to start the engine.
    (c) A 12 V golf cart battery rated at 260 A•h is used to run the electric engine.

Think Critically

21. A multimeter can be set to either AC or DC. What will a multimeter read if it is set to the DC current mode, but placed in an AC circuit?
22. Use $P = VI$ to explain why Edison's DC system was inefficient.
23. Most small electronic devices, such as electronic games, digital cameras, cell phones, and MP3 players, come with a transformer. Research to determine how a tranformer works, the purpose of a transformer, and the type of current that a transformer requires.

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Reflect On Your Learning

24. How has what you have learned about work, energy, and power affected your use of these words in everyday language?

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UNIT C

Review

Characteristics of Electricity

Unit Summary

In this unit, you learned about static electric charges—how they are produced and transferred, and how they interact. You also learned about current electricity and investigated how current results from the movement of electrons in a circuit. You have seen how to relate the use of electrical energy to power consumption.

Create a concept map that relates these ideas. You may use pictures, sketches, and text to show how the ideas relate to each other. You may also use sample problems and their solutions. Check the Key Ideas and Vocabulary at the end of each chapter to make sure that you have included all the major concepts in your concept map.

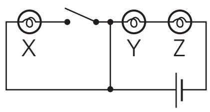
Review Key Ideas and Vocabulary

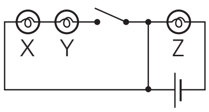
1. The atom is composed of three basic particles: the electron, the neutron, and the proton. Which row of the table correctly indicates the charge on each particle?

	Electron	Neutron	Proton
(a)	–1	0	+1
(b)	–1	+1	0
(c)	+1	–1	0
(d)	+1	0	–1

2. Why does a copper rod rubbed by a paper towel not acquire a static charge when held in a hand?
   (a) Copper is a solid.
   (b) Copper is a very good insulator.
   (c) Copper is a very good conductor.
   (d) Electrons will not move through copper.
3. A neutral atom has electrons removed from it. Which statement about the atom is true?
   (a) The atom still has a neutral charge.
   (b) The atom has become a positive ion.
   (c) The atom has become a negative ion.
   (d) The atom has become a different element.
4. A pith ball hanging by a thread is attracted to a positively charged plastic rod. What can you determine about the charge of the pith ball?
   (a) The pith ball has a positive charge.
   (b) The pith ball has a negative charge.
   (c) The pith ball could be neutral or have a positive charge.
   (d) The pith ball could be neutral or have a negative charge.
5. Which statement best describes the electric current in a light bulb?
   (a) It represents how fast the electrons are moving in the light bulb.
   (b) It represents the average kinetic energy of the electrons in the light bulb.
   (c) It represents how much energy the electrons lose going through the light bulb.
   (d) It represents how many electrons are going through the light bulb each second.
6. Which of the following materials is a conductor?
   (a) gold
   (b) glass
   (c) dry air
   (d) acetate

7. Which of the following diagrams shows a circuit in which light bulbs Y and Z will light, but NOT light bulb X?

(a)


(c)


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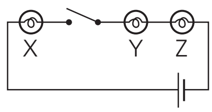

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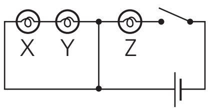
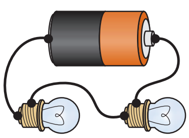
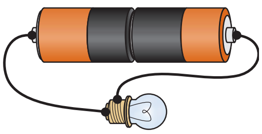
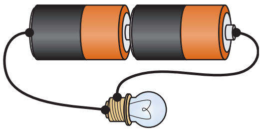
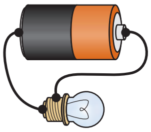


8. Identical cells and bulbs were used to make the following circuits shown. In which circuit would the light bulb(s) be the brightest?

(a)


(c)


(b)


(d)


9. Three cells, each with a voltage of 1.3 V, are connected as shown in Figure 1. What voltage is measured by the voltmeter?

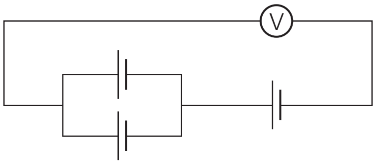


Figure 1

(a) 1.3 V
(b) 2.6 V
(c) 3.9 V
(d) 0.43 V

10. Which value is equal to 24 mA?
(a) 0.024 A
(b) 0.24 A
(c) 2.4 A
(d) 24 000 A

11. What is the reading shown on the kilowatt hour electricity meter dials in Figure 2?

Figure 2

(a) 72913
(b) 72923
(c) 73913
(d) 83923

12. In a series circuit, the ___?___ is constant. In a parallel circuit, the ___?___ is constant.

13. Write a definition of "static electric charge" in your own words.

14. What are two possible ways to give an object a static charge?

15. What is the difference between conducting and insulating materials?

16. How does the strength of the electric force depend on the amount of charge and the distance between charged objects?

17. Why is it unsafe to use a tree for protection during a thunderstorm?

18. What is a complete electric circuit?

19. Why are secondary cells, not primary cells, used for car batteries?

20. What is the difference between conventional current and electron current?

21. What is the difference between potential energy and kinetic energy?

Use What You've Learned

22. If a rod made of a conducting material, such as aluminum, is held in a person's hand, the rod is not able to acquire a static charge because the person grounds the rod. However, if the rod is held in an insulating material, a static charge could form. (If aluminum had been included in the electrostatic series on page 276, it would have been between silk and paper.)

(a) If you hold an insulated aluminum rod in your hand, rub it with a paper towel, and then bring the rod toward a suspended pith ball, the ball will not be attracted to the rod. Why?

(b) If the paper towel is replaced by rabbit fur, will the aluminum rod attract the pith ball? State your reasoning.

23. After being rubbed on a sweater, a balloon sticks to the wall. However, after a time, the balloon falls to the floor. Explain why this happens.

24. Draw diagrams to show how the leaves of a neutral electroscope will respond if

(a) a positive rod is brought close to, without touching, the ball of an electroscope

(b) a positive rod touches the ball of the electroscope

(c) the ball of a positively charged electroscope is touched by a human finger

25. Some buildings have metal roofs. Are these buildings more dangerous to be in during a thunderstorm? Use research to support your answer.

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26. Draw a circuit with three resistors in series connected to a battery. The battery is composed of three cells in series. Include an ammeter that measures the current through the first resistor and a voltmeter that measures the voltage drop in the middle resistor.

27. In how many ways can six 1.5 V cells be connected to produce 3.0 V? Draw diagrams to show your possible arrangements.

28. Two resistors are connected in series to a voltage source. If the resistors have different resistances, which resistor will feel warmer?

29. Two resistors are connected in parallel to a voltage source. If the resistors have different resistances, which resistor will feel warmer?

30. An electric kettle has 12 A of current passing through it when it is plugged into a 120 V source. What is the resistance of the kettle?

31. An electric motor operated on 45 V for fifteen minutes. If the current was 1.4 A, how much energy was used by the motor?

32. Figure 3 shows three light bulbs (A, B, and C) in a circuit. The current in light bulbs A and B is 125 mA.

(a) What is the current in light bulb C?

(b) If the cell shown has a voltage of 1.5 V, what is the total resistance of all the light bulbs combined?

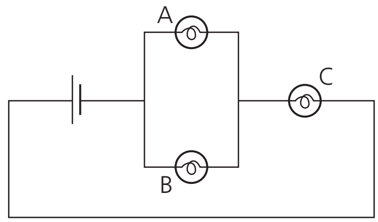

Figure 3

33. Figure 4 shows three resistors, each with a resistance of 22 Ω connected to a 1.3 V cell. Copy the diagram into your notebook.

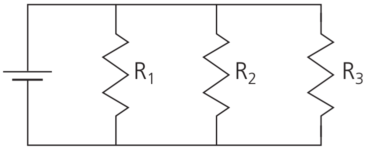

Figure 4

(a) Is this a series circuit or a parallel circuit?

(b) Indicate on your diagram where you would attach a voltmeter to measure the voltage in the third resistor (R_3) and where you would attach an ammeter to measure the current in the first resistor (R_1).

(c) What current is flowing through the second resistor (R_2)?

34. How much current does a 25 W light bulb draw from a household electrical outlet? The voltage of the outlet is 120 V.

35. A laptop computer operated for 3.5 h with 16 W of power before the battery needed recharging. How much energy did the battery provide?

36. The circuit diagram in Figure 5 shows two resistors connected in series. The value of R_1 is 100 Ω, and the value of R_2 is 150 Ω, respectively. The voltage applied (V_T) to the circuit is 30 V.

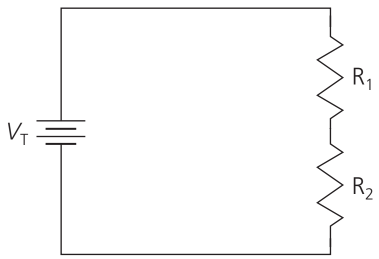

Figure 5

(a) What is the total resistance of the circuit?
(b) What is the current through the resistors?
(c) What is the voltage in each resistor?
(d) What is the power of each resistor?
(e) What is the power delivered by the voltage source?

37. The circuit diagram in Figure 6 shows two resistors connected in parallel. The values of R_1 and R_2 are 100 Ω and 150 Ω, respectively. The voltage applied (V_T) to the circuit is 30 V.

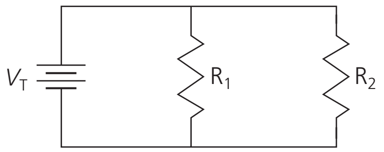

Figure 6

(a) What is the current in each resistor?
(b) What is the power of each resistor?
(c) What is the total current delivered by the voltage source?
(d) What is the power delivered by the voltage source?

Think Critically

38. Do you think there are more advantages than disadvantages of static electricity? Defend your answer.

39. Rechargeable batteries should not be used in smoke detectors. Research to find out why and determine the type of batteries that should be used.

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40. The electrical outlets in Canadian homes are 120 V. The electrical outlets in European homes are 240 V. What are the advantages and disadvantages of each system? Research your answer.

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41. Ammeters are made with low resistance. Voltmeters are made with high resistance. Give an explanation for this difference.

42. What is the difference between AC and DC current? What are the advantages of using AC current?

43. Fibre optics are used to replace electric circuits for some applications. Research to learn about the use and benefits of fibre optics. Write a short essay about your findings.

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Reflect on Your Learning

44. Write a short essay about how your attitude toward electricity has changed. Possible topics include safety, consumption, and how different circuits work.

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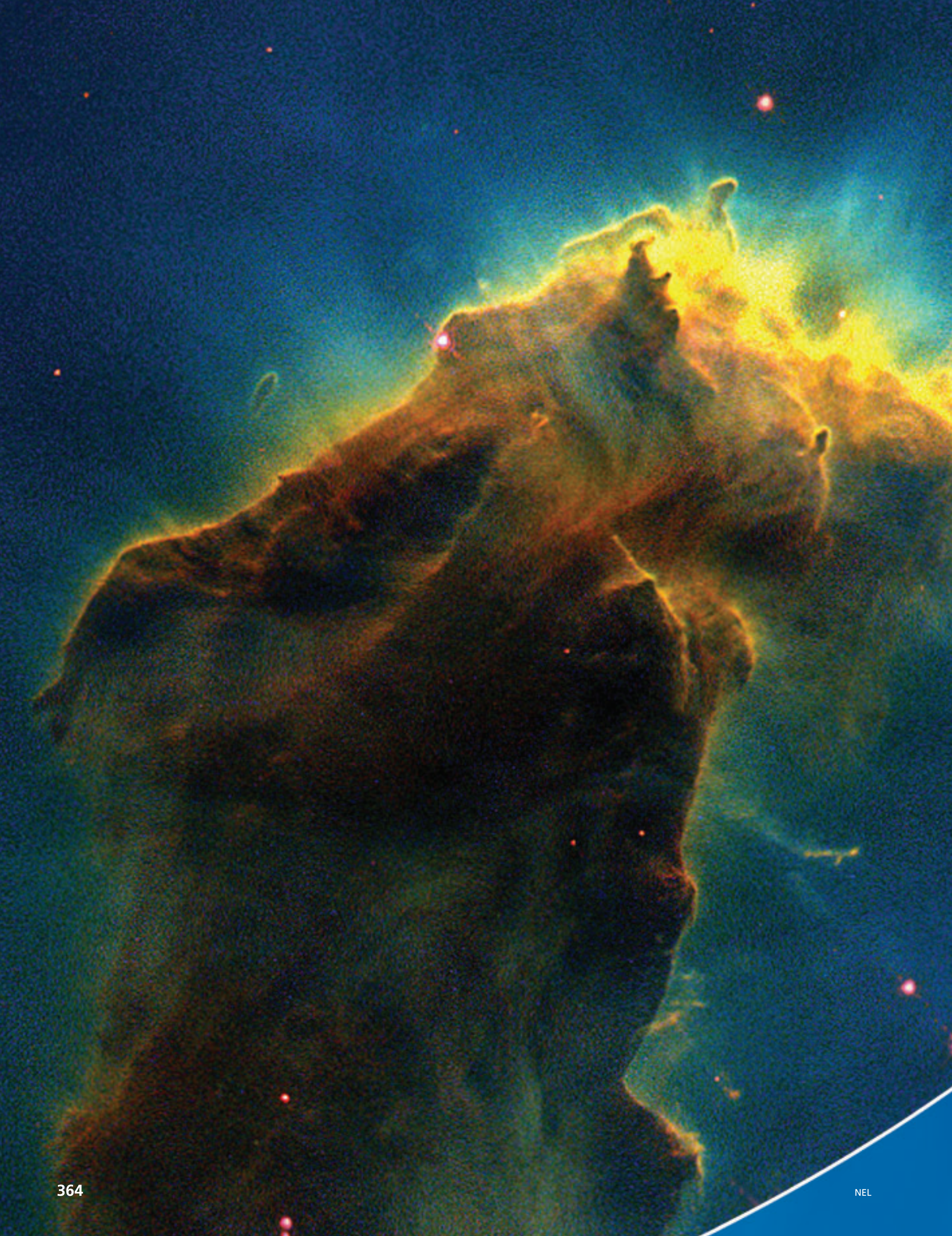


UNIT

D

SPACE EXPLORATION

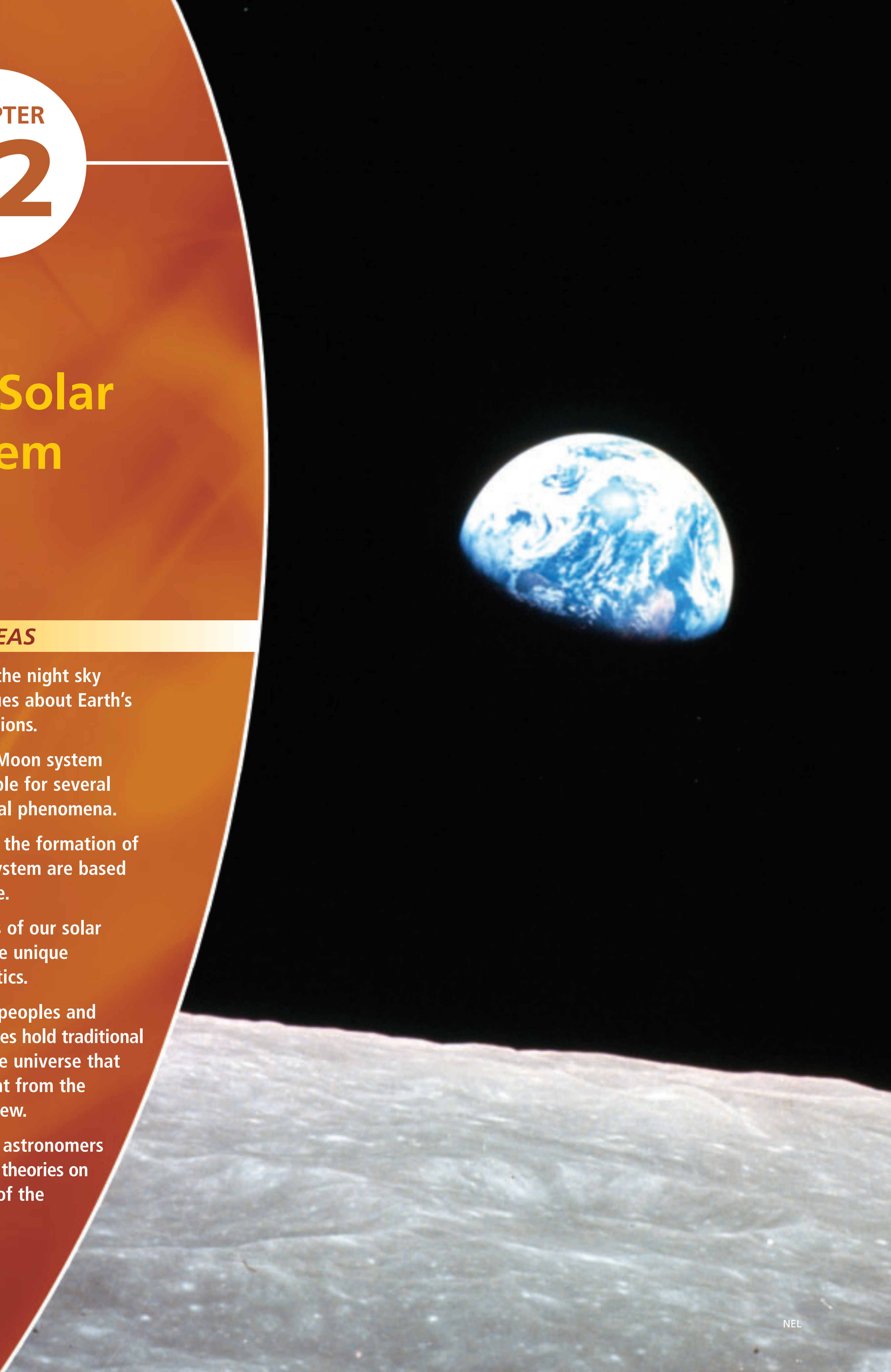
Unit Preview

Today more than ever before, the vastness of space lies at our doorstep. Our own solar system is revealing surprising new discoveries. We are now a solar system of eight planets, not nine. Will life be found elsewhere in our solar system?

How old is the universe? How did it begin? Enormous clouds where stars are forming are being discovered throughout the depths of space. What happens to a star as it ages? Where does our star, the Sun, fit within our own galaxy, the Milky Way? We have watched the stars for thousands of years. Early Aboriginal and Indigenous peoples developed many legends and stories about the universe, which brought the distant stars into the daily lives of early peoples. Will we ever to be able to cross the vast distances to stars? Where will we go next? Do we have the right to change other worlds we visit?

CHAPTER 12

The Solar System



KEY IDEAS

- Observing the night sky gives us clues about Earth's unique motions.
- The Earth–Moon system is responsible for several astronomical phenomena.
- Theories of the formation of our solar system are based on evidence.
- The planets of our solar system have unique characteristics.
- Aboriginal peoples and other cultures hold traditional views of the universe that are different from the scientific view.
- Many early astronomers contributed theories on the nature of the universe.

Chapter Preview

The word "phenomenon" is used to describe an event that is perceptible by the senses. Every time you watch the Sun set below the horizon, you are witnessing the phenomenon of Earth's rotation about its axis. What causes the seasons? How does the Moon affect the tides on Earth? What conditions are required for a solar or lunar eclipse to occur? How did our solar system form? All of these events are astronomical phenomena.

In this chapter, you will learn about the science behind these and other astronomical phenomena in our solar system and the many objects we find there. You will also learn about some of the people responsible for changing our ideas about the universe and how our solar system is organized, as well as perspectives from other cultures.

TRY THIS: *Your First Observations*

Skills Focus: conducting, recording, communicating, interpreting data

Materials: flashlight with red cellophane covering, plain paper and clipboard, pencil and other sketching implements, pictures of constellations from your teacher

Make sure you get permission from a parent or guardian, you have chosen a safe location to go to at night, and that an adult accompanies you.

1. With classmates and an adult, go to a dark site to observe the night sky.
2. Draw a line at the bottom of your paper to represent the horizon. Sketch any trees or buildings that are along the horizon. You will use these objects as landmarks.
3. Record the date, exact time of your observations, detailed description of the position from which you made your observations, and the cloud conditions for that evening.
4. Using your handouts, locate and draw two or more constellations. Return 2 h later; repeat the process.
5. After two weeks, at the same time, return to the location and record your observations of the same constellations.

A. What change in the position of the constellations did you notice after 2 h?

B. How significant was the change in positions after two weeks?

12.1 The Night Sky

LEARNING TIP

Skim Section 12.1. Consider information gathered from the title, headings, figures, and words in bold. What do you expect to learn in this section?

Astronomy is the branch of science that involves observations and explanations of events and objects that occur beyond Earth and its atmosphere. An **astronomer** is a scientist who studies astronomy. Different astronomers study different aspects of astronomy. Some astronomers study the Sun, some study the planets, while others study objects such as galaxies and black holes.

Do you ever watch the stars at night move slowly across the sky and wonder why they all move in the same direction? Do you ask yourself questions such as, "What causes the phases of the Moon?" and "How was our solar system formed?" Do you look at the night sky when it is clear so that you can find your favourite constellation? If your answer to these questions is yes, then you are thinking like an astronomer.

Earth's Motions

Earth undergoes two distinct and important motions: rotation and revolution. **Rotation** is the spinning of an object around an imaginary line called an axis. **Revolution** is the motion of an object around another object (Figure 1).

Figure 1 In this amusement park ride, the teacup rotates on its axis while revolving around the centre of the ride.

Effects of Earth's Rotation

Earth takes 24 h to complete one full rotation about its axis, which is tilted 23.5° (Figure 2). If you stood above the North Pole and looked down, Earth would appear to be rotating in a counterclockwise direction. As a result of Earth's rotation, we have day and night. During rotation, the part of Earth that faces the Sun experiences daylight, and the part that faces away from the Sun experiences darkness. The number of hours of daylight between sunrise and sunset is called the **photoperiod**. 12A *Investigation*

12A *Investigation*

Sunrise and Sunset: Measuring the Photoperiod

To perform this investigation, turn to page 404.

In this investigation, you will learn how the photoperiod varies in your area.

The rotation of Earth is responsible for the movement of other objects in the sky. The Sun, Moon, and planets all appear to rise in the east and set in the west. As a result, to people who live in the northern hemisphere, these objects appear to move in a clockwise direction.

Ancient Greek astronomers noted that five particularly bright points of light moved differently, compared with the other stars. They seemed to wander through 12 constellations, which the Greeks called the animal signs, or zodiac constellations. The Greeks called the five bright points of light "planets," or wanderers. The eight **planets**, or large objects that we now know orbit the Sun in our solar system, include these five Greek "planets." We now understand their motion—Earth and the other planets are travelling around the Sun. Because the other planets are much closer to Earth than the stars, they appear to move through the stars, which are actually behind.

Ancient astronomers saw an unusual motion that remained unexplained until the Sun was accepted as the centre of the solar system. This unusual motion is called retrograde motion. **Retrograde motion** is the apparent slowing, reversal, and then looping of a planet in its path across the sky, as in Figure 3(a). GO This seemingly impossible motion occurs because Earth travels around the Sun faster than some of the other planets, such as Mars, Jupiter, and Saturn (Figure 3(b)). 12B Investigation

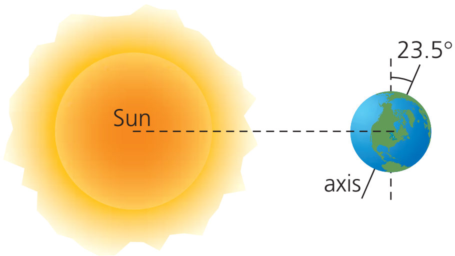


Figure 2 Earth's imaginary axis is tilted 23.5° (not to scale).

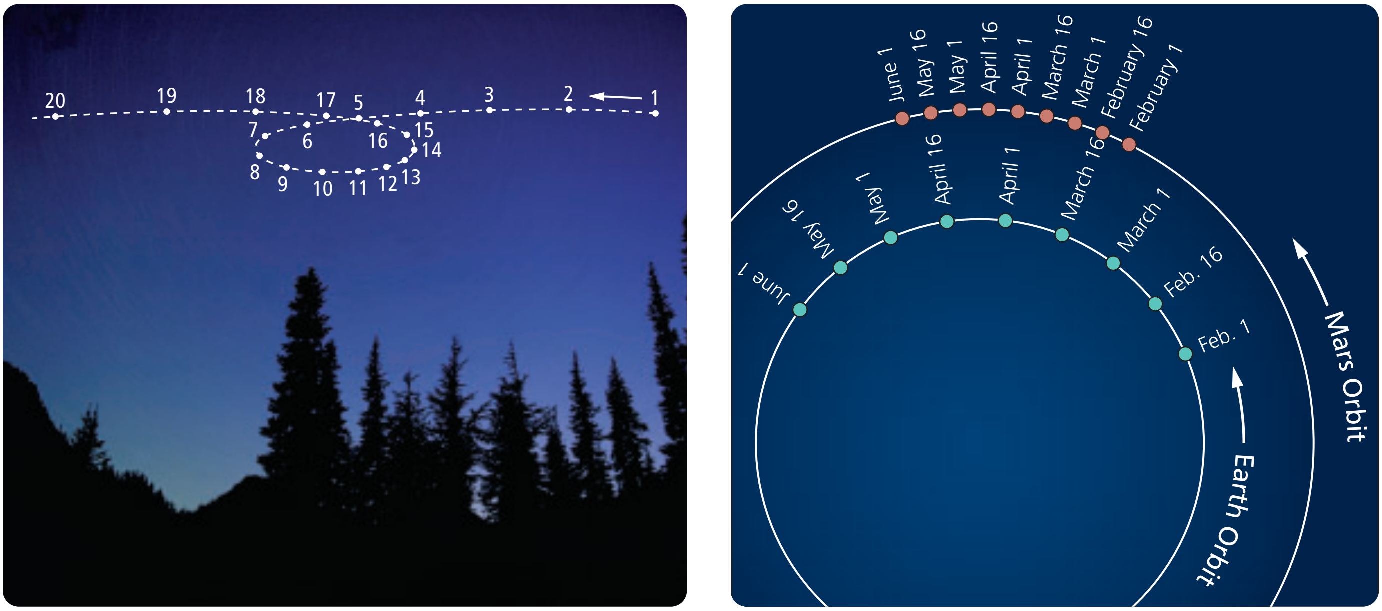
If you would like to learn more about retrograde motion, go to **www.science.nelson.com** GO

12B Investigation

Retrograde Motion

To perform this investigation, turn to page 405.

In this investigation, you will model Mars' retrograde motion.



(a) **(b)**

Figure 3 (a) Jupiter's path across the sky shows retrograde motion. The number with each dot represents Jupiter's position as it travels across the sky over several months. The path of the planet forms a loop as a result of retrograde motion. (b) The speed of Earth in its orbit compared to the speed of Mars causes the retrograde motion of Mars.

Precession

Earth's axis has not always pointed in the same direction. In fact, Earth's axis slowly traces a circle every 26 000 years. Consider a spinning top. The tip of the top does not usually point straight up. This is similar to the tilt of Earth's axis. Furthermore, the tip of the spinning top does not remain in one fixed position. It, too, traces a circle, and it tends to wobble as it spins (Figure 4). Although the angle of Earth's axis is constant, the direction in which it points slowly changes. The changing direction of Earth's axis is called **precession**. One effect of precession is the changing position of the North Celestial Pole. If you could extend the tip of Earth's axis north to the stars, it would point to a location astronomers call the North Celestial Pole. The North Celestial Pole is currently very close to the star Polaris. Therefore, astronomers call Polaris the pole star. About 12 000 years from now, however, due to precession, the North Celestial Pole will be close to Vega, a star in the constellation Lyra. In 26 000 years, the North Celestial Pole will once again be Polaris (Figure 5).

LEARNING TIP

You have learned that Earth behaves much like a spinning top. As you study Figure 4, consider that one complete "wobble" of the spinning top (in which the top moves in a backward circle) takes Earth 26 000 years to do!

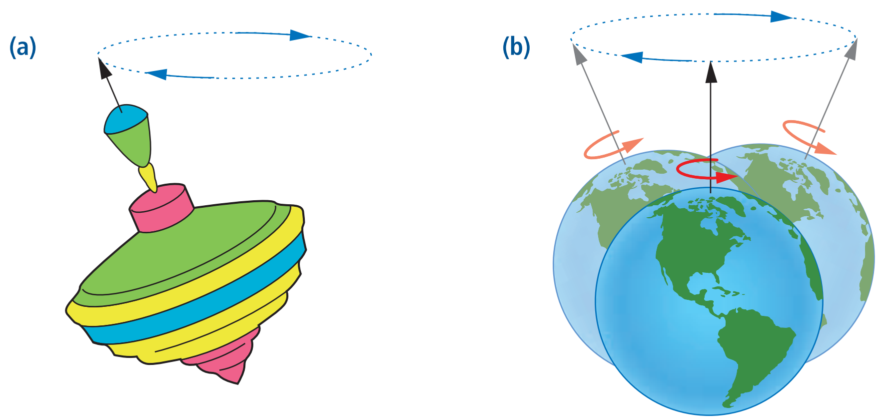


Figure 4 Like a spinning top (a), the tip of Earth's axis slowly traces a circle in the sky (b).

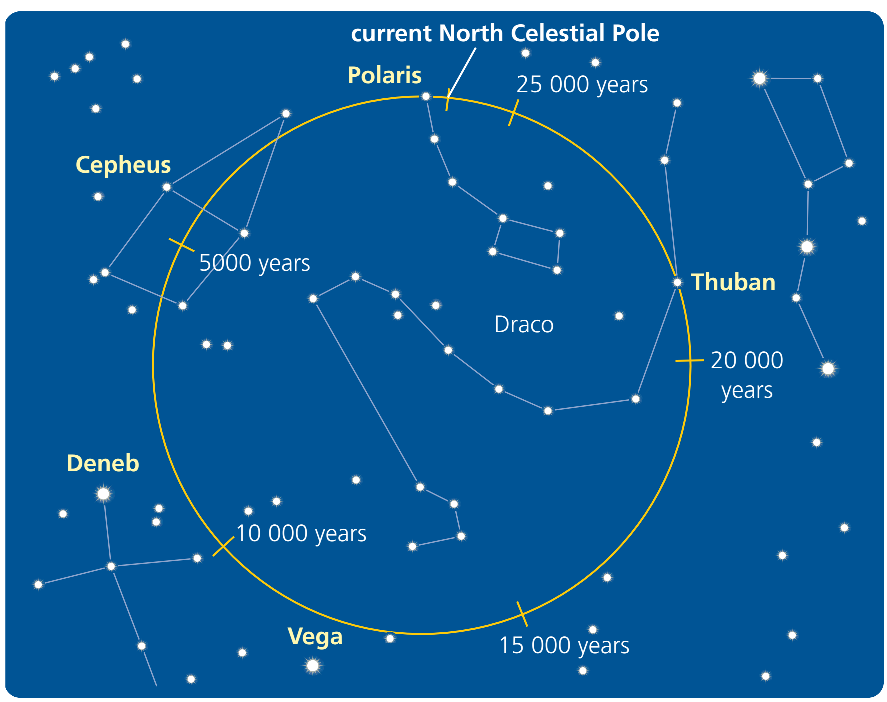


Figure 5 If you could transfer the circle made by Earth's axis over time onto the sky, you would see how the position of the North Celestial Pole changes over 26 000 years. Can you estimate when the star Thuban will be the pole star?

Effect of Earth's Revolution

The second important motion of Earth is its revolution. Earth takes approximately 365¼ days to complete one revolution around the Sun. In other words, Earth rotates 365¼ times as it revolves around the Sun once. Earth's orbit around the Sun is not quite a circle; it is an ellipse. An ellipse resembles a flattened circle. The Sun is not in the centre of the ellipse; it is located at one of two focal points. There is no object at the second focal point. Consequently, there is a time when Earth is closer to the Sun and a time when Earth is farther from the Sun (Figure 6). The **perihelion**, the point at which Earth is closest to the Sun, occurs around January 3. The **aphelion**, when Earth is farthest from the Sun, occurs around July 4. Note the perihelion actually occurs during the northern hemisphere's winter. Therefore, we know that the cause for the seasons has nothing to do with Earth's distance from the Sun. Earth is closest to the Sun during the summer in the southern hemisphere, which correlates with higher southern summer temperatures and more deserts. It also correlates with a colder pole—Antarctica is colder than the Arctic.

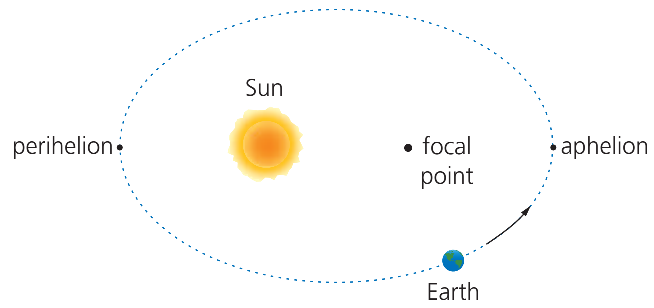


Figure 6 At perihelion, Earth is 1.47×10^8 km from the Sun. At aphelion, Earth is 1.52×10^8 km from the Sun. (The ellipse is exaggerated.)

The Seasons

The cause for the seasons on Earth is often mistakenly attributed to Earth's elliptical orbit. In fact, the seasons are due to the tilt of Earth's axis (Figure 7). In the northern hemisphere, summer is warmer because the northern hemisphere is tilted toward the Sun in the summer. The Sun is higher in the sky, and there are more hours of sunlight. In winter, the northern hemisphere is tilted away from the Sun. The Sun is lower in the sky, and there are fewer hours of sunlight.

LEARNING TIP
Check your understanding. Use Figure 7 to explain to a partner why we have seasons on Earth.

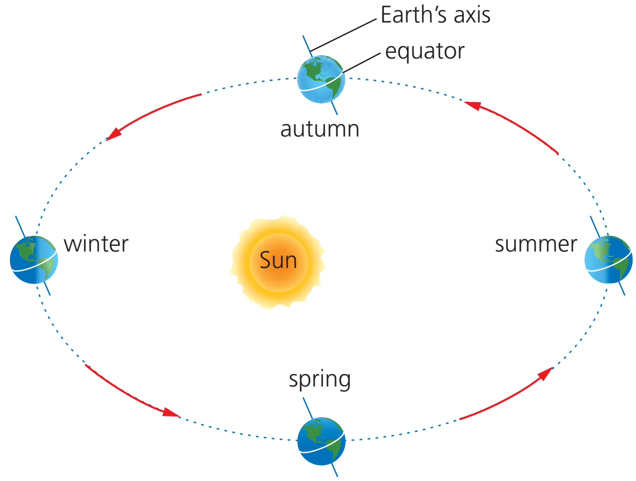


Figure 7 When places on Earth are tilted toward the Sun, those places experience summer because the Sun's rays approach from a more direct angle.

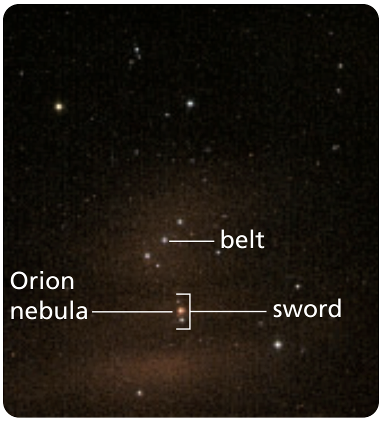


Figure 8 To people in ancient times, this constellation looked like a hunter, whom they called Orion. His belt, sword, and the great nebula in the sword's sheath are indicated.

Constellations

To the Aboriginal peoples and ancient astronomers, certain patterns of stars suggested mythical figures and animals. Today, astronomers recognize 88 different patterns, which are called **constellations**. One of the most impressive of these patterns is Orion, the hunter (Figure 8). There are other patterns in the sky, too, that are not official constellations. These patterns are called asterisms. The Big Dipper, only a part of the constellation Ursa Major, is an asterism. As Earth rotates, the patterns of stars appear to move across the night sky. As Earth revolves around the Sun, we see different constellations.

12C *Investigation*

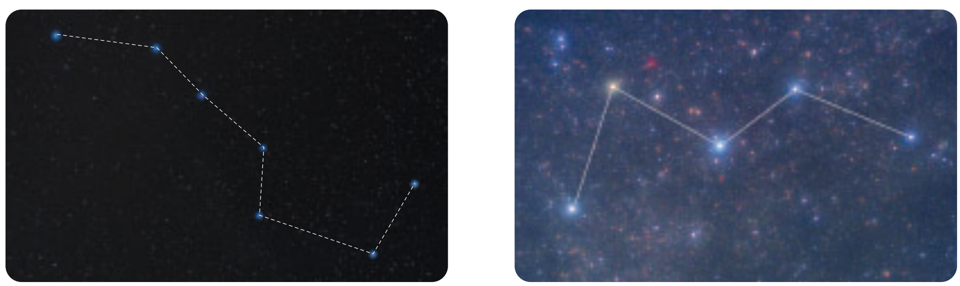
12C *Investigation*

Using a Star Map

To perform this investigation, turn to page 406.

In this investigation, you will learn how to use a star map.

Assigning people and animals to represent star patterns is the work of our imagination and the completion of shapes by our brain. Indigenous and ancient peoples have been doing this for as long as stories have been remembered or recorded. The Big Dipper is clearly a cup with a long handle (Figure 9(a)). However, finding shapes in other groups of stars often takes a great deal of imagination. Cassiopeia looks more like a W or an M than a queen sitting on her throne (Figure 9(b)). The constellation names that you are probably most familiar with are based on Greek and Arabic mythology. The major stars all have Arabic names.



(a) (b)

Figure 9 (a) The Big Dipper (b) Cassiopeia

Because the stars are so far away, their motion relative to each other is very slight, so we see the constellations unchanged from year to year. However, the stars in a constellation are all moving through space. The pattern of stars in a constellation changes over a very long time. The change in the Big Dipper over 200 000 years is shown in Figure 10.

Did You KNOW?

The Big Dipper

The Big Dipper is well known across cultures. The Anishinaabe people (also known as the Chippewa or Ojibway people) observed the sky and recorded changes and new events. The changing sky is related to story telling, ceremonies, and life activities. For example, the Anishinaabe watched the Big Dipper as it moved across the sky. When it was high overhead in the early evening, they knew that spring was close.

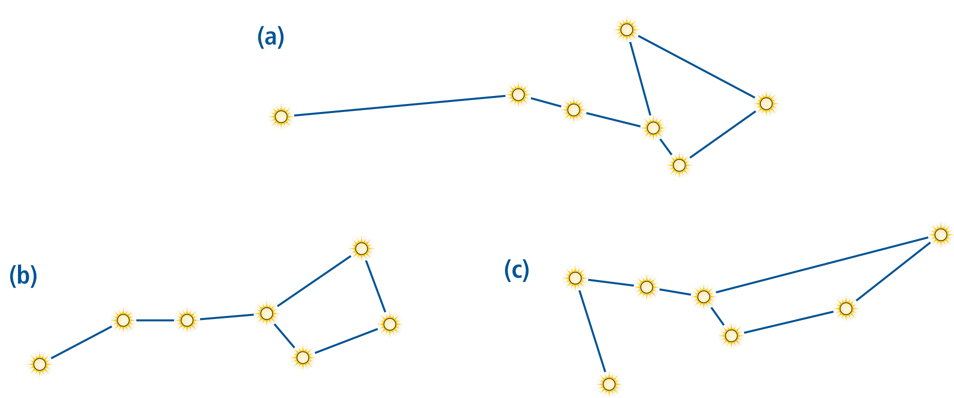


Figure 10 This sequence of diagrams shows the movements of the main stars in the Big Dipper: (a) The pattern 100 000 years ago (b) How the Big Dipper looks today (c) How the Big Dipper will look 100 000 years from now

The Celestial Sphere

In the Middle Ages (450–1450 CE), people still believed that the sky was solid, with the stars fixed to an invisible crystal sphere. They believed that the planets and the Sun were fixed in separate orbits closer to Earth, while the stars were held in positions farther from Earth. Since the planets were closer, they appeared to travel farther than the stars in the background. If such a sphere existed, it would rotate around Earth once a day, and it would move all the bodies in the sky with it. For convenience, this is called the **celestial sphere**. We now understand that it is Earth that rotates, not the sky.

If Earth's equator were extended out to the celestial sphere, it would create a **celestial equator** and divide the night sky into two hemispheres (Figure 11). Within these hemispheres, astronomers use a plotting system similar to latitude and longitude to mark the positions of stars and bodies in the sky.

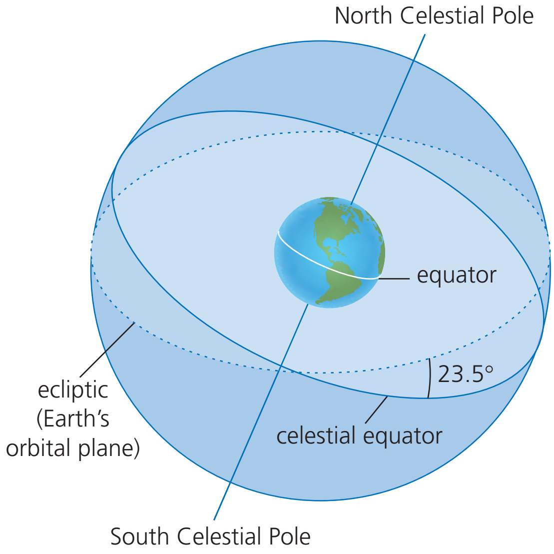


Figure 11 The celestial sphere is an imaginary crystal sphere around Earth in which all the objects in the sky are embedded. The celestial poles and the celestial equator are projected onto the sphere from the poles and equator on Earth.

The path the Sun takes through the sky is marked against the 12 constellations of the zodiac. This path is called the **plane of the ecliptic**. Because Earth is tilted 23.5° on its axis, the angle between the ecliptic and the celestial equator is also 23.5°. The two dates when the Sun, on the ecliptic, crosses the celestial equator are around March 21 and September 22, the spring (vernal) and fall (autumnal) **equinoxes**. On these days, the number of hours that the Sun is above the horizon and below the horizon is equal. The Sun follows this apparent path because of Earth's rotation and revolution around the Sun.

The **solstices** occur when the Sun reaches its highest and lowest positions in the sky, when Earth is tilted toward or away from the Sun (due to the 23.5° axis tilt). The summer solstice occurs when the Sun reaches its highest position in the sky, usually on June 21. The summer solstice marks the first day of summer, and we experience the longest photoperiod of the year. Conversely, the winter solstice occurs when the Sun reaches its lowest position in the sky, and we experience the shortest photoperiod of the year. Because of Earth's tilt, the Sun does not rise very high in the sky. Therefore, it spends less time above the horizon, and we have fewer hours of daylight. The winter solstice usually occurs on December 21 and marks the beginning of winter.

Circumpolar Constellations

In the northern hemisphere, especially in Canada, some constellations never disappear below the horizon as Earth rotates. A constellation that is always above the horizon is said to be **circumpolar** (Figure 12). The three main circumpolar constellations are Ursa Minor (which contains the Little Dipper, with Polaris at the end of its long handle), Ursa Major (which contains the Big Dipper), and Cassiopeia.

If you would like to learn more about astronomy and the night sky, go to **www.science.nelson.com**

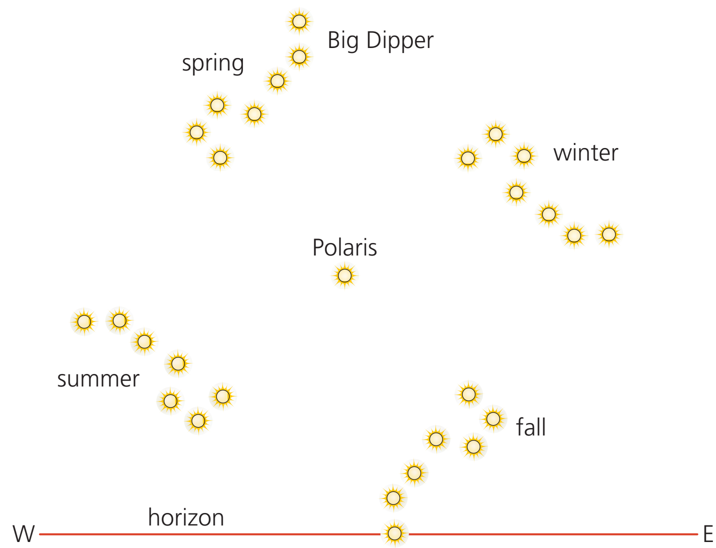


Figure 12 The Big Dipper and Polaris are always above our horizon.

TRY THIS: You Are Earth

Skills Focus: conducting, communicating

Materials: diagrams of the Big Dipper, the Little Dipper, Cassiopeia, Aquila, Pegasus, Orion, and Leo

In this activity, you will turn your classroom into a planetarium.

1. Place diagrams of the Big Dipper, the Little Dipper, and Cassiopeia on the ceiling, in their correct orientation.
2. Place these four constellations on the walls:
   - Aquila (summer) on the east wall
   - Pegasus (autumn) on the north wall
   - Orion (winter) on the west wall
   - Leo (spring) on the south wall
3. Pick one classmate to be the Sun in the middle of the room. Pretend that you are Earth, and stand east of the Sun. When your back is to the Sun, it is night on Earth.
4. Slowly spin around counterclockwise. When you are facing the Sun, it is daylight.
5. Repeat this activity for positions north, west, and south of the Sun to represent the positions of Earth during different seasons.

A. Which constellation is visible in which season?

B. Which constellation could you not see? Why?

12.1 CHECK YOUR Understanding

1. Describe how the rotation of Earth is responsible for the movement of the stars.
2. Describe Earth's rotation in terms of its axis and length of time to rotate.
3. Describe how the movement of Earth is responsible for day and night.
4. If you were to look down on Earth from above the North Pole, in which direction would Earth appear to rotate?
5. What is the photoperiod?
6. How does the photoperiod differ between the two solstices?
7. What is unique about the photoperiod at the two equinoxes?
8. On any given day, why does the photoperiod vary throughout the world?
9. What is precession?
10. Using Figure 5 on page 370, name the star that might be considered the Pole Star 5000 years from now.
11. Describe Earth's revolution around the Sun in terms of the shape of the orbit and the length of time to complete one revolution.
12. Describe the path of the Sun through the sky using terms you have learned in this section.
13. What is the astronomical significance of the zodiac constellations?
14. The cause of the seasons on Earth is often mistakenly attributed to the elliptical orbit of Earth around the Sun. What is the actual cause of the seasons?
15. What is the astronomical significance of January 3 and July 4?
16. Copy Figure 13 into your notebook. On your drawing, indicate
    (a) the direction of Earth's rotation and revolution
    (b) the four seasons
    (c) Earth's tilt

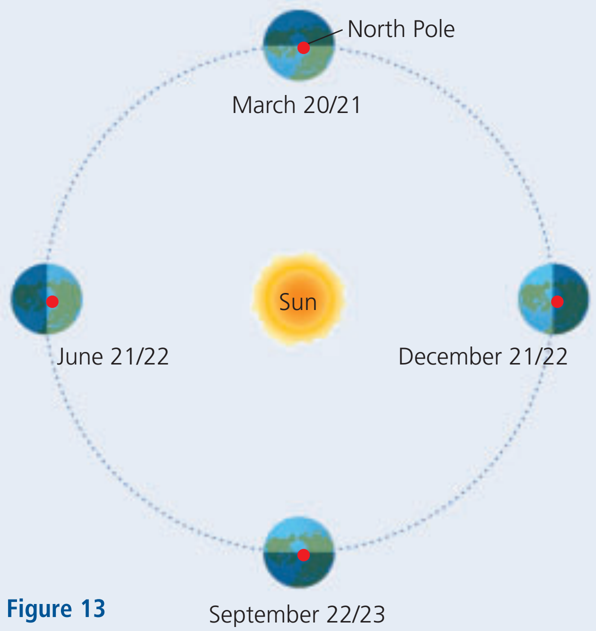


Figure 13

17. Explain why we see different constellations as Earth revolves around the Sun.
18. If you were to visit another planet, you might be able to see the same stars but would you see the same constellations? Explain your answer.
19. Describe the celestial sphere in your own words.
20. Why do the planets appear to move through the constellations instead of with the constellations as Earth rotates?
21. Copy Table 1 into your notebook. Place checkmarks in the boxes to relate the phenomena to one of Earth's two distinct motions.

Table 1

Phenomenon	Perihelion	Aphelion	Seasons	Apparent movement of stars	Solstices	Equinoxes	Photoperiod
Rotation							
Revolution							

12.2 The Earth–Moon System

Did You KNOW?

The Moon Illusion

Have you ever wondered why the Moon looks so much bigger when it's close to the horizon? This is actually an optical illusion. When the full moon is close to the horizon, as it is when it is rising, it is often near the tree line or buildings. Since the trees or buildings are near you, the full moon appears to be just as close. As a result, your brain makes sense of the image by perceiving the Moon to be larger than normal.

The Moon is Earth's closest neighbour. It is highly influential in our lives because it causes the oceans' tides. The Moon is also responsible for eclipses.

The Phases of the Moon

The Moon revolves around Earth every 27.3 days. The Moon also takes 27.3 days to rotate. Therefore, the same side of the Moon is always facing us.

Like all bodies in the solar system, one side of the Moon is always illuminated by the Sun. However, this so-called bright side does not always face Earth. Therefore, we see different amounts of the lit side at different times. The extent to which the Moon's illuminated surface faces us results in the various phases of the Moon. We call the Moon's phases the **lunar cycle**, which can be divided into eight distinct stages. Since the Moon is spherical, the illuminated portion we see is curved.

The lunar cycle begins with the new moon phase, when the Moon is not visible from Earth (except during a solar eclipse; see below) (Figure 1). We do not see the new moon because the side that is illuminated by the Sun is not facing us. After this phase the illumination waxes, or increases in size, during the first half of the lunar cycle so that more and more of the lit side of the Moon is visible on Earth. The waxing crescent Moon appears like an arched sliver of light.

The first quarter phase of the Moon appears to us as a half moon, since the other half of the lit portion is facing away from us. Following this phase, the Moon continues into its waxing gibbous, or bulging phase, in which the Moon appears to be more than half but less than fully illuminated by direct sunlight.

A full moon appears as a completely lit circle in the sky, when the entire side of the Moon that is lit faces us. After the full moon phase, the lunar cycle wanes, and the amount of illumination that we see decreases. The lunar cycle progresses through the waning gibbous moon to the last quarter phase to the waning crescent moon until the new moon phase is reached once again (Figure 2). A simple way to remember the order of the phases is to think of

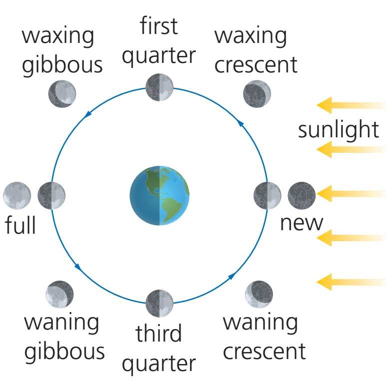


Figure 1 The phases of the Moon

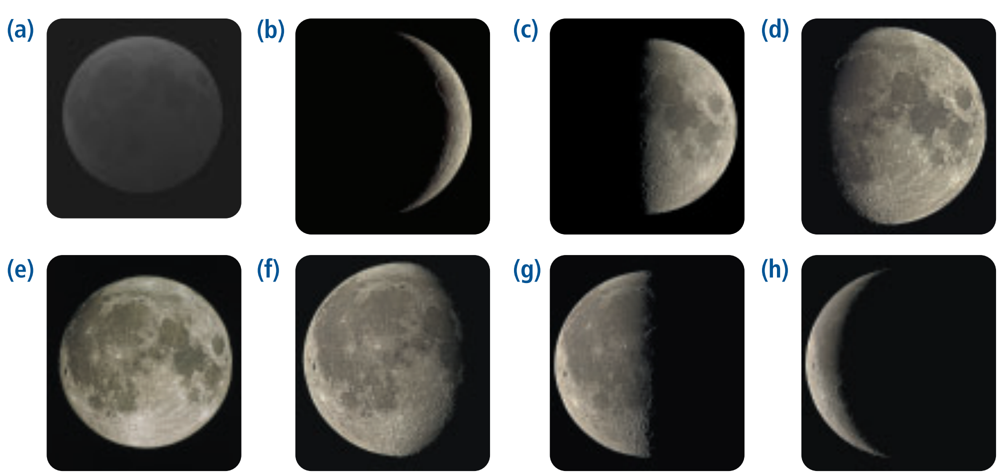


Figure 2
(a) New moon (darkened image to represent the new moon, which we cannot see)
(b) Waxing crescent
(c) First quarter
(d) Waxing gibbous
(e) Full moon
(f) Waning gibbous
(g) Third quarter
(h) Waning crescent

the lit side increasing from right to left across the surface of the Moon during the waxing phases and the dark side increasing from right to left during the waning phases.

Eclipses

Although the Sun is approximately 400 times larger than the Moon, it is also approximately 400 times farther away from Earth than the Moon. For this reason, the Moon and the Sun appear to be the same size in the sky. It is the same apparent size of the Moon and the Sun plus the alignment of Earth, the Sun, and the Moon which sometimes result in one of the most breathtaking phenomena visible from our planet, a solar eclipse. A **solar eclipse** occurs during a new moon, when the Moon is directly between Earth and the Sun (Figure 3(a)). Because the Moon and the Sun appear to be the same size, the Moon completely covers the Sun during a total solar eclipse, leaving only the outer atmosphere of the Sun, called the corona, visible (Figure 3(b)). Total eclipses can last from a few seconds to just over 7 min. They occur approximately once every two years somewhere on Earth. During a total eclipse, when the Sun is covered by the Moon, astronomers can safely study bursts of gases from the Sun, called solar flares, without damaging their eyes. Partial and annular solar eclipses occur when the Moon does not cover the entire disk of the Sun (Figure 4(a) and (b)).

(a) (b)

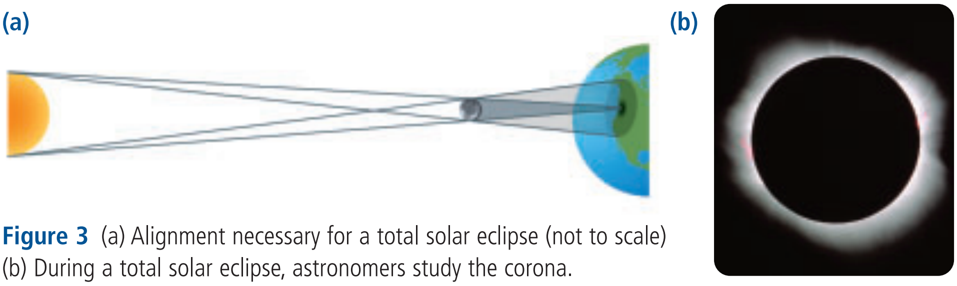


Figure 3 (a) Alignment necessary for a total solar eclipse (not to scale) (b) During a total solar eclipse, astronomers study the corona.

(a) (b)

Figure 4 (a) A partial solar eclipse (b) During an annular eclipse, the Moon is farther from Earth in its orbit, so it appears to be smaller than the Sun. As a result, we see a ring, or annulus, of the Sun.
Note: Never look directly at the Sun because you will permanently damage your vision.

A **lunar eclipse** results when Earth is positioned between the Sun and the Moon such that Earth casts its shadow on the surface of the Moon (Figure 5(a)). A total lunar eclipse results when the entire Moon passes through Earth's shadow. If only part of the Moon passes through Earth's shadow, there is a partial lunar eclipse. During a total lunar eclipse, you might expect the Moon to be barely visible since it is hidden in Earth's shadow. Sometimes it is barely visible; however, sometimes the Moon takes on a bright red glow (Figure 5(b)).

(a) (b)

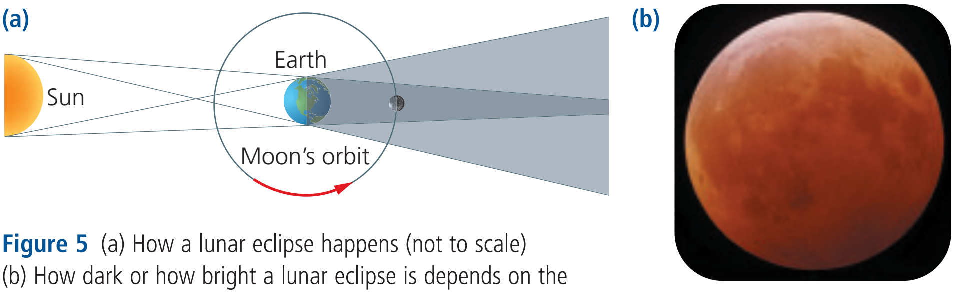


Figure 5 (a) How a lunar eclipse happens (not to scale) (b) How dark or how bright a lunar eclipse is depends on the amount of particles in Earth's atmosphere at the time of the eclipse.

Did You KNOW?

Egg-Shaped Moon

The Moon is slightly egg-shaped. We only see a circular disk at full moon because the Moon's tip, which is the small end of the "egg," always faces us.

Sunlight is bent by Earth's atmosphere onto the Moon. The light is red for the same reason that the sunset is red: the shorter (bluer) wavelengths are scattered away by Earth's atmosphere, leaving longer (redder) wavelength light to shine on the Moon.

Why do we not have a solar eclipse every new moon or a lunar eclipse every full moon? The reason for this lies in the nature of the Moon's orbit around Earth. Recall that Earth's path lies on an imaginary flat surface called the plane of the ecliptic. The Moon, too, has its own orbital plane as it revolves around Earth. The Moon's orbital plane, however, is not in the same plane as Earth's ecliptic plane. In fact, the Moon's orbital plane is tilted 5° to Earth's ecliptic plane (Figure 6). There are two points, or **nodes**, at which the Moon's orbital plane intersects Earth's orbital plane. Consequently, for a solar eclipse to occur, the new moon must be positioned between Earth and the Sun, at a node. Similarly, for a lunar eclipse to occur, the full moon must be aligned with Earth and the Sun, at a node. Usually, the Moon's position is above or below the disk of the Sun or Earth's shadow. Therefore, these phenomena do not occur every lunar cycle, but they do occur every six months.

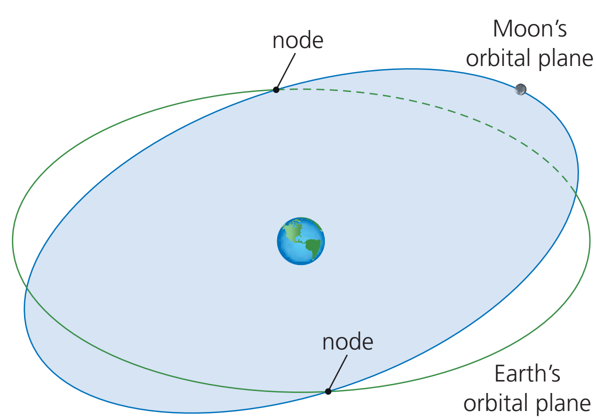


Figure 6 The nodes are the two points at which the orbital planes of Earth and the Moon intersect. If the Moon passes through a node during a new moon, a solar eclipse will result. If the Moon passes through a node during a full moon, then a lunar eclipse will result.

Tides

Tides are the alternate rising and falling of the surface of large bodies of water (Figure 7). Tides are caused by the interaction between Earth, the Moon, and, to a lesser extent, the Sun. The gravitational pull of the Moon on Earth results in the oceans bulging in the direction of the Moon.

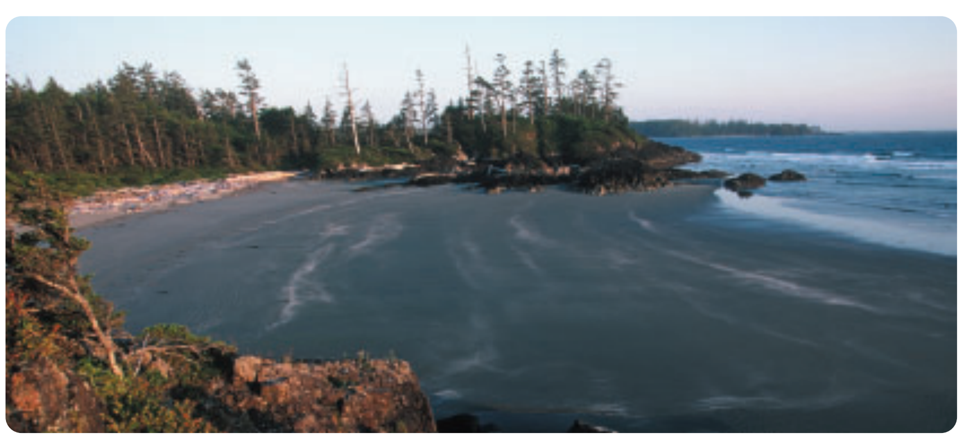


Figure 7 Low tide on Vargas Island, Pacific Rim National Park, British Columbia. Note the difference between the water level at the right and the high tide mark near the forest. What evidence indicates where the high water level is?

In Figure 8, notice that the ocean also bulges on the opposite side, since Earth is also being pulled toward the Moon and away from the water on the far side. There are two tide cycles each day: high tide and low tide.

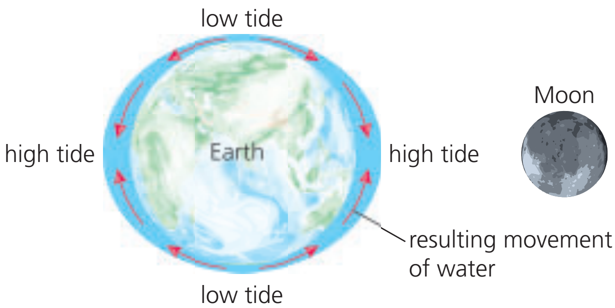


Figure 8 The Moon is primarily responsible for the tides. (Water levels are exaggerated.)

During the new and full moon phases, when the Sun, Moon, and Earth are in a line, the gravitational pull on Earth is strong, causing very high tides called spring tides. The weaker neap tides occur when the Sun and the Moon are perpendicular to each other with respect to Earth, as they are during the first and third quarter moon phases. Therefore, the gravitational pull of the Sun somewhat counteracts the pull of the Moon on the oceans (Figure 9).

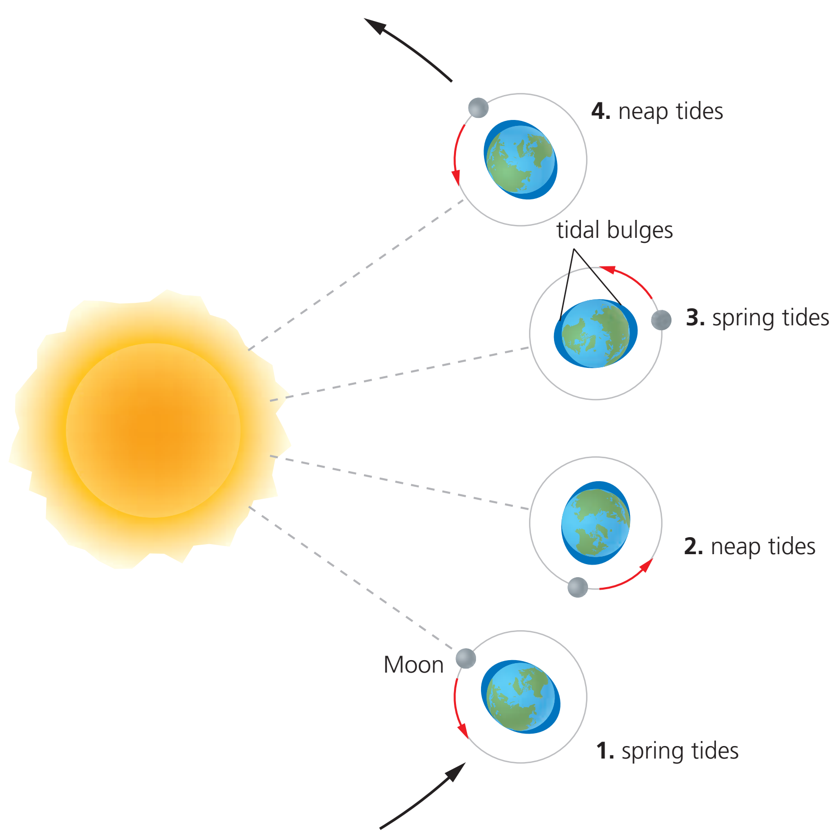


Figure 9 Spring tides result when the Sun, Moon, and Earth form a straight line. Note that the word "spring" has nothing to do with the season. Neap tides result when the Sun and the Moon are perpendicular to each other with respect to Earth.

LEARNING TIP

As you study Figure 9, look at each part of the diagram to see how it is organized. Examine the use of labels and arrows. Try to visualize (create a mental image of) the tides.

12.2 CHECK YOUR Understanding

1. In your own words, describe the lunar cycle.
2. Why is only one side of the Moon visible from the Earth at all times?
3. Without referring to the text, reorder the phases of the Moon in Figure 10, starting with the new moon. Write the letters in the appropriate sequence. Write the names of the phases next to the letters.

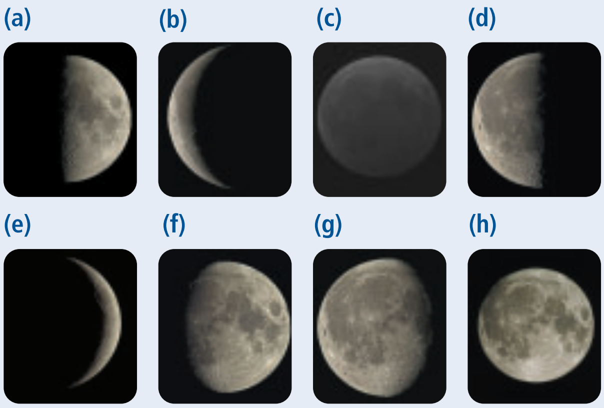


Figure 10

4. Are the phases of the Moon caused by Earth's shadow cast on the Moon? Explain.
5. With the help of a diagram, describe the alignment of Earth, the Sun, and the Moon during a solar eclipse.
6. What part of the Sun is visible during a total solar eclipse?
7. Why are solar eclipses important to astronomers?
8. With the help of a diagram, describe the alignment of Earth, the Sun, and the Moon during a lunar eclipse.
9. In your own words, explain why we do not have a solar eclipse every new moon.
10. Explain the difference between a partial solar eclipse and an annular solar eclipse.
11. (a) What are nodes?
    (b) How often do nodes occur in the lunar cycle?
    (c) How are nodes related to solar eclipses?
    (d) How are nodes related to lunar eclipses?
12. (a) What are tides, and how are they caused?
    (b) What role does the Sun play in the formation of tides?
13. (a) What are spring tides, and why do they occur?
    (b) What are neap tides, and why do they occur?
    (c) Are spring tides more common during the spring? Explain.
14. For each phenomenon, sketch the necessary alignment of Earth, the Sun, and the Moon
    (a) total solar eclipse
    (b) total lunar eclipse
    (c) spring tides
    (d) neap tides
15. Identify each astronomical phenomenon in Figure 11.

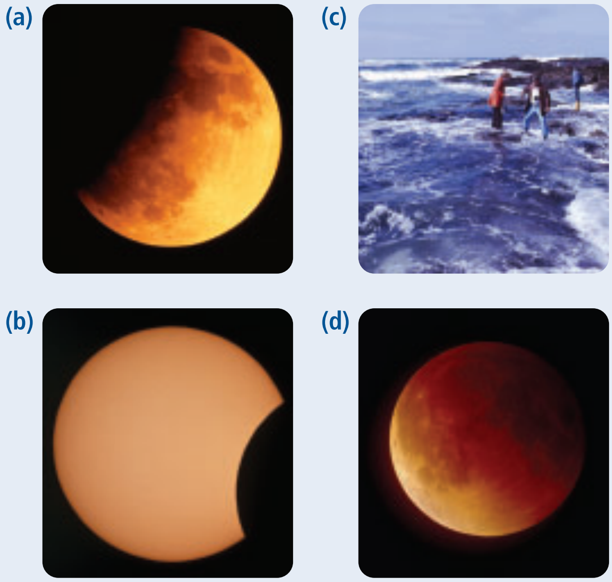


Figure 11

16. If you could stand on the Moon and look at Earth, Earth would appear to revolve around the Moon. Knowing this, explain whether Earth would appear to have phases to an observer on the Moon.

12.3 Our Solar System

If we consider Earth to be our celestial home, then the solar system is our celestial neighbourhood. Just like your neighbourhood, our solar system is composed of a variety of objects and places. Do you remember the first time you went out by yourself to explore your neighbourhood? Over the past few decades, scientists have begun to explore our celestial neighbourhood in more detail. Using modern technologies such as telescopes, scientists have learned much about the objects in our solar system. Many questions remain. What makes up our solar system? Are there more objects in our solar system than we knew about a couple of decades ago? How did the solar system form?

LEARNING TIP
Pause and think after reading each paragraph in this section.

Formation of the Solar System

In 1983, scientists from the National Aeronautics and Space Administration (NASA) launched the Infrared Astronomical Satellite (IRAS) into orbit around Earth (Figure 1). As a result, they made exciting discoveries that led to clues about the formation of our solar system. IRAS' instruments detected a large cloud of tiny particles, mostly dust and gases, orbiting a bright star. For the first time, scientists had direct evidence that solid matter exists around another star, like our Sun. Scientists thought that the clouds of particles could be the early stages in the development of planets. Four months later, IRAS discovered another star with solid material in orbit. From these observations emerged the theory that planets form while a star is forming.

Figure 1 The IRAS satellite

The current leading theory is that our solar system began as a spread-out collection of dust and gases, called a **nebula**. This nebula consisted mainly of hydrogen and helium gases and, to a lesser extent, particles of solid matter, such as iron, rock, and ice. These particles likely came from the massive explosion of an older star called a supernova and moved closer together due to gravity. (A supernova is a star in its final phases of life, when it explodes to many times its original size.) As the nebula collapsed, its internal pressure and temperature increased. As more particles were attracted to the nebula, the nebula continued to collapse under its own gravity. When the temperature and pressure inside this collapsing dust and gas cloud become great enough, complex reactions began. The reactions caused the release of large amounts of energy, creating massive explosions. At the core of the nebula, our Sun began to develop.

In its early stages, the nebula began to rotate due to the condensing gaseous material. As the nebula collapsed under the force of gravity, its speed of rotation increased. Eventually, its speed of rotation became too great to hold all the matter together at the centre, so much of the matter spread out from the centre like a pancake. At the centre of the pancake, a bulge of matter remained and eventually formed the Sun. Finally, while the Sun was forming, smaller clumps of cooler matter, called **protoplanets**, began to appear in the outer regions of the nebula. Forced together by gravity, the protoplanets condensed to form the planets of our solar system (Figure 2). As the protoplanets formed into defined orbital paths around the Sun, they swept up much of the remaining debris, becoming bigger in the process. This theory, called the rotating nebula theory, best explains the formation of the **outer planets**, also called the **gas giants**—Jupiter, Saturn, Uranus, and Neptune—because most of the nebula was made of gases (hydrogen and helium). The main composition of the gas giants has been confirmed by unpiloted spacecraft to consist of hydrogen and helium.

Earth plus the planets that are similar to Earth—Mercury, Venus, and Mars—are classified as the **inner**, or **terrestrial**, **planets**. Does the rotating nebula theory also support the formation of the terrestrial planets? Scientists believe that the terrestrial planets formed when our young Sun flared up in a sudden burst of energy. This flare-up blasted most of the hydrogen and helium gases into the outer regions of the solar system, leaving denser chunks of solid matter behind. It is from the chunks of solid matter that the terrestrial planets are thought to have formed. These chunks collided with each other and eventually grew in size over millions of years.

According to the rotating nebula theory, if the planets were formed from a nebula, they should all revolve around the Sun (formerly the centre of the nebula) in the same direction and, roughly, in the same orbital plane (in line with the pancake's surface). This is true. In fact, most of the planets rotate around their axes in the same direction, and the axis tilt for most planets is approximately perpendicular (90°) to their orbital planes (Figure 3).

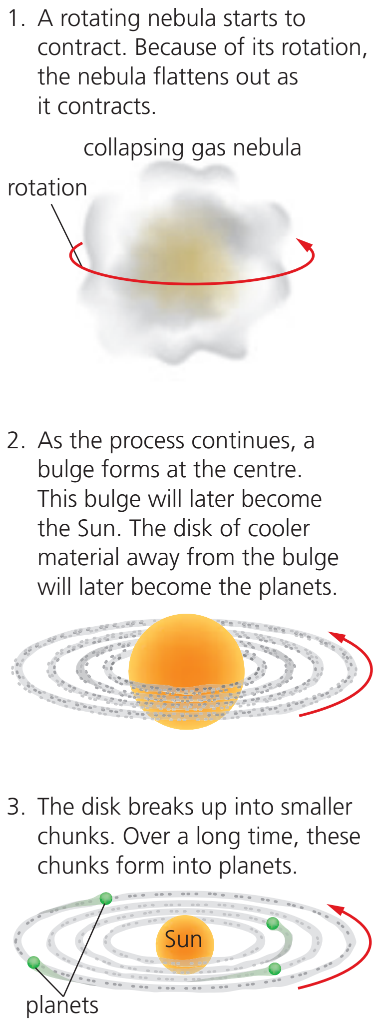


Figure 2 Possible stages in the formation of the solar system

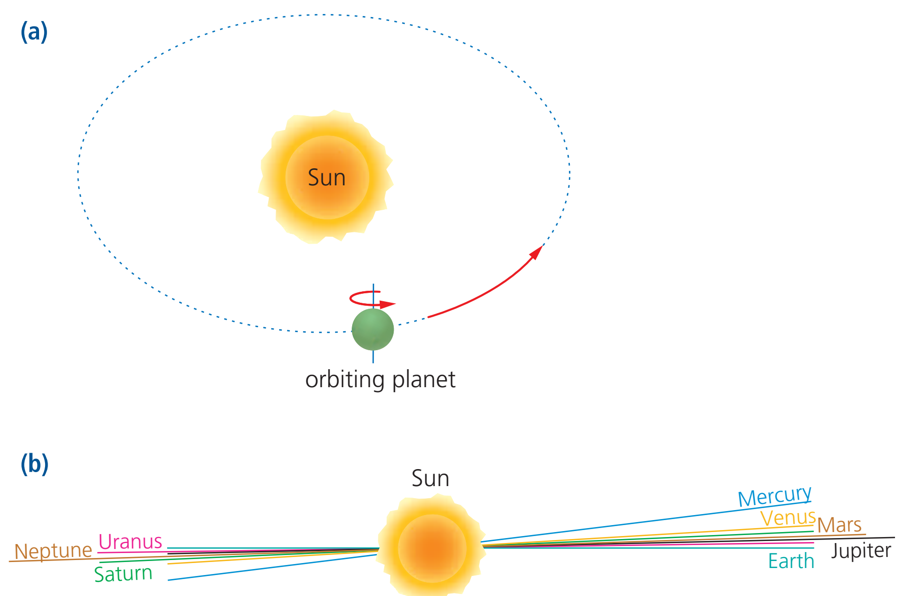


Figure 3 (a) The direction of revolution and rotation are the same for most planets. In addition, the rotational axis and the orbital plane are approximately perpendicular for most planets, providing support for the rotating nebula theory. (b) The planets orbit the Sun in approximately the same orbital plane.

LEARNING TIP

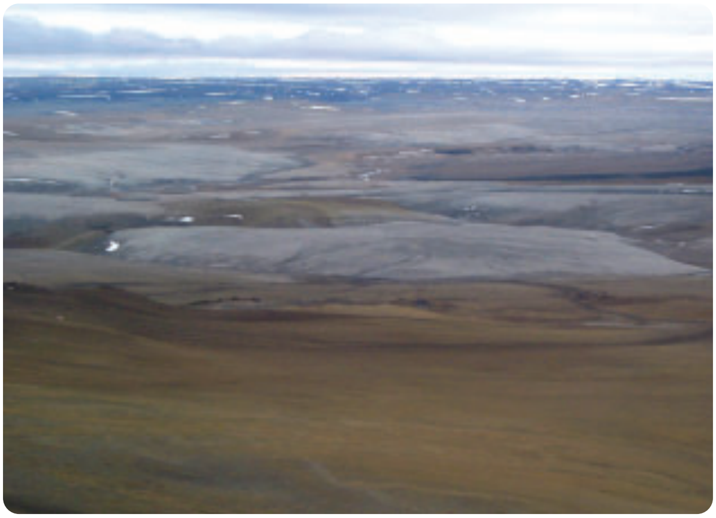
Check your understanding. Discuss with a partner how the nebula theory explains the formation of the outer and inner planets.

Minor Bodies

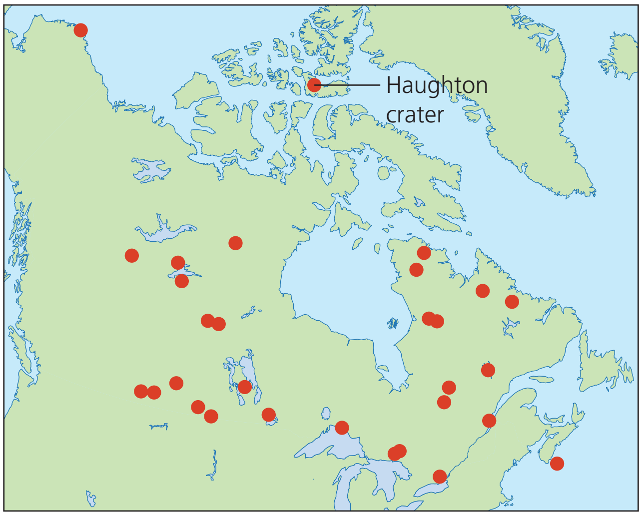
Over time, most of the matter in the solar system was pulled into planets. Today, the remaining non-planetary matter is referred to as **minor bodies**. The minor bodies include asteroids, meteoroids (meteors and meteorites), and comets. **Asteroids** are rocky and metallic objects that revolve around the Sun, but are too small to be called planets. The word "asteroid" comes from a Greek word meaning starlike. Most of the asteroids settled in the asteroid belt, which is between Mars and Jupiter. Many probes have been sent to survey the surface of asteroids.

Meteoroids are lumps of trapped rock or metal that encounter Earth as they travel through space. **Meteors** are smaller chunks of solid matter that burn up in our atmosphere due to friction, creating a bright streak of light. Meteors are often called shooting stars. **Meteorites** are larger meteors that actually reach Earth's surface. The impact craters that meteorites leave on Earth's surface can vary in size (Figure 4). This process has been happening since Earth's formation. The best-preserved example is the Barringer Crater near Winslow, Arizona, caused by a massive meteorite. Evidence gathered from rocks in the crater suggests that it was formed approximately 20 000 years ago. The crater is 1.2 km in diameter and 120 m deep. There are several impact craters in Canada (Figure 5).

Figure 4 Why do you think most craters are this shape?



(a)

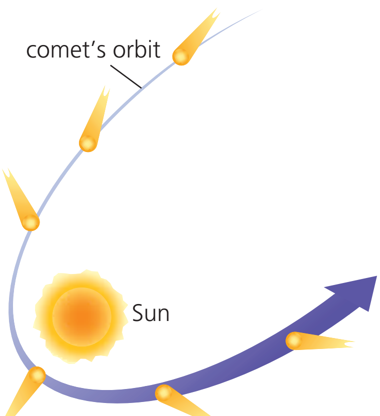


(b)

Figure 5 (a) The Haughton impact crater is on Devon Island, Nunavut. It is 24 km in diameter and approximately 24 million years old. (b) Meteor craters in Canada

Comets are chunks of frozen matter that orbit the Sun in very long elliptical paths. They come from the outer reaches of the solar system, beyond Neptune. To see a comet is to observe one of the most exciting astronomical phenomena (Figure 6(a) on the next page). Some comets are bright enough to be visible in daylight. During most of its orbit, a comet is far from the Sun. When it approaches the Sun, however, the comet is warmed by the Sun. This warming causes the frozen materials to become gases. The gases are pushed outward and away from the Sun by the solar wind (charged particles from the Sun) and radiation pressure from the Sun (Figure 6(b)). The solar wind and radiation pressure cause the formation of a bright, glowing tail that may extend over 100 million km. Many comets have regular periods (revolutions) around the Sun, and this allows us to predict when they will be close enough to view. A regular visitor to our solar system is Comet Halley. Comet Halley has a period of 76 years and was last seen in 1986. Many comets do not have periodic orbits, however, and visit our solar system only once.

(a)



(b)

Figure 6 (a) Comet Hale Bopp, which visited the solar system in 1995 (b) Notice the direction of the comet's tail with respect to the Sun. What causes the tail to point this direction?

Formation of our Moon

Earth is thought to have formed 4.6 billion years ago, at a time when our newly formed solar system was extremely chaotic and full of debris. Smaller objects were attracted to larger objects by the gravitational pull of greater masses. Many of the larger bodies in space consist of the combined materials of more than one object.

Although there are several theories to explain how Earth's Moon was formed, the Big Splash theory is the currently accepted theory. The **Big Splash theory** states that, approximately 4.5 billion years ago, a large object the size of Mars collided with Earth. The force of this collision created extremely high temperatures and pressures, which caused the denser materials (such as iron) of the impact object to become part of Earth's core. The less dense materials were blasted into space. Even the low-density portions of Earth's crust would have been blasted into space, adding to the material in orbit around Earth. Most of the rocky leftovers produced by the collision were somewhat concentrated in the same region above the atmosphere. These materials began to gravitate and condense into each other through more heat and pressure. The result is a rocky object—our Moon—which is less dense than Earth and formed by the remnants of the explosive collision (Figure 7).

The evidence to support the Big Splash theory came from rock and soil samples taken during the *Apollo* landings on the Moon in the 1960s and the 1970s. Scientists found that the Moon rocks did not contain any of the less dense elements. This suggests that the less dense elements may have been boiled off, such as would occur during extreme heating.

The *Apollo* astronauts also placed seismometers on the Moon. Seismometers measure movements of the ground and can reveal information about composition. According to the seismometers, the Moon's nickel core is smaller than predicted. The smaller core supports the Big Splash theory. Earth, like most space objects, has a core of dense matter surrounded by outer material that is less dense. The Moon would have formed mostly from Earth's mantle and the outer, less dense material from the object that hit Earth.

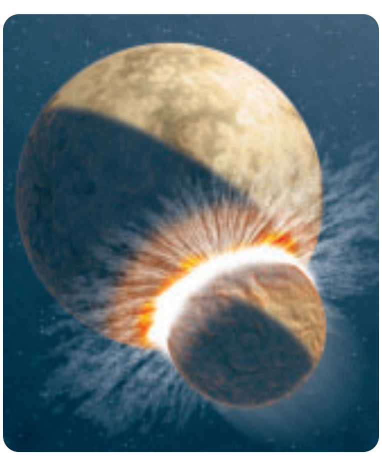


Figure 7 The current theory is that the Moon formed after an object collided with Earth (artist's rendition).

12.3

CHECK YOUR Understanding

1. (a) What important discovery did IRAS make?
   (b) How did this discovery provide astronomers with clues about the formation of our solar system?
2. What is a nebula?
3. What caused the nebula that formed our solar system to rotate?
4. (a) What were the main elements that made up the nebula from which our solar system was formed?
   (b) Where did these materials come from?
5. (a) What theory describes the formation of our solar system?
   (b) Using Figure 8, describe the formation of the solar system.
   (c) Why does this theory best explain the formation of the gas giants?
   (d) According to this theory, how were the terrestrial planets formed?

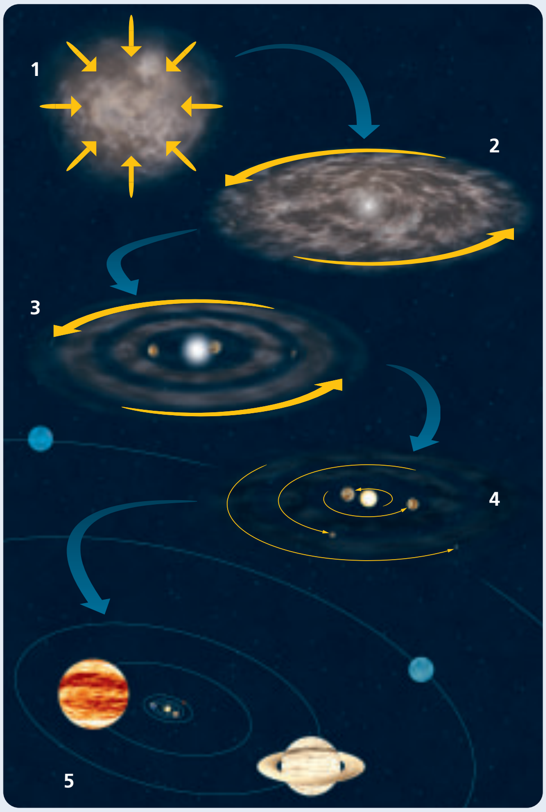


Figure 8

6. What are asteroids? How are they formed?
7. What are meteoroids?
8. (a) Explain the difference between a meteor and a meteorite.
   (b) Create a mnemonic (a memory device) to help you remember the difference between meteors and meteorites.
9. What happens as a comet approaches and moves away from the Sun?
10. Both comets and planets orbit the Sun. How do their orbits differ?
11. Copy and complete Table 1.

Table 1

Minor body	Asteroid	Meteor	Meteorite	Comet
Similarities				
Differences				

12. Can you tell whether the objects in Figure 9 are asteroids, meteors, meteorites, or comets? What other information would you need in order to classify this object?

Figure 9

13. Discuss the evidence that astronomers use to support the rotating nebula theory.
14. (a) Describe the current theory on the formation of the Moon.
    (b) Describe the evidence that supports this theory.

12.4 A Closer Look at the Planets

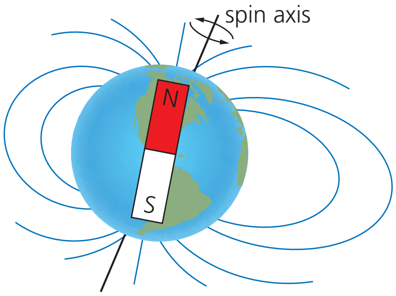
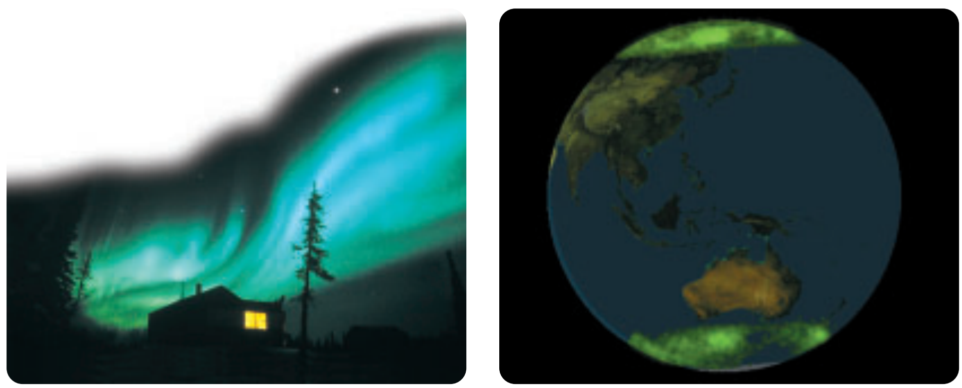


Figure 1 Earth's magnetic field resembles the field of a large bar magnet.

The Sun and most of the planets have a magnetic field that extends into space. The English physicist Sir William Gilbert determined, in the 16th century, that Earth's magnetic field resembles the field of a large bar magnet (Figure 1). The magnetic field of a planet directs charged particles from the Sun toward the magnetic poles of the planet. Often, swirls of light can be seen on a planet as the charged particles give off light when they interact with molecules in the atmosphere. On Earth, these swirls of light are called the aurora borealis in the northern hemisphere and the aurora australis in the southern hemisphere (Figure 2). The aurora borealis is commonly referred to as the northern lights.



(a) **(b)**

Figure 2 (a) The aurora borealis (b) An image of Earth showing auroras occurring simultaneously at both magnetic poles

TRY THIS: Planetary Preview

Skills Focus: recording, communicating, questioning

In this activity, you will record your current understanding about the planets in our solar system and then any new understanding you gain from reading this section. You will also record any questions you still have about the planets so that you can research them later.

1. Copy Table 1 into your notebook.

Table 1

Name of planet	What I know	What I wonder	What I learned

2. Write the names of the planets in the first column, in the order they are found from the Sun. If you are unsure of the order, look at the headings on the next few pages. The planets are described in their order from the Sun.
3. Under "What I know," write down any facts or special features you already know about each planet, such as how many moons it has or whether it has rings.
4. Under "What I wonder," write any questions you have about each planet. Try to write at least one question for each planet.
5. Under "What I learned," write any new information you learned by reading this section.

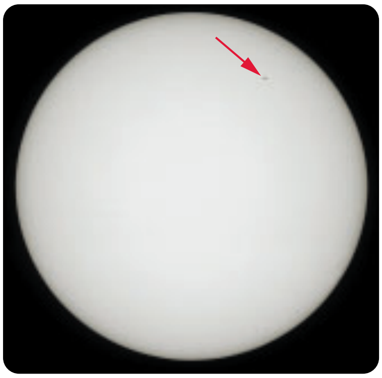
The Terrestrial Planets

The terrestrial (or inner) planets have relatively high densities, slow rotations, solid metal cores (usually iron), solid surfaces, and no rings.

Mercury

- Mercury, the planet closest to the Sun, has daytime temperatures around 427 °C because it receives 10 times the sunlight that Earth receives. With no atmosphere to trap heat, however, its nighttime temperatures fall to −173 °C.
- Mercury is very close to the Sun, so it is rarely visible in the night sky. When it is visible, it is always just before sunrise or just after sunset.
- The many craters on its surface were caused by collisions with chunks of rock or meteorites (Figure 3(a)).
- Mercury orbits the Sun at 50 km/s, which is faster than any other planet.
- Despite its quick revolution, Mercury has a sluggish rotation. It completes only three rotations for every two revolutions around the Sun.
- Observers on Earth can watch Mercury pass in front of the Sun 13 times each century in an event called a transit (Figure 3(b)). The first two transits this century were on May 7, 2003, and November 8, 2006. The next transit is in 2016. GO

(a)



(b)

Figure 3 (a) The surface of Mercury (b) A transit of Mercury

If you would like to learn more about transits of Mercury, go to **www.science.nelson.com** GO

Venus

- Venus's atmosphere is composed mainly of carbon dioxide gas. This gas acts like the glass of a greenhouse, keeping the surface temperatures high enough to melt lead. The surface temperature averages 462 °C.
- Lava from the 1.7 km high volcano shown in Figure 4 flowed hundreds of kilometres to create the wild landscape of Venus.
- Not including the Sun and the Moon, Venus is the brightest object we can see in the sky. This is due to Venus's closeness to Earth and its thick atmosphere, which reflects light from the Sun. Venus is so bright that it is sometimes called the evening or morning star. It is called the evening star because, when above the horizon at night, it is the first object seen in the sky after sunset. It is called the morning star because, when above the horizon during the day, it is the last object seen after sunrise.
- The harsh environment on Venus makes exploration of this planet difficult. The space probe *Magellan* used radar cameras that could penetrate Venus's thick atmosphere and "see" the features on its surface, including its many impact craters.
- Like Mercury, Venus can be seen from Earth as it passes in front of the Sun. Transits occur in pairs, eight years apart. The last transit took place on June 8, 2004, and the second transit in the pair will occur on June 6, 2012. The next pair of transits will occur in the next century.

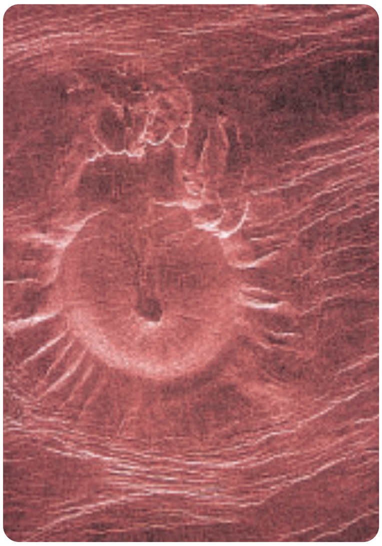


Figure 4 Volcanoes on Venus

- Earth and Venus have more features in common than any of the other planets. Earth and Venus have a similar size, composition, and distance to the Sun. Unlike Earth, however, Venus has no oceans and rotates in a clockwise direction.
- The European Space Agency's spacecraft *Venus Express* has been in orbit around Venus since April 2006. It was sent to study Venus's atmosphere so that we can better understand Earth's atmosphere. GO

If you would like to learn more about *Venus Express*, go to **www.science.nelson.com** GO

Earth

- The conditions on Earth are ideally suited to promote the origin of life as we know it. Astronomers use Earth and our solar system as a model to search for life on other planets and even outside our solar system.
- Earth's unique atmosphere contains mostly nitrogen, oxygen, and water vapour. It also contains a small amount of ozone, which filters some of the damaging radiation from the Sun. The atmosphere is also responsible for keeping the temperatures on Earth relatively constant between day and night, although there is a wide variation of temperatures between the poles and the equator, ranging from about −88 °C to 58 °C.
- About 70 % of Earth's surface is covered by water in the form of oceans, seas, lakes, rivers, and ice or snow (Figure 5).
- Rich soils and moisture are an ideal medium for plant life to adapt and grow.
- Earth has many impact craters.
- Weathering, erosion, active volcanoes, and earthquakes are changing the surface of Earth, although Earth is considered to be stable.
- Earth has a magnetic field, which causes the auroras.

Figure 5 Earth is often referred to as the blue planet because of the abundance of water over its surface.

Mars

- The surface temperature on Mars ranges from –90 °C to –5 °C.
- Mars, the fourth planet from the Sun, is sometimes called the red planet because of its reddish soil (Figure 6). It is one of the brighter objects in the sky.
- Giant dust storms periodically engulf Mars, changing its wind-swept landscape.
- Today, Mars is a dry and barren planet with many impact craters. However, there is evidence to suggest that Mars once had volcanoes, glaciers, and floods of water. For this reason, scientists believe that life may have existed there. In fact, in May 2002, the spacecraft *Mars Odyssey* discovered a large quantity of ice only 1 m below the surface.

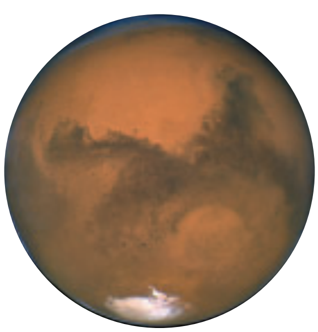


Figure 6 Scientists believe that Mars is a possible location for a space colony.

The Gas Giants

The atmospheres of the gas giants (outer planets) consist mainly of hydrogen and helium gases, so these planets have low densities. The cores of these planets may be denser and may contain metals, much like the terrestrial planets do. Although the gas giants are less dense than the terrestrial planets, their immense sizes result in masses that are far greater than the masses of the terrestrial planets. Their large masses result in stronger gravitational fields, which can pull more debris and moons into orbit.

Jupiter

- The average temperature on Jupiter is −148 °C.
- Jupiter is the largest planet in our solar system. It has a diameter that is 11 times greater than Earth's diameter, and its mass is greater than the masses of all the other planets combined. Due to its immense size and the light reflected off its clouds, Jupiter is easily visible in the sky at certain times of the year. However, we are unable to see its orbiting ring of rocks from Earth.
- Jupiter has over 60 known moons, four of which are visible from Earth with only binoculars. These moons (Io, Europa, Ganymede, and Callisto) are commonly referred to as the Galilean moons because they were discovered by the famous astronomer Galileo Galilei.
- Jupiter is famous for its coloured bands and the Great Red Spot, a huge hurricane fed by constant high winds. This hurricane, which is the size of two Earths, shows no signs of dying since it was first discovered by Galileo almost four centuries ago (Figure 7).
- Water is known to exist deep within Jupiter's atmosphere and can even be seen through the gaps in the storm clouds.
- The atmosphere on Jupiter resembles the atmosphere of the Sun. Immense pressure and high temperatures cause hydrogen gas to become a liquid metal and give rise to electric currents, which result in the planet's strong magnetic field. Jupiter's magnetic field is 20 000 times stronger than Earth's.

Figure 7 Jupiter and one of its moons; also visible is the Great Red Spot

Saturn

- The cloudy atmosphere is windy due to Saturn's high speed of rotation. Saturn is colder than Jupiter (approximately −178 °C on average).
- With a diameter that is about five-sixths the diameter of Jupiter, Saturn is the second largest planet in our solar system. Saturn is the least dense of all the planets, and it may not have a solid core.
- Saturn is mainly composed of hydrogen and helium and has a volume that is 755 times greater than Earth's.
- Detailed images sent by space probes *Voyager* and *Cassini* showed that Saturn has nearly one dozen rings (Figure 8). Astronomers are not certain whether the rings formed from the crumbled remains of Saturn's many moons and other nearby objects or whether they formed around the same time as the planet did.
- Saturn currently has over 50 moons with undoubtedly many more waiting to be discovered. One of Saturn's moons, Titan, is actually larger than Mercury. Conditions on Titan are very similar to the conditions on early Earth.
- Saturn has a magnetic field, which is over 500 times stronger than Earth's.

Figure 8 Saturn and its rings

Did You KNOW?

Saturn in Your Tub?

The density of Saturn is less than the density of water. If you could find a bathtub big enough, Saturn would float!

Uranus

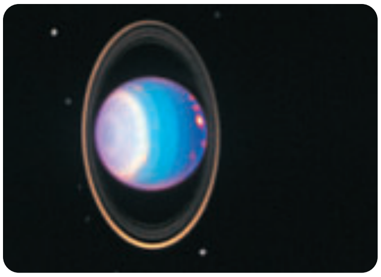


Figure 9 Uranus's rings are almost invisible from Earth.

- The average surface temperature on Uranus [pronounced YUR-uh-nuhs] is −216 °C.
- The atmosphere consists mainly of hydrogen, with traces of helium and methane. Uranus has winds that blow up to 500 km/h.
- Despite appearing to us on Earth like a faint star, Uranus's diameter is four times greater than Earth's diameter. Uranus is so far away that it is difficult to see in the night sky. Uranus was thought to be a star until 1781, when its motion around the Sun was discovered.
- In 1986, the space probe *Voyager 2* passed near Uranus and gathered much of the data we still use today.
- Uranus is unusual in that it spins on its side. Like Venus, Uranus also rotates in the opposite direction from Earth. The unusual rotation of Uranus may be due to a collision that knocked it out of its original rotation early in its formation.
- The white patch in the digitally enhanced image in Figure 9 is a polar cap over the south pole.
- Uranus has a weak, irregular magnetic field.

Neptune

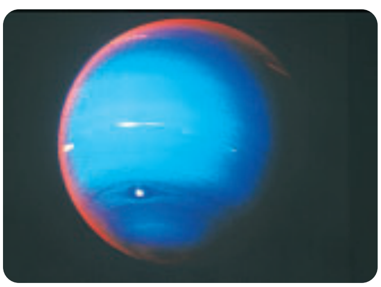


Figure 10 The cause of Neptune's brilliant blue colour is not fully understood, although the methane in its atmosphere is known to reflect blue light.

- Neptune's average surface temperature is −214 °C.
- Computer-enhanced images sent from *Voyager 2* in 1989 revealed that Neptune has bright blue and white clouds and a dark region, called the Great Dark Spot, that appears to be the centre of a huge storm (Figure 10). The Great Dark Spot is missing in Hubble Space Telescope pictures taken in 1994, suggesting that Neptune's atmosphere is much more dynamic than scientists had previously thought.
- Some thin rings and 13 moons orbit Neptune.
- Neptune was discovered through a feat of scientific reasoning. Neptune is so far from Earth that it can barely be seen, even with powerful telescopes. Astronomers noted that Uranus's orbit was irregular, almost as if it was being tugged into an uneven orbit by the gravitational attraction of another object. Using detailed calculations, they predicted where this hidden object might be and consequently discovered Neptune in 1846.
- Neptune has six rings that are thought to have formed much later than the planet itself.
- One of Neptune's 13 moons, Triton, actually revolves around Neptune in the opposite direction to the planet's rotation.
- Like Uranus's magnetic field, Neptune's magnetic field is weak and irregular.

All the planets in our solar system have unique characteristics. They are made of different combinations of chemicals, which is one reason why no two planets are alike. They also differ in size, surface temperature, and density. These and other properties are summarized in Table 2.

The planets have unifying characteristics as well. They all orbit in the same direction, they all rotate about an axis, and they all contain four common elements: hydrogen, helium, oxygen, and carbon. These elements are found throughout the solar system but in differing amounts on different planets. Hydrogen and helium are gases at ordinary pressures and are found in the Sun and the four largest planets. Oxygen is a gas that is found in various forms in all planets. Carbon is an element that is found in all planets.

LEARNING TIP

Table 2 helps you identify specific information about each planet. As you examine Table 2, ask yourself, "How is it organized?" Look at the headings. They will help you focus on what is important in the table.

Table 2 Properties of the Planets

Planet	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Average distance from Sun ($\times 10^6$ km)	57.9	108	150	228	778	1427	2870	4497
Orbital period	88.0 d*	224.7 d	365.26 d	687 d	11.9 a**	29.5 a	84.1 a	164.8 a
Average diameter (km)	4880	12 100	12 750	6790	142 800	120 700	50 800	48 600
Mass (kg)	3.3×10^{23}	4.9×10^{24}	5.9×10^{24}	6.4×10^{23}	1.9×10^{27}	5.7×10^{26}	8.7×10^{25}	1.0×10^{26}
Mass (Earth = 1)	0.06	0.8	1.0	0.1	320	97	15	17
Time for one rotation	59 d	243 d***	24 h	24 h 39 min	9 h 50 min	10 h 39 min	17 h 18 min***	15 h 40 min
Main substances in the atmosphere	none	carbon dioxide, nitrogen	nitrogen, oxygen	carbon dioxide, nitrogen	hydrogen, helium, methane	hydrogen, helium, methane	hydrogen, helium, methane	hydrogen, helium, methane
Average surface temperature (°C)	−173 to 427	462	−88 to 58	−90 to −5	−148	−178	−216	−214
Density (g/cm³)	5.44	5.25	5.52	3.95	1.31	0.70	1.18	1.66
Surface gravity (Earth = 1)	0.39	0.90	1.0	0.38	2.58	1.11	1.07	1.4
Number of moons	0	0	1	2	63	56	27	13

* The symbol d stands for day. It means one Earth day.

** The symbol a stands for year (from *annum*, the Latin word for year). It means one Earth year.

*** The rotation is in the opposite direction to the rotation of other planets.

Other Objects in Our Solar System

It is important that you do not think of our solar system as ending at Neptune. Beyond the eighth planet, there are many other objects of interest. These objects are classified generally as trans-Neptunian objects (TNOs). Since the number of TNOs and the variety of properties they display are vast, it is important for astronomers to classify them into categories that are distinct and, therefore, convenient to use. The categories are planetoids (dwarf or minor planets, natural satellites, and minor bodies), the Kuiper [pronounced KI-per] Belt, and the Oort Cloud. Pluto, for example, is a dwarf planet that resides in the outer reaches of our solar system. In fact, Pluto is more than double the distance of Uranus from the Sun. Once considered a planet, Pluto's orbit actually crosses Neptune's orbit, making it closer to the Sun than Neptune for a period of about 20 Earth years. In 2006, the size of Pluto plus its unusual orbit led astronomers to reclassify Pluto as a dwarf planet instead of a planet. This reclassification is an example of how our scientific understanding of the universe can change over time.

LEARNING TIP

Imagine what it would be like if you had to measure distances in space without the astronomical unit (AU). It would be like trying to measure the distance from Toronto to Vancouver in centimetres!

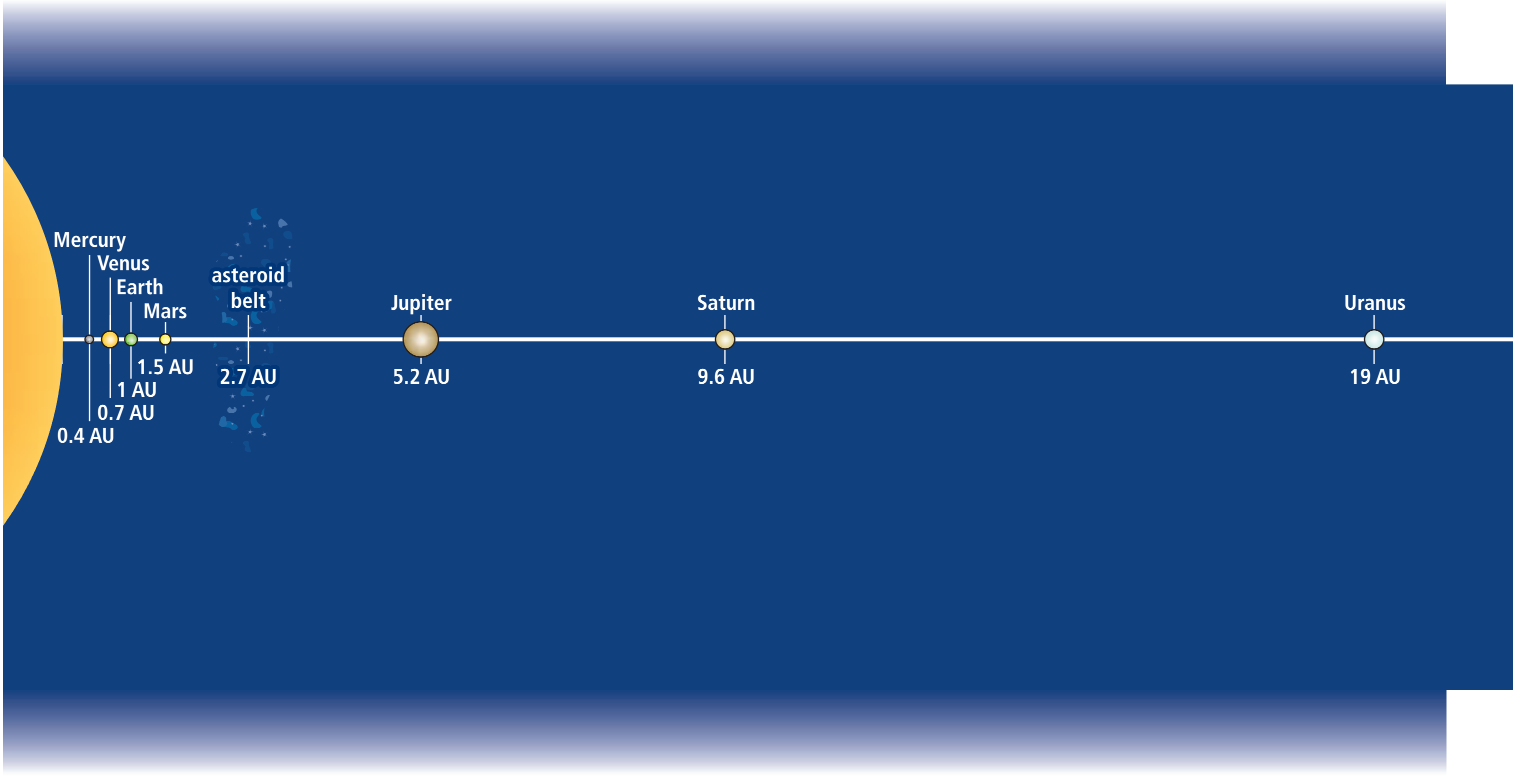


Figure 11 Distances in the solar system

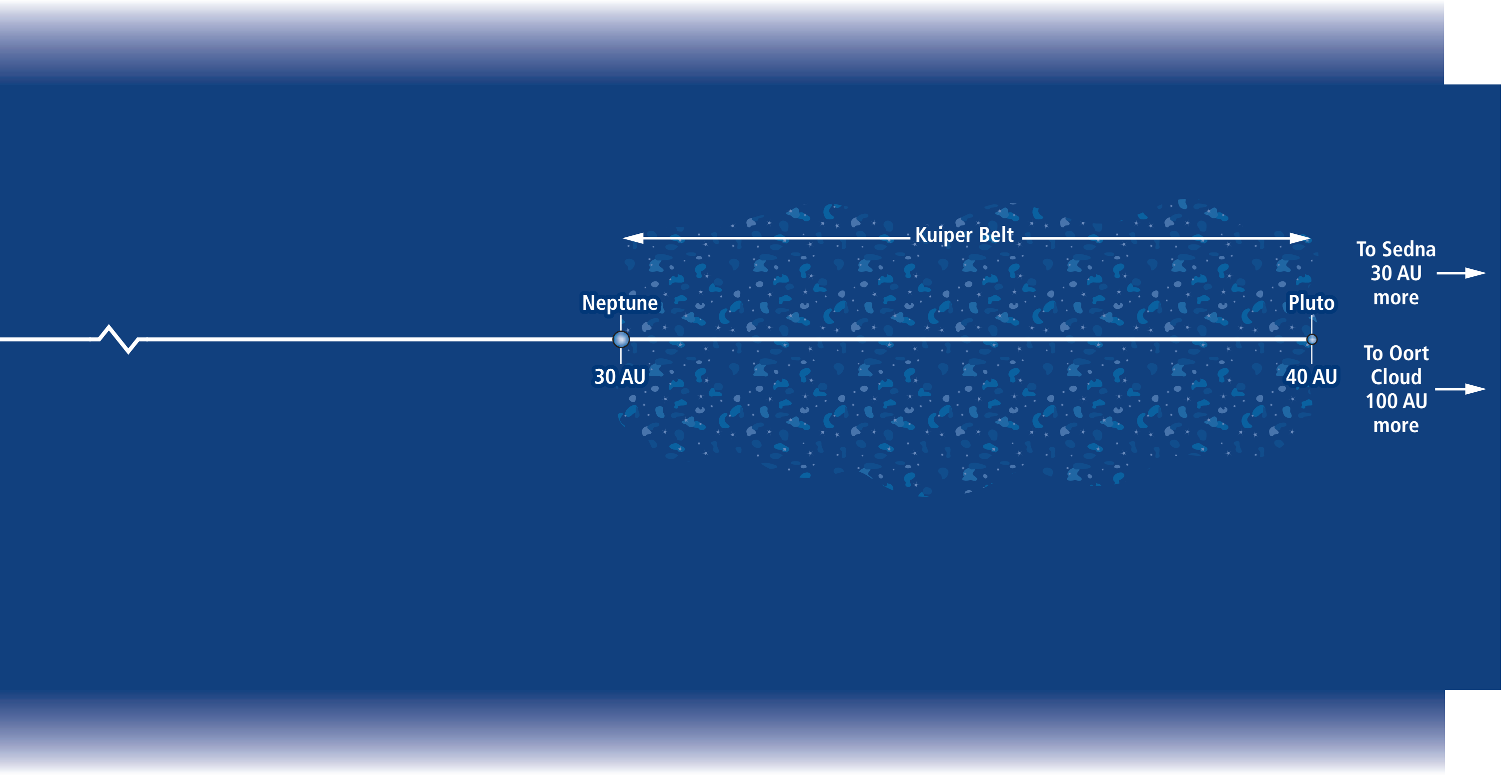
The Kuiper Belt is a disk-shaped collection of thousands of small, icy bodies. In fact, some of these icy bodies, such as Eris, are larger than Pluto. Beyond this region, just inside where the Sun's physical and gravitational influence ends, is a spherical swarm of icy bodies called the Oort Cloud. Astronomers believe that many comets arise when passing stars disturb the Oort Cloud or the Kuiper Belt.

The distances to the planets and other objects in our solar system are large, so it is convenient to use astronomical units, instead of kilometres, when referring to these distances. An **astronomical unit (AU)** is defined as the distance from Earth to the Sun, which is 150 million kilometres. The farthest known object is Sedna, a minor planet about three-quarters the diameter of Pluto. Sedna's orbit is highly elliptical, ranging from 1000 AU at aphelion to 76 AU at perihelion. Figure 11 illustrates the distances of major objects in the solar system from the Sun.

Did You KNOW?

Sedna

Sedna is the coldest known object in the solar system. The team who discovered this icy body named it in honour of Sedna, the Inuit goddess of the sea. According to the Inuit legend, all sea creatures were created by Sedna.



12.4

CHECK YOUR Understanding

1. Create a mnemonic to help you remember the names and the order of the planets.
2. Why are the first four planets called terrestrial planets? Why are they also called inner planets?
3. In a table, organize the features that the terrestrial planets share.
4. Describe how our planet is unique in the solar system.
5. List the planets with little or no atmosphere.
6. How does the presence of an atmosphere affect the conditions and features on the surface of a planet (Figure 12)?

Figure 12

7. Why does Earth have so few visible craters?
8. Mercury is much closer to the Sun than Earth. With this in mind, account for Mercury's much colder nighttime surface temperature of −173 °C. Hint: Refer to Table 2 on page 391.
9. Why do some scientists believe that life may have existed on Mars?
10. In your own words, describe how astronomers reasoned the existence of Neptune before they could see it.
11. Describe one effect of Earth's magnetic field.
12. (a) What phenomena are visible in Figure 13?
    (b) What causes these phenomena?

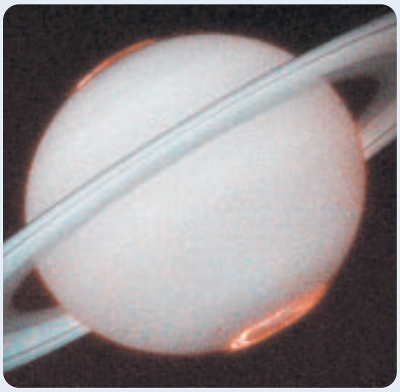


Figure 13

13. Write your own theory to explain Uranus's rotation in the opposite direction. You don't need direct evidence to support your theory, but you should provide a reason why you think it might be true.
14. Identify and describe the three main categories of trans-Neptunian objects.
15. Using the distances in astronomical units, write three statements that compare the relative distances between pairs of planets or objects. For example, Saturn is approximately 9.5 times farther from the Sun than Earth.
16. Why do the gas giants have more moons than the terrestrial planets?
17. In a table, organize the properties that the gas giants share.
18. Is there a relationship between a planet's density and its distance to the Sun? Try to explain this relationship using the currently accepted theory for the formation of the solar system.
19. (a) List three criteria that could be used to distinguish the terrestrial planets from the gas giants. (Hint: See Table 2 on page 391.)
    (b) List two properties of planets that relate to their distance from the Sun.

PLUTO: TOO PUNY TO BE A PLANET

The International Astronomical Union (IAU) has decided that Pluto is no longer considered a planet.

You have probably grown up with the idea that our solar system has nine planets. In fact, you probably had your own mnemonic to remember the names of the planets! Since its discovery in 1930, Pluto has been the favourite planet of many people.

Pluto is a fascinating object within our solar system. It has an orbital period of 248 Earth years, and its orbital plane is titled 17° to the ecliptic. Once Pluto's moon Charon was discovered in 1978, astronomers analyzed data and concluded that Pluto was never a moon of Neptune, as some believed, but that it likely formed during the formation of our solar system (Figure 1).

Now, Pluto is no longer considered to be a planet. On August 24, 2006, after much debate at an international conference of the IAU, Pluto was demoted from its planetary status.

A new definition of planet was at the root of the IAU's decision. According to this new definition, a planet must meet the following three criteria:

- It must orbit the Sun.
- It must have enough gravity to form a round shape.
- It must have cleared the neighbourhood of its orbit of any other objects.

Since Pluto's orbit crosses Neptune's orbit, Pluto is considered to have not cleared the "neighbourhood of its orbit of any other objects." Thus, Pluto fails to qualify as a planet under this definition.

Now, under the eight-planet solar system, Pluto is categorized as a dwarf planet. The designation "dwarf planet" means any planet that is smaller than Mercury. This classification may prove to be quite significant in the world of astronomy because more objects may be studied in the future, bringing greater insight to our understanding of our solar system.

Conversely, other objects in our solar system have been upgraded as a result of the new definition. For example, Ceres, formerly an asteroid, has been promoted to the same grouping as Pluto.

For decades, Pluto has been the centre of much controversy among astronomers worldwide. Many astronomers believe that Pluto does not qualify to be a planet because of its many unusual features. Other astronomers, however, disagree with the new definition of a planet, claiming that more planets, including Earth, might not even qualify. Given the controversy over the new definition, Pluto may, in years to come, once again achieve the privileged position of a planet.

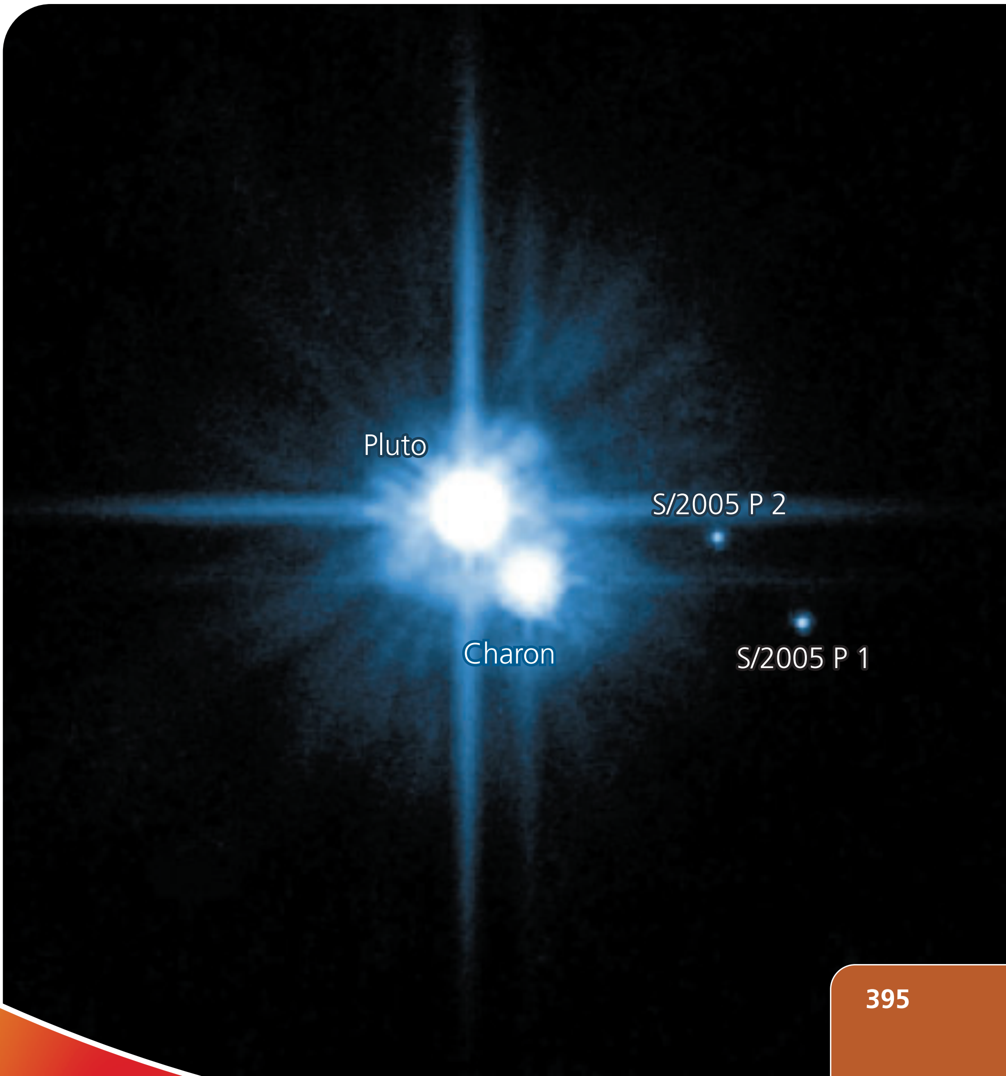


Figure 1 This image of Pluto with its three moons was taken by the Hubble Space Telescope.

12.5 The History of Astronomy

Figure 1 This cedar sculpture by Bill Reid depicts Raven finding the first human beings in a clam shell on Rose Spit beach, Queen Charlotte Islands. Raven is coaxing the humans to leave the shell and join him in his world. (from the Museum of Anthropology, University of British Columbia)

Cultures all over the world have used legends (traditional stories) to interpret astronomical events and objects. Canadian Aboriginal peoples have many legends about creation, the Sun and stars, the Moon, and special events such as meteor showers and lunar eclipses.

Aboriginal Legends

A famous Haida story about creation begins during a time when there was only water and the sky above. All the great beings lived on top of a single reef in the water. Raven couldn't find a spot on the reef, so he flew to the sky, where he scooped the chief's granddaughter out of her skin and took her place, becoming Raven Child.

While holding Raven Child, a great being dropped him, and Raven Child fell on the water. There, Raven Child's grandfather let him into a house, where Raven Child met a man who looked like a seagull. The man said to Raven Child, "Put this speckled stone in the water first and the black one next. Then bite off a piece of each and spit it out. You will see them unite and become one." Raven Child did as he was told. When the two pieces came together, they were trees. He put them in the water, where they stretched and became the land called Haida Gwaii. After this, Raven Child made many things, including the Haida. When the Haida look at their country, they understand the story of Raven. His creation is all around them (Figure 1). For some Aboriginal cultures, this story represents the way in which the universe was formed, through the powers of the great Raven.

The Tsimshian of the West Coast tell the following legend to explain the formation of the Moon and the stars: Each night the Sun went to sleep in his house but allowed the light from his face to shine out of the smoke hole in the roof. The stars were sparks that flew out of the Sun's mouth. The full Moon was the Sun's brother, who rose in the east when the Sun fell asleep.

The Menomini of the Great Lakes region tell this legend about meteors: When a star falls from the sky it leaves a fiery tail. It doesn't die. Instead, its shade goes back to shine again.

The Kwakwaka'wakw, also of the West Coast region, believed that a lunar eclipse occurred when the sky monster tried to swallow the Moon. By dancing around a smoky fire, they hoped to force the monster to sneeze and cough up the Moon.

Figure 2 This ancient Aztec carving shows that Aztec astronomers studied the sky and were familiar with many constellations. The Aztecs had two calendars: one for rituals and ceremonies (260 days) and another for important dates, such as when they should plant and harvest their crops (365 days).

Ancient Science

Evidence found in caves and tombs and on pottery shows that people studied astronomy thousands of years ago, making astronomy one of the oldest sciences (Figure 2).

About 7000 years ago, people began using the regular cycles of the Sun and Moon to plan a calendar. This is the time when people began settling on farms and in towns. The calendar helped them decide when to plant and harvest crops and when to hold their feasts. These early astronomers became quite skilful in mapping the night sky.

Built over 3600 years ago, the huge stones of Stonehenge, located in southern England, are arranged in a well-organized pattern (Figure 3). Some scientists have studied the pattern for many years and now think that the people who built Stonehenge used the pattern to predict repetitive events. The arrangement of the stones marks the longest and shortest days of the year (solstices) as well as the equinoxes.

Figure 3 Stonehenge

More than 3000 years ago, using their observations of the Sun and the stars, the Chinese developed a very accurate calendar of 365 days. They also recorded comets, meteors, and what they called guest stars. (We now know that guest stars are supernovas, which are visible for a few weeks or months.) Both the Chinese and the Greeks created star maps more than 2000 years ago, showing the position and approximate brightness of more than 800 stars. They did this using only their eyes and some instruments to measure angles.

The Maya live in Central America. Over 1000 years ago, they developed ways of accurately keeping track of the movements of the planets. They were particularly interested in Venus. One of the few remaining ancient Mayan books shows that the Maya were able to predict the appearance of Venus very accurately. Their predictions were off by only two hours in 500 years.

Figure 4 Claudius Ptolemy, 87–150 CE

The Early Years

Approximately 2000 years ago, a famous and influential Greek astronomer named Claudius Ptolemy (Figure 4) tried to explain the apparent motion of the Sun and the planets in the sky. Since telescopes had not been invented yet, Ptolemy had to rely on observations with his unaided eyes. He used a very simple tool, the **astrolabe**, to chart the sky (Figure 5).

Figure 5 An astrolabe measures angles much like a protractor.

Ptolemy devised a **geocentric**, or Earth-centred, model of the universe. This model, which he called the celestial sphere, places a motionless Earth at the centre, with all the planets and stars at fixed positions within eight concentric spheres that spun in circles called orbits (Figure 6).

Did You KNOW?

Ptolemy

Ptolemy knew that Earth was a sphere and not a flat disk. This was a concept that would not be accepted for many more centuries. Ptolemy is also credited with giving many of the constellations the names that we are familiar with, and for creating complex star charts and world maps. These maps were used by Columbus until his accidental discovery of America in 1492.

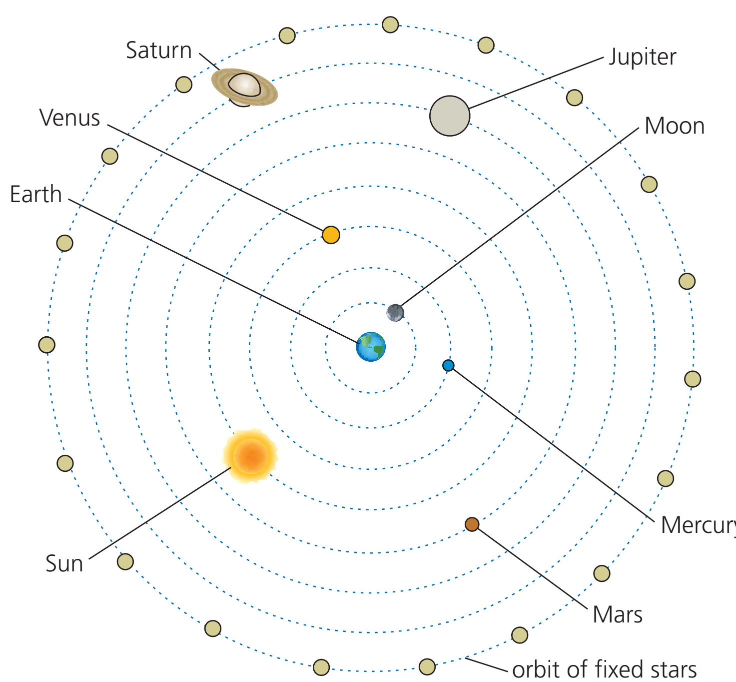


Figure 6 Many people in ancient times thought that Earth was the centre of the universe and that all other objects revolved around it. Why did early astronomers place the Sun where it is in this diagram?

What Ptolemy actually described was a model of our solar system, not the universe. At the time, people could not understand the existence of galaxies they could not see. Ptolemy's model provided a reasonable explanation for the approximate path of the planets and provided a method by which humans could navigate the globe. Ptolemy's model also enabled astronomers to create the first Christian calendar.

The Roman emperors trusted Ptolemy. As a result, his model became the accepted wisdom of the time. The Catholic Church even supported his model and included it in their teachings. With such high and powerful endorsements, it is easy to see why his model stayed with us for more than 1500 years!

Post-Middle Ages

Not everyone agreed with the geocentric model. Since the Church officially supported the geocentric view for centuries, however, any opposing ideas were seen as a threat to its authority. For example, during the Middle Ages (450–1450 CE), many people were burned at the stake as heretics for spreading unconventional ideas.

In 1473, Nicholas Copernicus (Figure 7) was born to a wealthy family in Poland. Copernicus was an avid reader and was sent to university as a young boy (a common practice for members of the upper class). He was passionate about astronomy, and by the time he was an adult, he was considered Poland's premier astronomer. In 1514, Pope Leo X hired him to revise the old Christian calendar. The calendar was then 1500 years out of date, and it no longer matched the seasons. Without revision, the old calendar would have eventually placed Christmas in the northern hemisphere's summertime! What Copernicus discovered during his investigation would challenge how people understood the heavens and Earth.

Ptolemy's geocentric model had many mathematical errors that could not be fixed as long as Earth remained the centre of the universe. After reading texts from ancient Greek philosophers who stated that Earth was in motion, it occurred to Copernicus that a simple switch between the Sun and Earth would greatly improve the geometric model. Not only did Copernicus's model make sense from a mathematical perspective, it also agreed with the long-held idea that the Sun warmed all the planets. With the Sun at the centre, radiant heat can easily reach all the planets, including Earth. Thus, the **heliocentric**, or Sun-centred, model of our solar system was devised.

However, this simple change caused much unrest among the authorities. Too many questions were raised. How could the Church support a flawed model for so long? If Earth is not the centre of the universe, what is? The human ego suffered a significant blow. Copernicus was a perfectionist, and he did not like the public spotlight. Maybe he feared that he would upset the Catholic Church. Consequently, he did not officially publish his new model, claiming that he felt it required further study.

Did You KNOW?

Flat Earth or a Sphere?

The concept that some stars could be seen from Greece but not from Egypt led the ancient Greeks to conclude that Earth was a sphere and not a flat plane. Furthermore, the ancient Greeks noted that the border of Earth's shadow on the Moon during a lunar eclipse was always circular, which also supported the idea that Earth is a sphere. The idea that Earth was flat was taught by the Church for centuries. As a result, the idea that Earth is a sphere was forgotten for nearly 2000 years, until the Renaissance period.

Figure 7 Nicholas Copernicus, 1473–1543

For the next couple of decades, the radical new idea that the Sun was the centre of the solar system faded into the background. It took a young Danish astronomer named Tycho Brahe (Figure 8) to revisit Copernicus' ideas. Brahe was appointed to a prestigious position by the King of Denmark and given the title "man of learning." Brahe could now afford to build an impressive observatory. He constructed the most detailed star maps that the world had ever seen. It is said that Brahe memorized the positions of all the stars that are visible to the unaided eye. Brahe's attention to detail paid off one November evening in 1572, when he saw something astonishing happen. A bright star lit up the night from a position where no star had existed before. This star was so bright that it could even be seen in daylight. What Brahe witnessed was a supernova. Until then, all the stars in the heavens were thought to be fixed and unchanging. The universe just got a whole lot bigger!

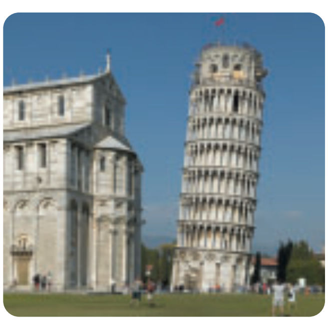
Figure 8 Tycho Brahe, 1546–1601

Shortly after Brahe's discovery, another prominent astronomer, Galileo Galilei (Figure 9), made his place in history. Galileo has become synonymous with the scientific revolution. An engaging lecturer, Galileo loved to be in the public eye. He taught at universities throughout Europe. Galileo is considered to be the father of the scientific method. He believed that scientific knowledge had to be acquired through careful and repeated measurements.

Did You KNOW?

Do All Objects Fall at the Same Rate?

Galileo dropped objects of different masses, supposedly from the top of the tower of Pisa, and discovered that they hit the ground at the same time regardless of their masses. This discovery led to Newton's ideas about universal gravity and even Einstein's theory of relativity.



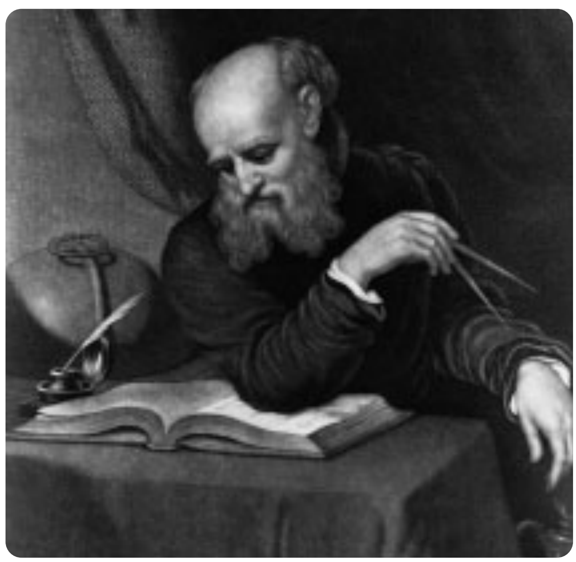


Figure 9 Galileo Galilei, 1564–1642

Galileo also constructed the most accurate telescopes at that time. His telescopes were so powerful that he discovered four moons orbiting Jupiter, now called the Galilean moons, and he could see the rings of Saturn, which he called ears. Apparently there was more to the universe than met the eye. He calculated the distances between the stars and the planets and determined that the stars were much farther away from Earth than the planets were. This evidence shattered the tidy arrangement of the celestial sphere into a new order. Galileo was very outspoken about his support of the Copernican model of the universe. He announced that the heliocentric model even explained the unusual retrograde motion of some planets. Eventually, Galileo was sentenced to permanent house arrest for his heretical beliefs. He was forced to recant his beliefs during a famous public inquisition. GO

If you would like to learn more about Galileo's life, go to **www.science.nelson.com** GO

Despite skepticism for the Sun-centred view, a young man named Johannes Kepler (Figure 10) was determined to prove to the world that Copernicus was right. Kepler purchased a telescope from Galileo and went to work as an assistant for the aging Tycho Brahe. Brahe's health was in serious decline. While on his deathbed, Brahe reluctantly handed over his life's work of calculations and star maps to young Kepler. With these documents and his own sharp intuition, Kepler made three profound conclusions. These conclusions are known today as **Kepler's Laws of Planetary Motion**:

1. The planets travel in elliptical orbits (not circles) around an off-centre Sun. The Sun is at one focal point.
2. The speed of a planet's orbit depends on its distance from the Sun. When a planet is close to the Sun, it moves faster. When a planet is farther away, it moves slower (Figure 11).
3. The farther a planet or dwarf planet is from the Sun, the longer its orbit. In other words, more distant planets and dwarf planets have longer years than closer ones. For example, Earth's year is $365^1/_4$ days, Pluto's year is approximately 91 000 Earth days (248 years), and Sedna's year is approximately 10 000 Earth years!

Figure 10 Johannes Kepler, 1571–1630

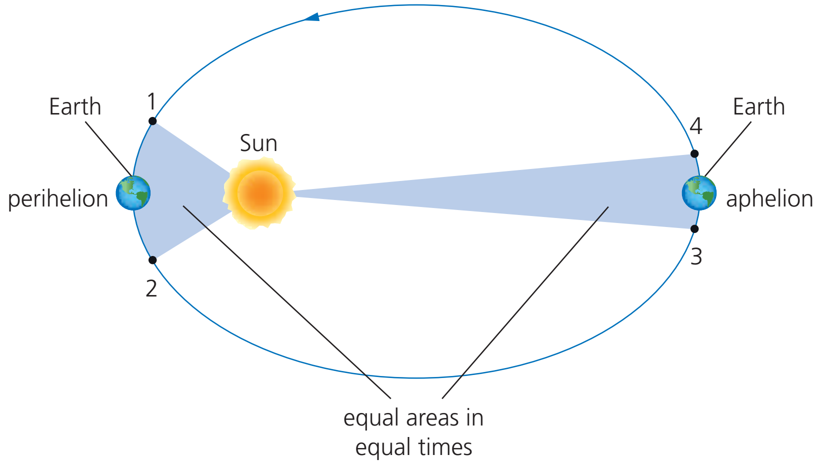


Figure 11 Planets orbit the Sun in elliptical orbits. If Earth takes the same amount of time to travel from 1 to 2 as it takes to travel from 3 to 4, then the two shaded areas are equal. The ellipse is exaggerated.

Kepler fully explained the motion of the planets in the sky, including the retrograde motion of Jupiter, without mathematical errors. However, one question remained. Why do the planets revolve around the Sun? It took the English scientist Isaac Newton to figure this out (Figure 12).

Thankfully, Newton's lack of friends in college did not seem to get in the way of his scientific inquiries. Newton was also curious about objects in motion, in particular, the motion of the planets around the Sun. Despite the slow acceptance for the heliocentric model in Newton's time, he was certain that Copernicus, Kepler, and Galileo were right. Newton pursued this topic intensely.

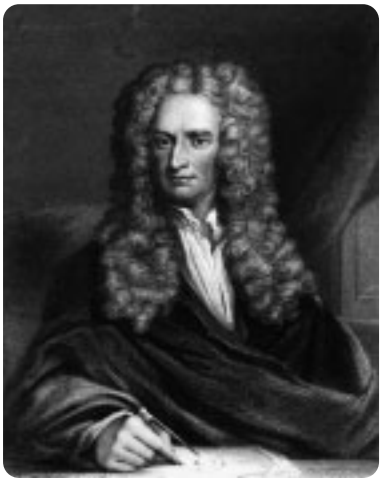


Figure 12 Isaac Newton, 1643–1727

LEARNING TIP

Check your understanding. Discuss with a partner who brought the heliocentric model to the forefront and why many scientists fought to keep the geocentric model.

After pondering the force that caused an apple to fall to the ground (the Greeks called this force "gravity"), Newton realized that the Moon's orbit (and indeed the orbits of all objects) is the combination of the force of gravity and the Moon's own motion. Newton also realized that the force of gravity depends on two things: the masses of the objects involved and the distance between them. That is, an object of greater mass exerts a greater gravitational force than a less massive object, and the closer an object is to another, the greater the force of gravity between the two objects.

Changing commonly accepted ideas is a slow process that requires as much patience as it does evidence. The Sun-centred model of the universe, conceived by Copernicus and supported and proven by others, has finally become today's universally accepted model. In 1991, the Catholic Church made a public statement that absolved Galileo of any wrongdoing. He was found innocent of his alleged heresy.

Did You KNOW?

Supportive Sibling

William Herschel's younger sister, Caroline, worked for him as an assistant while also running their household. Caroline worked on building Herschel's famous telescopes and is credited with discovering eight comets and three nebulas.

Modern Astronomy

During the 20th century, we have learned more about the nature of the universe than in all the other centuries combined. Our understanding of the size of the universe and the diversity of the objects within it has expanded tremendously. With advancements in technology comes further discovery. Below are just a few of the many important recent contributions:

- The prediction of a returning comet every 76 years by Edmund Halley (1656–1742) has caused us to consider questions such as "Where does our solar system end?"
- The discovery of the planet Uranus, by William Herschel (1738–1822) in 1781, as well as many other objects, such as moons and star systems far beyond our galaxy, urged us to keep looking deeper and deeper into the seemingly limitless universe.
- In 1927, the Belgian priest Georges-Henri Lemaître (1884–1966) was credited with the theory that the universe began with a "big bang," a cosmic explosion that hurled matter in all directions.
- Around the same time, the American astronomer Edwin Hubble (1889–1953), using improved telescopes, confirmed that the distant fuzzy objects astronomers had been observing for years were, in fact, other galaxies. Hubble made further significant discoveries, which are discussed, along with the Big Bang theory, in Chapter 13.

12.5

CHECK YOUR Understanding

1. What observations contributed to each Aboriginal legend or belief mentioned in this section?
2. Identify the astronomical phenomenon behind each Aboriginal legend mentioned in this section. What does the legend say to listeners?
3. What skills must Chinese and Greek astronomers have acquired before they could construct their calendars?
4. The Moose Mountain medicine wheel in Saskatchewan, considered a twin of the Big Mountain medicine wheel in Wyoming (Figure 13), was constructed by the Northern Plains people around 2000 years ago. Many astronomers believe that the Moose Mountain medicine wheel indicates the point on the horizon where the Sun rises on the first day of summer and in the week before the first day of winter. The wheel also shows where the stars Aldebaran, Sirius, and Rigel rise, just before the Sun, at one-month intervals during the summer and where the star Fomalhaut rises at dawn around the winter solstice. How do you think the Northern Plains people depended on the dates marked by the medicine wheel?

Figure 13

5. (a) Describe the model that people used to explain the solar system 1500 years ago.
   (b) Describe the model that we use today.
6. Some people believe that Ptolemy did not actually believe in the geocentric model. If so, why was the model so widely accepted?
7. Who first proposed that Earth revolves around the Sun? What evidence did he use?
8. Why was the geocentric model flawed?
9. (a) What astronomical phenomenon inspired Tycho Brahe?
   (b) Why did this phenomenon lead Brahe to describe the heavens as changing and not fixed?
10. Which model of the solar system best explained the problem of retrograde motion?
11. Describe Kepler's Laws of Planetary Motion in your own words.
12. What tools did Kepler use to determine his laws?
13. Copy and complete Table 1. List the astronomers mentioned in this section in chronological order.

Table 1

Astronomer	Years of birth and death	Contribution to astronomy

14. Our understanding of the universe today is much more complex than it was 2000 years ago. Explain how our understanding of the universe has improved in modern times.
15. Imagine how our lives may have been different if Tycho Brahe had not been willing to share his data with Kepler. Do you think Kepler, or someone else, would have eventually figured out that Earth revolves around the Sun?

12A Investigation

Sunrise and Sunset: Measuring the Photoperiod

The photoperiod varies throughout the year, based on the apparent motion of the Sun. In this Investigation, you will learn more about the photoperiod in your area.

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Question

Throughout the year, how do the times of sunrise and sunset vary in your area?

Hypothesis

If there is a difference in the sunrise and sunset times throughout the year, then the times will change by the same amount each day.

Prediction

Predict how the times of sunrise and sunset in your area vary monthly throughout the year. To begin, consider when the longest and shortest days of the year occur and what the length of the photoperiod is for these days.

Design

This Investigation is called a retrospective study. It is the type of investigation in which you take available data, analyze it, extract new information, and make predictions. The data you will analyze are sample sunrise and sunset times in your area.

Materials

- local newspapers, books, Internet sites, and other sources of information for the times of sunrise and sunset in your area

Procedure

1. Find the times of sunrise and sunset in your area. Select biweekly data over a year, starting January 1.
2. Record your data in a table. (Hint: It may be easier to complete your analysis if you convert your times to the 24 h format.)
3. Plot your data on a graph. Make separate lines for sunrise and sunset on the same graph to see the trend of the changing photoperiod. Place the time of year on the *x*-axis and the length of the photoperiod on the *y*-axis.

Analysis

(a) Describe the actual shape of your graph.

(b) Answer the Question.

(c) Was your prediction accurate?

(d) Write a conclusion about how the sunrise and sunset times in your area change throughout the year.

Evaluation

(e) How confident are you that your sources of information are accurate? Why do you think they are accurate?

Synthesis

(f) Speculate how the photoperiod in different regions across Canada might affect the demand for electricity.

12B Investigation

Retrograde Motion

Some planets, for example, Mars, Jupiter, and Saturn, exhibit retrograde motion once every year. The apparent backward loop of these planets is caused by the fact that they have orbits of differing lengths and speeds. In this Investigation, you will model Mars's retrograde motion. You will see that the heliocentric model of the solar system accounts for a planet's retrograde motion, while the geocentric model does not.

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ○ Evaluating
- ○ Synthesizing
- ● Communicating

Question

When is Mars in retrograde motion?

Prediction

Using the drawing from your teacher, predict when Mars is in retrograde motion.

Materials

- 2 "planets" (polystyrene balls, one red and the other blue, on 1.5 m sticks)
- whiteboard marker
- measuring tape
- 22 cm × 36 cm paper
- graph paper
- ruler

Procedure

1. Create a clear floor space in front of the whiteboard in the classroom. Your teacher has marked the orbits of Earth and Mars on the floor using masking tape and a marker.
2. At the far right of the whiteboard, mark a point O at the same height as the "planets" on sticks. Label it 0 cm.
3. Work in a group of three. Choose a date for which your group will record the positions of Earth (blue ball) and Mars (red ball).
4. For the first date (February 1), the Earth person closes one eye and tells the recorder at the whiteboard where to place an X on the whiteboard so that the X is directly in line with the two planets. The Mars person holds Mars in place.
5. The recorder measures the distance from O to X and the date for which the measurement was taken.
6. Repeat steps 4 and 5 so that all the groups have recorded a date.
7. Copy the information on the whiteboard onto the 22 cm × 36 cm paper. Title it "Retrograde Motion of Mars."
8. Copy and complete Table 1.

Table 1 The Motion of Mars

Date	Distance from 0 cm
February 1	
February 15	

Analysis

(a) Plot the data from Table 1 onto a graph, with the date on the *x*-axis and the distance on the *y*-axis.

(b) When was Mars in retrograde motion?

(c) Which tool (table or graph) was easier to use to determine when Mars was in retrograde motion?

(d) Which planet, Earth or Mars, takes longer to orbit the Sun?

(e) Why does Mars exhibit retrograde motion?

12C Investigation

Using a Star Map

In this Investigation, you will learn how to use a star map. Star maps show the constellations and bright stars in the sky that are visible from either the northern or southern hemispheres at a certain time of the year. Although some star maps are specific to each month, the star map you will use can be used throughout the year and is specific to the northern hemisphere. See "Using Star Maps" on page 533 in the Skills Handbook.

INQUIRY SKILLS

○ Questioning	● Conducting	○ Evaluating
○ Hypothesizing	● Recording	○ Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

Question

Can the stars of the Big Dipper be used to locate other constellations in the northern hemisphere?

Prediction

Examine the star map, and predict how you can use the Big Dipper to locate other constellations.

Materials

- star map
- ruler

Part 1: Circumpolar Constellations

Procedure

1. Locate the Big Dipper in Figure 1. Using a ruler, draw lines on your star map to join the stars that create the image of the Big Dipper.

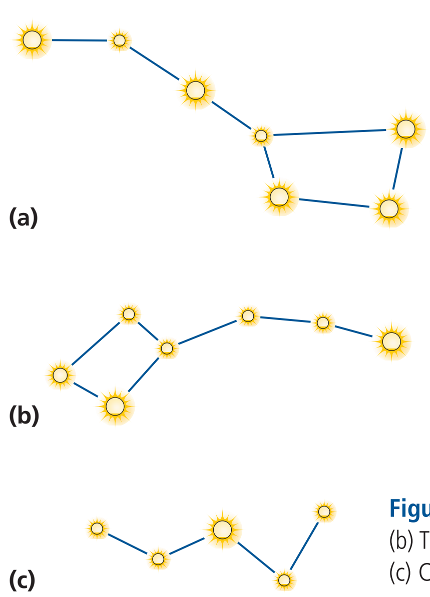


Figure 1 (a) The Big Dipper (b) The Little Dipper (c) Cassiopeia

2. Find the Little Dipper in Figure 1. On your star map, draw in the lines for the Little Dipper. Label the star at the tip of the handle "Polaris." Regardless of your position in the northern hemisphere or the time of year, this star is always visible. Polaris is also called the North Star because you need to face toward the North Pole in order to see it.
3. On your star map, locate the two stars of the Big Dipper that are the farthest from the handle. These two stars are called pointer stars because they can be used to point toward other constellations. Using the pointer stars, draw a straight dashed line to Polaris.
4. Continue your dashed line until you reach Cassiopeia, a constellation that resembles a stretched out M or W (Figure 1(c)). Join the stars of Cassiopeia.
5. Label all three constellations on your star map. Check with your teacher to make sure that you have labelled your star map correctly so far.
6. There are several other constellations that are visible in the Canadian night sky during different seasons (Figure 2). On your star map, locate the three stars in the constellation Orion that make up the imaginary hunter's belt. Draw in this constellation. You will notice that Orion is located near a region of the star map marked "December." Orion can be seen most easily during the month of December. Label the stars Rigel and Betelgeuse within Orion too.

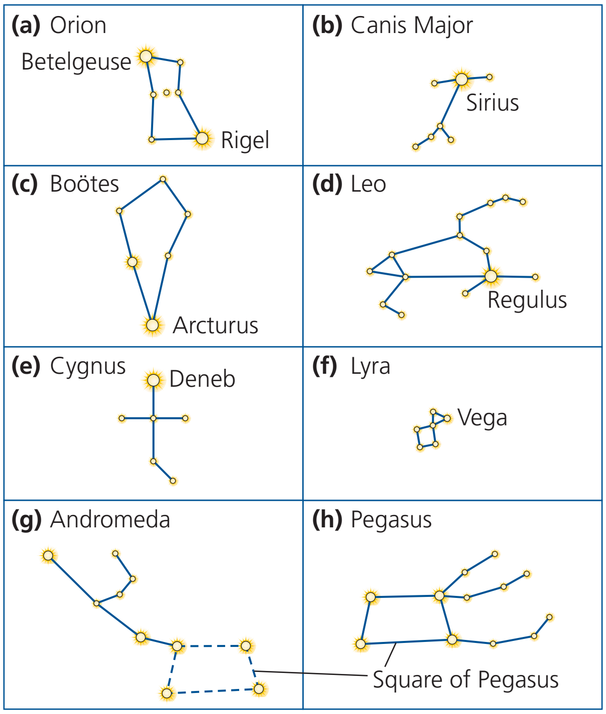


Figure 2

7. Draw a dashed line to show how you would use Orion's belt to locate the brightest star in the night sky, Sirius. Draw Canis Major, the constellation that contains Sirius.
8. Locate and draw the constellation Boötes on your star map. To find Boötes, first look for the star Arcturus, which is part of this constellation. Draw a dashed line to show how you would use the handle of the Big Dipper to find Arcturus.
9. Draw the constellation Leo on your star map. Leo contains the star Regulus. Draw dashed lines to show how you would use two stars of the Big Dipper as pointer stars to Regulus.
10. The three bright stars Deneb, Vega, and Altair form the Summer Triangle. Join them with dashed lines. Deneb and Vega are in the constellations Cygnus and Lyra. Draw these constellations.
11. Draw the lines for the remaining constellations in Figure 2 on your star map. Follow the order of the constellations as they appear in Figure 2.

For each constellation, use a dashed line from another constellation. When you have finished locating and drawing all the constellations, show your teacher your map and explain how you used pointer stars. You will share your results with the class.

Part 2: Locating the Constellations of the Zodiac

12. You will notice there are still many unlabelled constellations on your star map. These are the zodiac constellations. They are visible during specific months, and the planets can be seen passing through them. You have already labelled one of the zodiac constellations, Leo. There are 11 more for you to find. The months in which they are best viewed are shown in the margin of the star map. Starting with Leo, move in a counterclockwise direction and label the rest of the zodiac constellations as follows: Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, Pisces, Aries, Taurus, Gemini, and Cancer.

Analysis

(a) Which constellations are visible from Canada in all seasons?

(b) Using your star map, identify two constellations that you can see from Canada during each of the four seasons.

(c) Describe how you used pointer stars in the Big Dipper to find three other constellations. Was your prediction accurate?

(d) Look at your star map again. Can you find any other uses for pointer stars? Draw these uses with dashed lines, and describe them.

(e) To locate the constellations at night, you stand facing north and hold the star map with the current month at the top. Why do you hold the star map this way?

CHAPTER 12

Review

The Solar System

Key Ideas

Observing the night sky gives us clues about Earth's unique motions.

- Earth rotates around an axis, causing day and night. Changes in the Sun's position in the sky are caused by rotation and revolution. The seasons are caused by the tilt of Earth's axis (23.5°) and Earth's revolution around the Sun.
- The time required for Earth to complete one full rotation is defined as one day (24 h).
- Earth's axis undergoes precession.
- Earth's revolution around the Sun takes one year ($365\frac{1}{4}$ days).
- The planets travel in elliptical orbits around the Sun.
- The celestial sphere was a model used by ancient astronomers to explain the sky in relation to the Earth. This model, with the stars, planets, and Sun held together in fixed positions as they spun around Earth, was eventually replaced about 2000 years later.

The Earth–Moon system is responsible for several astronomical phenomena.

- The phases of the Moon occur in eight distinct stages that make up the lunar cycle.
- Solar eclipses result when the Moon is positioned between the Sun and Earth, at a node.
- Lunar eclipses result when the Moon, at a node, passes through Earth's shadow.
- The Moon is primarily responsible for the tides.

Vocabulary

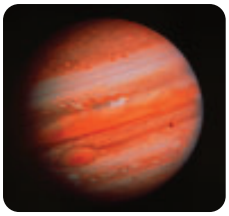
astronomy, p. 368
astronomer, p. 368
rotation, p. 368
revolution, p. 368
photoperiod, p. 368
planet, p. 369
retrograde motion, p. 369
precession, p. 370
perihelion, p. 371
aphelion, p. 371
constellation, p. 372
celestial sphere, p. 373
celestial equator, p. 373
plane of the ecliptic, p. 373
equinoxes, p. 373
solstices, p. 373
circumpolar, p. 374
lunar cycle, p. 376
solar eclipse, p. 377
lunar eclipse, p. 377

Theories on the formation of our solar system are based on evidence.

- According to the Big Splash theory and evidence collected by the *Apollo* astronauts, the Moon is thought to be the result of an impact of a large body with Earth.
- The solar system is thought to have formed from a rotating, collapsing nebula. Evidence supporting this theory was found by the satellite IRAS, which detected a cloud of dust and gases orbiting a bright star.

The planets of our solar system have unique characteristics.

- Many planets have unique characteristics, such as their composition, size, atmospheric conditions, and distance from the Sun.
- All planets orbit the Sun in the same direction, spin on their axes, and are composed of leftover materials from the formation of our solar system.


Aboriginal peoples and other cultures hold traditional views of the universe that are different than the scientific view.

- Many Canadian Aboriginal peoples use legends to explain astronomical phenomena.
- Aboriginal peoples and other ancient civilizations studied the movement of objects in the sky, making astronomy one of the oldest branches of science.

Many early astronomers contributed theories on the nature of the universe.

- Ptolemy's celestial sphere is a geocentric model of the universe that states that the Sun, all the other planets, and the stars revolve around Earth at fixed and unchanging positions in the sky.
- Noting errors in Ptolemy's mathematical formulas, Copernicus improved this model by switching the Sun and Earth.
- Copernicus's model, called the heliocentric view, explained the movement of planets in the sky better than the geocentric model.
- Tycho Brahe observed a very bright object, called a supernova, in the sky where no object had been known to exist. Brahe's observation sparked new interest in the idea that the universe is changing, unlike Ptolemy's celestial sphere.
- Kepler used Brahe's data to devise what are known as his three laws of planetary motion. He proved mathematically that the Sun is the centre of our solar system.

nodes, p. 378
tides, p. 378
nebula, p. 381
protoplanet, p. 381
outer planets, p. 382
gas giants, p. 382
inner planets, p. 382
terrestrial planets, p. 382
minor bodies, p. 383
asteroid, p. 383
meteoroid, p. 383
meteor, p. 383
meteorite, p. 383
comet, p. 383
Big Splash theory, p. 384
astronomical unit (AU), p. 393
astrolabe, p. 398
geocentric, p. 398
heliocentric, p. 399
Kepler's Laws of Planetary Motion, p. 401

Review Key Ideas and Vocabulary

1. Which of the following astronomical phenomena is caused by the rotation of Earth?
   (a) the seasons
   (b) day and night
   (c) the solstices
   (d) the changing photoperiod
2. Which of the following astronomical phenomena is caused by the tilt of Earth on its axis?
   (a) the seasons and the solstices
   (b) day and night and the changing photoperiod
   (c) day and night and the solstices
   (d) both (a) and (c)
3. Spring tides are
   (a) rare
   (b) common
   (c) very high
   (d) especially low
4. Neap tides are
   (a) rare
   (b) common
   (c) very high
   (d) especially low
5. During one day Earth ____?____, and during one year it ____?____.
6. The longest day of the year is called the ____?____.
7. The shortest day of the year is called the ____?____.
8. When the number of daylight hours equals the number of nighttime hours, the ____?____ has occurred. The ____?____ occurs in March, and the ____?____ occurs in September.
9. Why is an eclipsed Moon sometimes dark red in colour?
10. In a table, compare four minor bodies that were mentioned in this chapter.
11. Compare the terms "geocentric" and "heliocentric."
12. There were excellent astronomers among the Chinese, Greeks, and other peoples in ancient times, yet their star maps contained only about 800 stars. What prevented these ancient astronomers from cataloguing more stars?
13. Ptolemy's geocentric model of the universe is now known to be incorrect. Why was this idea accepted for so long?
14. What is the Copernican view of the universe?

Use What You've Learned

15. Compare spring tides and neap tides. Include the causes of each type of tide.
16. Why do the Moon's crescent and gibbous phases appear curved?
17. What was significant about the supernova that Tycho Brahe observed, in terms of people accepting the heliocentric model?
18. In Canada, the Sun is highest in the sky on the first day of summer and lowest in the sky on the first day of winter. Use this information to design a simple calendar.
19. Refer to Table 2 in Section 12.4. Which group of planets has the greatest number of moons? What is the reason for this?
20. Copy and complete Table 1. Then plot your data in a graph, with distance from the Sun on the *x*-axis and period of revolution on the *y*-axis. What can you conclude?

Table 1

Planet	Period of revolution (years)	Distance from Sun (AU)
Mercury		
Venus		

Think Critically

21. Does the currently accepted model for the formation of the solar system suggest that there may be other solar systems, similar to ours, in the universe? Explain why or why not.
22. Do you think that the atmospheres on the other planets in the solar system might support life? Why or why not?
23. How would Earth be affected if the tilt of its axis changed to 45°? What might cause this to happen?
24. What is an effect of precession? Why do we not notice it from year to year?

25. Describe what might happen if a giant meteorite crashed into Earth's surface (a) on land or (b) on water. Look at the map of the world in Figure 1. Where would a meteorite have the least impact on human life?

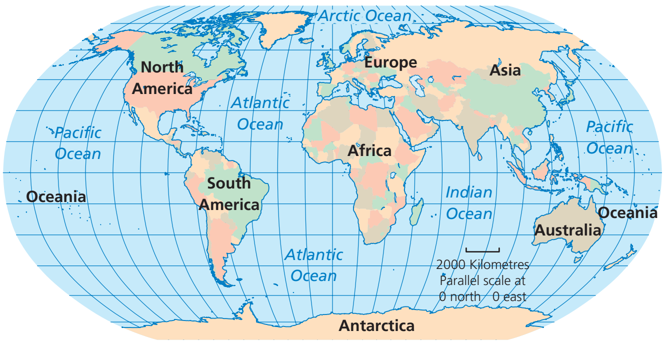


Figure 1

26. To investigate how craters on the Moon and other celestial objects are formed, drop spheres (such as rocks and rubber balls) into a box lined with sand. Try dropping the same spheres from different heights and angles. Draw the shapes of the craters you made during each trial. Summarize your findings in a table, or write a brief report stating what you have learned.

27. "Earth, the Sun, and the Moon all play a part in an eclipse, but the Moon's role is the most critical." Do you agree with this statement? Why or why not?

28. Debate the International Astronomical Union's decision to demote Pluto. Should Pluto return to its status as a planet, or should it stay classified as a dwarf planet?

29. Research the Tsimshian creation legend, and compare it with the Haida creation legend from Section 12.5. How are the legends similar? How are they different?

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30. In today's advanced world of scientific discoveries, do you think that an incorrect idea could remain in use for very long? Explain your answer using examples.

31. Build a concept map of what you have learned in this chapter.

32. In southwestern New Mexico, the Mimbres people demonstrated a sophisticated appreciation of astronomical phenomena, such as the Moon's motion, eclipses, and supernovas, in the art on their pottery. One burial bowl shows a representation of the 1054 supernova, the Crab Nebula (Figure 2). Burial bowls had ceremonial purposes. What do you think is the significance of recording astronomical phenomena on a burial bowl? Do you think a burial bowl with a specific phase of the Moon depicted on it gives a clue to when the person may have died?

Figure 2

Reflect on Your Learning

33. Discuss some of the hardships that many of the astronomers mentioned in this chapter had in their lives. How do you think their lives were similar to your life? How were their lives different?

34. If you could go back in time to meet one of the astronomers mentioned in Section 12.5, who would it be? Prepare five questions you could ask this astronomer.

35. Write one question about each planet that you would like to have answered.

36. Briefly describe a time when you were stubborn about changing your opinion. What made you change your opinion? Why did it take so long for you to accept this new idea or fact?

Visit the Quiz Centre at

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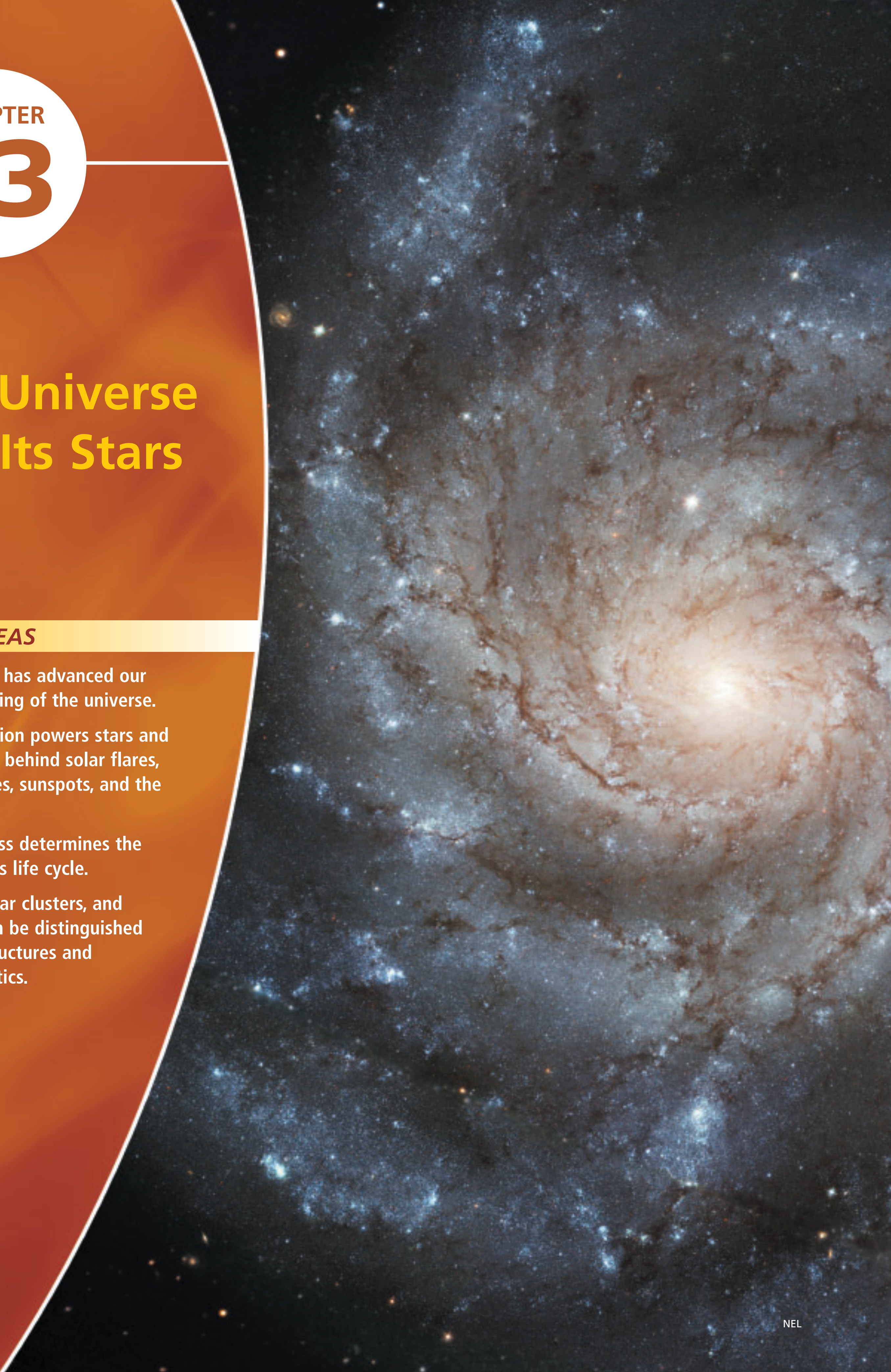
CHAPTER

13

The Universe and Its Stars



KEY IDEAS

- Technology has advanced our understanding of the universe.
- Nuclear fusion powers stars and is the force behind solar flares, prominences, sunspots, and the solar wind.
- A star's mass determines the stages of its life cycle.
- Galaxies, star clusters, and nebulas can be distinguished by their structures and characteristics.

Chapter Preview

On a clear, moonless summer evening, far away from city lights, you may look into the night sky and see a band of stars that crosses the darkness above. This band of stars is an arm of the Milky Way, the galaxy in which we live. How big is the Milky Way? Are there other galaxies like ours? If so, where are they? How close are they? Where did these galaxies come from? How do the stars produce heat and light? Are all the stars we see related in some way? In this chapter, you will learn the answers to these and many other questions about our universe and its origins.

TRY THIS: Structure in the Milky Way

Skills Focus: conducting, recording, analyzing, communicating

Materials: 216 mm × 279 mm piece of paper, clipboard, pencil

As you gaze into the night sky, the stars of the Milky Way stand out. But is the Milky Way just a simple band of stars?

Do this activity with an adult present.

1. On a clear night, away from as much light as possible, locate the Milky Way. If the night is not clear, obtain an image of the Milky Way from your teacher.
2. On a blank piece of paper draw a circle with a diameter of 15 cm as your sky map.
3. Label the bottom of the circle "North" and the top of the circle "South." Label "East" to the right and "West" to the left. Face north, and hold the paper over your head so that the "North" on your sky map points north.
4. Draw the rough outline of the Milky Way on your sky map.

A. Explain why you labelled the circle in step 3 this way.

B. Is the Milky Way a simple band of stars, or does its shape change from one end to the other? Explain.

13.1 The Origin of the Universe

Figure 1 The Hubble Space Telescope over a cloudy Earth, with its protective flap open

Figure 1 is the Hubble Space Telescope. It is named after astronomer Edwin Hubble, who made two significant discoveries. First, in 1924, Hubble confirmed the existence of other galaxies besides our own. Second, he determined that these galaxies are moving away from us and that the farther away they are, the faster they are moving. Hubble recognized the **expanding universe**.

The Evidence for an Expanding Universe

When making his discoveries Hubble relied on the phenomenon of light energy travelling as a wave. Within the visible spectrum, ROYGBV (red, orange, yellow, green, blue, violet), each colour has its own particular range of wavelengths. Red light has the longest wavelengths, and violet has the shortest wavelengths (Figure 2). Every galaxy gives off light in its own particular wavelengths. In addition, the spectrum shifts, depending upon whether the light source is standing still or moving. You will study the spectrum and tools used by astronomers in more detail in Chapter 14.

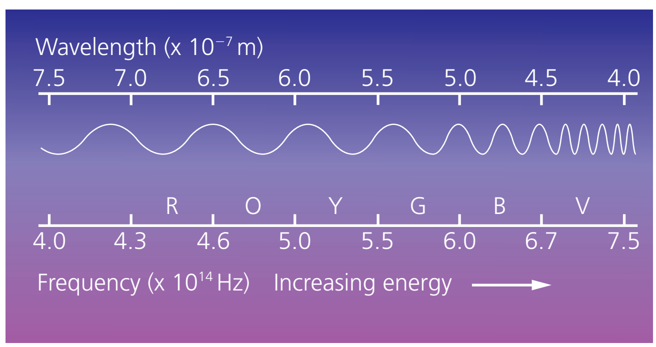


Figure 2 The visible spectrum. The wave patterns are not drawn to scale.

To understand this evidence, imagine a toy boat floating in a still pond. The slightest movements of the boat create ripples in the water that spread evenly outward from the boat (Figure 3). The distance from the crest of one ripple to the crest of the next ripple is one wavelength. This pattern represents a light source that is not moving.

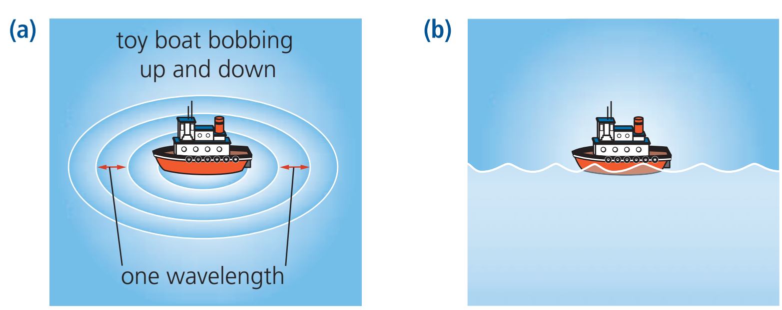
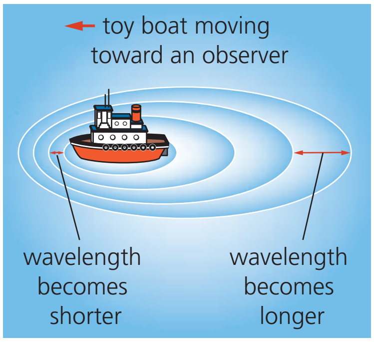


Figure 3 (a) This model shows an energy source (the boat) sending out waves (the water ripple) with a constant wavelength. (b) Side view of the boat and the waves

As the boat moves, the wavelengths of the ripples in front of the boat shorten, while the wavelengths of the ripples behind the boat become longer (Figure 4). Therefore, if all you could see were the ripples in the water, you could tell whether the moving object is moving toward you or away from you. Light and sound behave in much the same way as the water in this example. Light from a source that is moving toward an observer would have shorter wavelengths (toward the blue end of the spectrum), while light from a source that is moving away would have longer wavelengths (toward the red end of the spectrum).

Hubble and other astronomers, using an instrument called a spectroscope, used this property of light to determine that the galaxies are in motion. A spectroscope diffracts light; that is, it splits and spreads out light into a spectrum. It does this by using a diffraction grating. Diffraction gratings that contain 10 000 slits per centimetre are common and allow the precise measurements of wavelengths of light (Figure 5). The greater the number of slits in a grating, the sharper the image. 13A Investigation

By examining the light from different galaxies with a spectroscope, Hubble and other astonomers discovered that the spectra from the galaxies, although unique, had some common features. When the pattern for hydrogen in the spectrum of one galaxy was examined, it appeared to be shifted toward the red end of the spectrum, compared with the pattern for hydrogen observed in a laboratory. By being shifted toward the red end of the spectrum, where wavelengths are longer, astronomers concluded that the galaxy being observed was moving away from us. Such a movement of the spectral lines into the longer wavelengths of the red end of the visible spectrum is called a **red shift** (Figure 6). The greater the red shift, the faster the galaxy is moving away, and the farther away it has to be. This is a relationship explained by Hubble's expanding universe.



(a)

(b)

Figure 4 (a) The wavelengths become shorter in one direction and longer in the other direction. (b) A side view of the waves created by a boat moving to the left

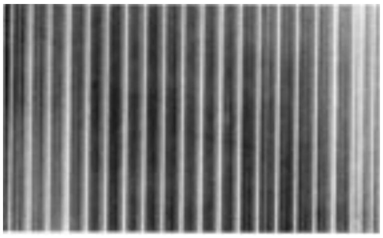
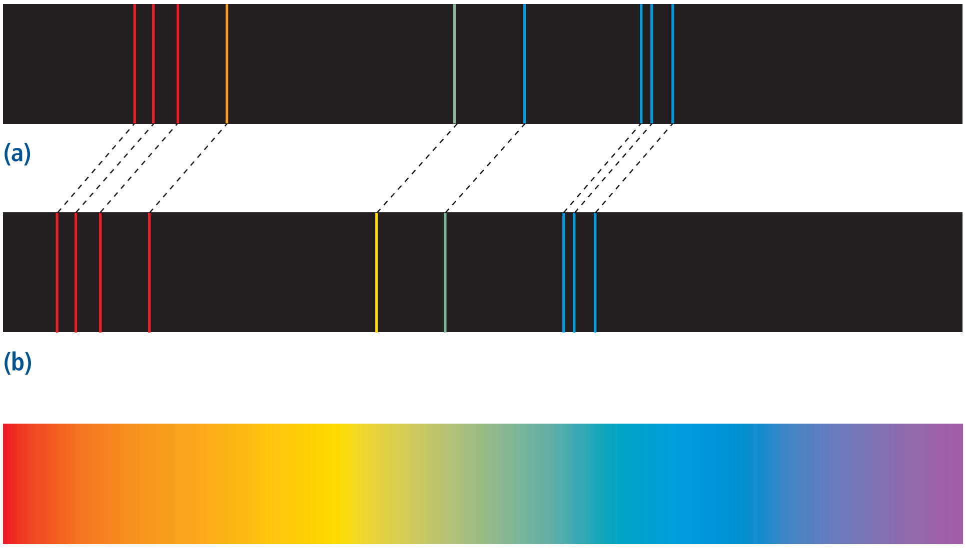


Figure 5 A microscopic view of a ruled grating



(a)

(b)

(c)

Figure 6 (a) A sample spectral shift for a stationary galaxy (b) The same spectrum with the galaxy moving away from Earth (c) The spectrum for white light as a reference

13A Investigation

Bright Line Spectra

To perform this investigation, turn to page 446.

In this investigation, you will use a spectroscope to observe the spectra of a variety of light sources.

In the 1930s, it did not take long for astronomers to take Hubble's idea one step further. They hypothesized that if the galaxies are speeding away from each other, then there must have been a point in space and time when the universe had a beginning. This beginning point, or time zero, is currently accepted as being 13.7 billion years ago. The location is unknown. At time zero, all the matter and energy in the universe were packed together into one immeasurably dense, hot mass. From this point of origin, an enormous fireball hurled everything outward in a "big bang." This scientific theory, known as the **Big Bang theory**, is the most widely accepted explanation of the phenomena we observe in the universe, including the origin of the universe itself.

TRY THIS: *The Ballooning Universe*

Skills Focus: conducting, recording, analyzing, evaluating, communicating

Materials: large balloon (to be inflated to 30 cm in diameter)
water-soluble marker

Hubble's expanding universe can be modelled by an ordinary spherical balloon. Two characteristics of the expanding universe can be demonstrated in this model: expansion and the boundary.

1. Inflate the balloon slightly, and draw a series of equally spaced dots (about 1 cm in diameter) to represent galaxies.
2. Inflate the balloon to about 30 cm in diameter. Be careful not to overinflate it. Record your observations.
3. Slowly deflate the balloon to about 10 cm. Again, record your observations.
4. Completely deflate the balloon.

A. What happened to the distance between the dots as you inflated the balloon to 30 cm in diameter?

B. How does the change in A correlate with what astronomers observe today?

C. After step 3, what happened to the distance between the dots?

D. In this model, what does the completely deflated balloon represent?

E. In this model, if the collapse could continue, what would happen to all the dots, or galaxies?

F. If the deflated balloon represents the starting point of the Big Bang 13.7 billion years ago, what does the surface of the balloon represent as it is inflating?

G. How is this model an accurate representation of the expanding universe? What are the shortcomings of this model?

Did You KNOW?

The Big Bang

Astronomer Fred Hoyle sarcastically used the phrase "this big bang idea" in response to a colleague's interpretations of Edwin Hubble's discovery (and Einstein's theories). Hoyle made the remark during a British radio program broadcast on March 28, 1949, and it appeared in print in 1950. The name stuck, and the idea has become a theory!

Modern Support for the Big Bang Theory

From the fireball 13.7 billion years ago, which began from an incredibly tiny and dense object, all the matter and energy in our universe have been spreading outward.

Astronomers can gather information about the Big Bang because looking into space is like looking back in time. For example, light takes about 8 min to reach us from the Sun. Therefore, the light we see now originated 8 min ago. The farther away the source of light or radiation, the longer it takes to reach us.

If we look deeply enough into space, we should be able to see what remains of the Big Bang. Furthermore, we should also be able to make our observations from anywhere within the universe. Regardless of where we look, the remnants of the Big Bang should be visible in any direction.

In 1965, using a new microwave antenna, researchers detected radiation coming from every direction. Today, many scientists believe that this radiation is the remnant of the Big Bang, and it likely represents the outer boundary of our universe. Scientists estimate that the radiation has a temperature of −273 °C and corresponds to an age of 13.7 billion years.

COBE and WMAP Provide Evidence for the Big Bang

In 1992, the Cosmic Background Explorer (COBE) satellite found very slight differences in the temperature of the cosmic microwave background radiation (Figure 7). This meant that matter spreading out from the Big Bang was not evenly distributed. The red and blue spots in Figure 7 are regions of different densities, representing the distribution of matter and energy in the early universe before the stars and galaxies condensed out of the Big Bang.

In 2006, data from the Wilkinson Microwave Anisotropy Probe (WMAP) confirmed the age of the universe to be 13.7 billion years ±200 million years. The warmer (red) and cooler (blue) spots in Figure 8 represent different densities in the matter of the early universe. They show the beginnings of all the galaxies that were to form. Studies of these images have helped scientists pinpoint when the first stars formed and have provided clues about the first trillionth of a second of the universe.

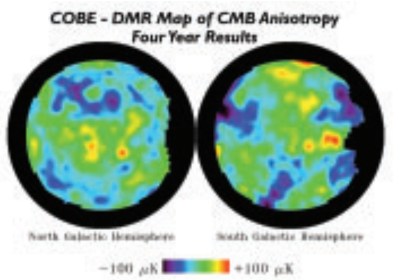


Figure 7 This updated (1996) COBE image shows tiny variations in the cosmic microwave background radiation, a remnant of the Big Bang (colour added).

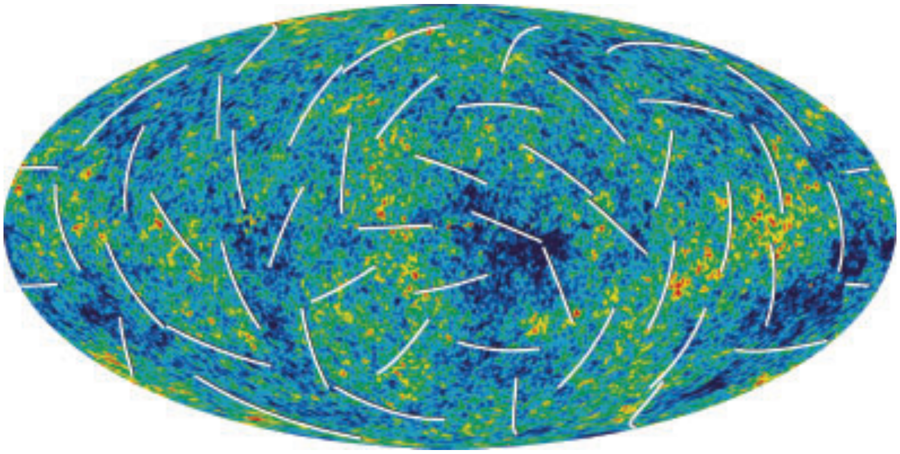


Figure 8 Data from WMAP (2006)

The COBE and WMAP evidence supports the Big Bang theory, but there are still some gaps in our knowledge. For example, parts of the theory can explain what scientists see from the present back to the smallest fraction of time after the Big Bang. Modern physics has yet to explain what happened during that fraction of a second after the Big Bang.

Changing our theories about the universe is all part of the ongoing process called science. New discoveries bring new knowledge, and with the new knowledge may come changes to a theory. This is not a fault of science; it is a strength. The scientific method can test scientific theories, explore them, and ultimately support or refute them with new evidence from new discoveries.

If you would like to learn more about the Big Bang theory, go to **www.science.nelson.com**

13.1 CHECK YOUR Understanding

1. Draw a simple labelled diagram to illustrate a wavelength.
2. What are the colours of the visible spectrum?
3. (a) List the wavelength ranges for red light and violet light.
   (b) Which has the greater energy, red light or violet light?
   (c) Using Figure 9 as a reference, draw and label a single wavelength of red light and a single wavelength of violet light. [Note: The wavelengths in Figure 9 are not drawn to scale.]

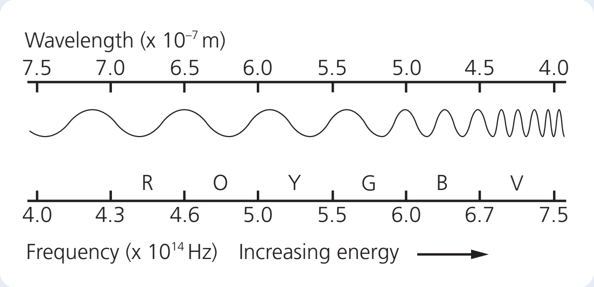


Figure 9

4. The ripples in Figure 10 were made by an unseen moving object. Copy Figure 10 into your notebook. Label the longer and shorter wavelengths. Place a dot where the unseen object is likely to be found. Indicate the direction in which the object is moving.

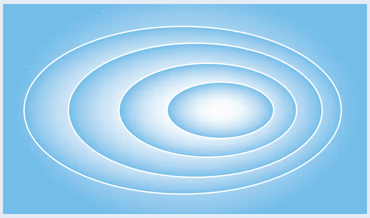


Figure 10

5. Describe what a spectroscope does.
6. What information can astronomers gain about stars by using a spectroscope?
7. Describe a red shift using a diagram.
8. Why does the spectrum of light given off by an object shift?
9. Explain why the spectrum of visible light that reaches Earth from another galaxy has shifted to the red end of the spectrum (Figure 11).

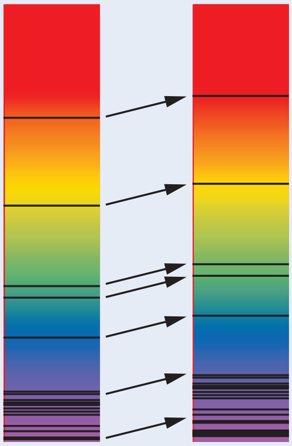


Figure 11

10. (a) In the science of astronomy, to what does the concept of time zero refer?
    (b) How long ago was time zero?
11. Why did scientists think they should be able to detect the remaining energy from the Big Bang by looking outward in any direction?
12. Explain what the red shift in the background radiation from the Big Bang tells us.
13. Why is looking out into space like looking back in time?
14. The COBE and WMAP data show the cosmic background radiation varying in temperature, density, and distribution. What did these differences in temperature, density, and distribution of matter create?
15. What is the temperature of the background radiation from the Big Bang?
16. The Big Bang theory developed after a long period of observing the universe and analyzing and interpreting the observations. The Big Bang theory will likely change as astronomers acquire new knowledge about the universe. What does this tell you about the nature of science?

13.2 Measuring Distances in Space

The universe. The word calls up images of vast, empty space, but a space that is home to all the stars in the sky. How many stars are in the universe? Our current best estimate for all the stars in all the galaxies of the universe is 1.0×10^{22} stars.

This enormous number of stars is concentrated in about 100 billion galaxies, all of different sizes and shapes. The size and shape of a galaxy affect the estimation of how many stars it contains.

LEARNING TIP

To review large numbers in scientific notation, see the section called "Scientific Notation" on page 523 in the Skills Handbook.

TRY THIS: *How Many Stars?*

Skills Focus: creating models, measuring, estimating

Materials: notebook or 216 mm $\times$ 279 mm piece of paper, calculator

How many stars can you see without binoculars? An average thimble holds enough grains of sand to represent the number of stars you can see on a clear, moonless night.

1. Draw a 1 cm $\times$ 1 cm square in your notebook or on a piece of paper.
2. Using a pen, mark a series of dots, the size of a grain of sand, along the length and width of the square.
3. Count the number of dots along each edge.

A. Calculate the number of dots needed to fill the square.

B. Calculate the number of dots (sand grains) needed to fill a cube that is 1 cm^3 in volume.

C. If an average thimble has a volume of 2.5 cm^3, how many dots or grains of sand would be needed to fill it?

D. Assuming that you had a grain of sand for each star in the Milky Way galaxy (200 billion, or 2×10^{11}), what would you need to carry this amount of sand: a 5 L pail, a household garbage can, or a dump truck? Explain how you arrived at your answer.

The 100 billion galaxies of our universe occupy a space that is unimaginably large. One estimate of the volume of our universe is 1×10^{30} cubic light years. A **light year** is the distance that light travels in one year. Light travels at a speed of 3.0×10^5 km/s, so at that speed, one light year is 9.5×10^{12} km. Although the galaxies are not evenly distributed in space, this estimate places one star for about every 1×10^9 cubic light years. The universe is mostly just empty space.

A Model of Our Local Space

The volume of the universe—1×10^{30} cubic light years—is so large that it is almost impossible to imagine. To help picture this, you can use a model. Suppose that you reduce the Sun to the size of a softball. Then you make Earth a grain of sand about 7 m away, and the Moon a pencil dot less than 2 cm from Earth. The planetary giant, Jupiter, is a marble 36 m from the Sun, while Pluto is a speck of dust about 300 m from the Sun. Sedna, in the Oort Cloud, would be two-thirds the size of Pluto and about 630 m from the Sun (as of 2006) and moving farther away.

If you would like to learn more about modelling the solar system, go to
www.science.nelson.com GO

Proxima Centauri, the nearest star, would be the size of an apricot. Each of its two companion stars, Alpha Centauri A and Alpha Centauri B, would be the size of an orange. These three stars would be 2000 km from the softball-sized Sun.

The distances are enormous, even for a model. An imaginary traveller walking non-stop with one big step every second, or 3.6 km/h, would reach Pluto in 5 min and Proxima Centauri in 23 days and a few hours. However, even after walking for almost 24 days, our traveller would only have reached our closest star neighbours and would not have made any progress out of our galaxy. GO

Measuring Distances in Space

Scientists cannot measure the distance to a star directly by laying down metre sticks or by driving to it. Therefore, they must find indirect methods to measure these great distances. There are more than a dozen ways to measure interstellar distances, that is, distances between the stars, within the universe. Radar, for example, works within the solar system to about 50 AU. Another method, using parallax, relies on mathematics.

Baselines and Parallax

The system called trigonometric parallax, or parallax, is a variation on a technique that has been used by surveyors for hundreds of years. **Parallax** is the apparent motion of a nearby star against the background of more distant non-moving stars. When measuring parallax, astronomers use a unit of distance called a

TRY THIS: *The Rule of Thumb for Parallax*

Skills Focus: conducting, observing, measuring, interpreting data, communicating

Even though people vary in size, the proportions of the human body are quite similar. For most people, the angle from a baseline formed by the distance between the eyes and a thumb at arm's length is very close to 6°. This angle is called the parallax of your thumb. Also, the distance from your eyes to your outstretched thumb is approximately 10 times the distance between your eyes.

1. Hold out your arm. With one eye open, line up your thumb with an object in the distance. Call it object A.
2. Keeping your arm and thumb still, close the open eye and open the other eye. You will notice that your thumb is no longer lined up with object A.
3. Keeping your arm and thumb still, select an object that your thumb now lines up with and that appears to be the same distance away as object A (Figure 1). Call it object B.
4. Make your best estimate of the distance between A and B. This can be done by comparing the distance between A and B with the estimated width of a building, length of a car, or distance between power poles or street lamps.
5. Given our body's proportions and the parallax effect of a thumb at arm's length, the distance from the observer to A and B is 10 times the estimated distance between A and B.

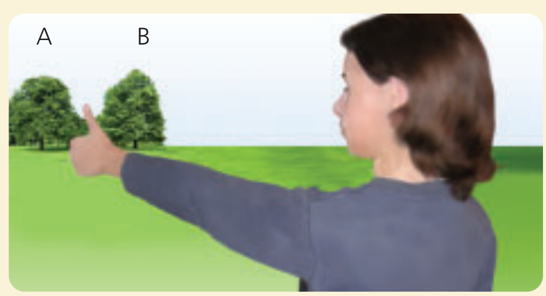


Figure 1

A. Using the method described in steps 1 to 4, estimate the distance to an object.

B. Compare your results with someone else who made the same measurement.

C. How accurate is this method?

parsec, which is equal to 3.26 light years. The first use of parallax to measure the distance to a star was in 1838. Astronomers also use a baseline to measure objects by parallax. A **baseline** is an imaginary line from which the distance to an object is measured; the length of the baseline is known.

If surveyors need to determine the distance to another object, they begin by marking out a baseline that is easy to work with, such as 30 m. They form a right-angled triangle using the baseline and the object (Figure 2). From the other end of the baseline, they measure the angle to the object. Then using a branch of mathematics called trigonometry, they determine the angle at the object and the distance back to the baseline (Figure 2). 13B *Investigation*

In astronomy, the distances to the stars are so large that very long baselines are needed to increase the accuracy of the calculations. The longest baseline astronomers can use is the diameter of Earth's orbit (Figure 3). To achieve this long baseline, astronomers must measure the angles to a star six months apart, when Earth is at opposite ends of its orbit.

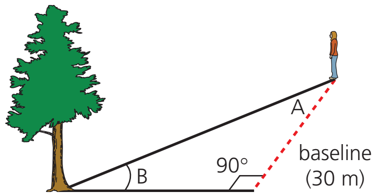


Figure 2 Using trigonometry and known values, you can determine the distance to an object.

13B *Investigation*

Triangulation: Measuring Distances to the Stars

To perform this investigation, turn to page 448.

In this investigation, you will use triangulation to measure the distance to an object.

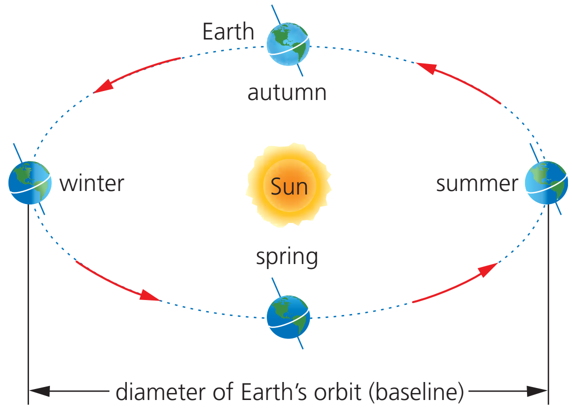


Figure 3 The diameter of Earth's orbit creates the longest possible baseline for astronomers.

The parallax method works well out to about 200 light years. At greater distances, the angles involved are so small that there are too many observation errors for calculations to be valid. As a result, for the more distant stars and galaxies astronomers must rely on other methods to calculate distances.

Cepheid Variables and Red Shift

Cepheid variable stars and red shift are the two most useful techniques for measuring distances in space.

Cepheid variable stars are one of the standard candles of the universe. **Standard candles** are objects of either known brightness or predictable behaviour that astronomers can use to determine distance. Cepheid variable stars are unstable, yellow supergiant stars that are about 1000 times brighter than our Sun and that pulse, or change in size and brightness (Figure 4). The large, bright Cepheids pulse more slowly than the smaller, dimmer Cepheids.

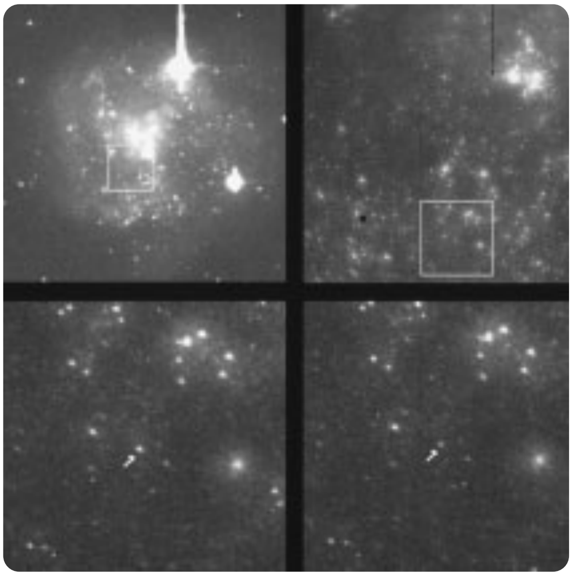


Figure 4 This galaxy is 16 million light years from Earth and contains 27 known Cepheid variable stars. The inset photos show two of its Cepheids varying in brightness.

Astronomers can use the connection between the rate of a Cepheid's pulse and its brightness, or absolute magnitude, as a measure of its distance from Earth. **Absolute magnitude** is the actual amount of light the star gives off, recorded at a standard distance. To determine distance, astronomers compare the Cepheid's absolute magnitude with its apparent magnitude. The **apparent magnitude** is the brightness of a star as it appears in the night sky (Figure 5). Therefore, when astronomers compare the absolute magnitude of the Cepheid with its apparent magnitude, they can calculate its distance from Earth because light fades with increasing distance from the observer. Fortunately, Cepheid variable stars are found in most galaxies.

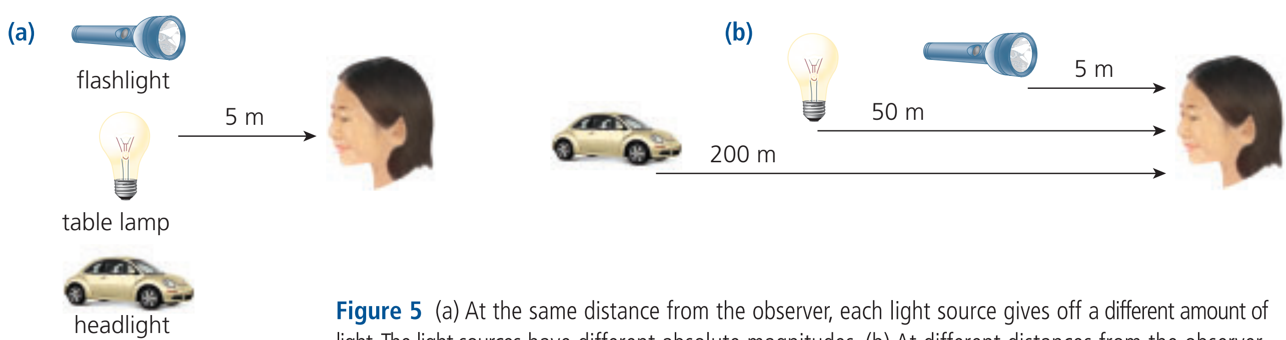


Figure 5 (a) At the same distance from the observer, each light source gives off a different amount of light. The light sources have different absolute magnitudes. (b) At different distances from the observer, all light sources seem to give off the same amount of light. They have the same apparent magnitude.

Using the red shift of a galaxy is another way that astronomers determine distance. Recall from Section 13.1 that the farther an object's spectral lines are shifted to the red end of the spectrum, the faster the object is moving away from Earth. Therefore, the more distant it must be as well. This connection is a direct result of our expanding universe. Red shift is a very useful way to measure distances to even the most remote galaxies (Figure 6).

LEARNING TIP

As you study Figure 6, ask yourself, "How do astronomers use red shift to determine speed and other properties of celestial objects?"

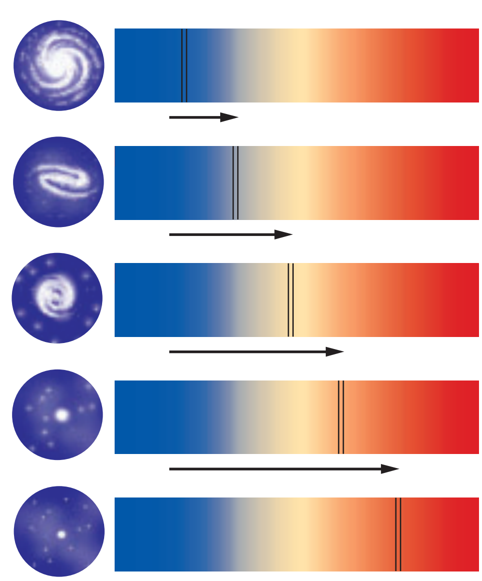


Figure 6 The farther the spectral lines are shifted to the red, as illustrated by the double lines, the faster the galaxy is moving, and the farther away it is.

SAMPLE PROBLEM 1

Determining Time to Travel Interstellar Distances

(a) The speed of light is 300 000 km/s. How far will light travel in three years?

(b) If you could travel at 14 500 km/h, how many years would you take to travel three light years?

(c) If a human generation averages 50 years, how many generations of people would be born and die in the time you would take to travel three light years?

Solution

(a) One light year is 9.5×10^{12} km.

$$3.0 \times 10^5 \frac{\text{km}}{\cancel{\text{s}}} \times 60 \frac{\cancel{\text{s}}}{\cancel{\text{min}}} \times 60 \frac{\cancel{\text{min}}}{\cancel{\text{h}}} \times 24 \frac{\cancel{\text{h}}}{\cancel{\text{d}}} \times 356 \frac{\cancel{\text{d}}}{\cancel{\text{year}}} \times 3 \cancel{\text{years}} = 28.5 \times 10^{12} \text{ km}$$
$$= 2.85 \times 10^{13} \text{ km}$$
$$= 2.9 \times 10^{13} \text{ km}$$

In three years, light will travel 2.9×10^{13} km.

(b) The formula needed to calculate time comes from the formula for speed:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Rearrange the speed equation to solve for time.

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

First, calculate the number of hours you would take to travel three light years.

$$\frac{2.9 \times 10^{13} \text{ km}}{1.45 \times 10^4 \text{ km/h}} = \frac{2.9 \times 10^{13} \cancel{\text{km}} \times \text{h}}{1.45 \times 10^4 \cancel{\text{km}}}$$
$$= 2.0 \times 10^9 \text{ h}$$

Second, convert the number of hours into years.

$$2.0 \times 10^9 \cancel{\text{h}} \times \frac{1 \cancel{\text{d}}}{24 \cancel{\text{h}}} \times \frac{1 \text{ year}}{365 \cancel{\text{d}}} = 0.000\,228 \times 10^9 \text{ year}$$
$$= 2.28 \times 10^5 \text{ year}$$
$$= 2.3 \times 10^5 \text{ year}$$

You would take 2.3×10^5 years to travel three light years, at 1.45×10^4 km/h.

(c)
$$230\,000 \cancel{\text{years}} \times \frac{1 \text{ generation}}{50 \cancel{\text{years}}} = 4600 \text{ generations}$$

In 2.3×10^5 years, 4600 generations of people will be born and die.

Practice

(a) A nearby Sun-like star with a known planet is Epsilon Eridani. Epsilon Eridani is 10.5 light years away. If you could travel at 50 000 km/h, how many years would you take to reach this star?

(b) If a human generation averages 50 years, how many generations of people will be born and die in the time you would take to travel to Epsilon Eridani?

LEARNING TIP

If you are having difficulty completing the practice problem, go back through the problem and go step by step to try to find where you went wrong.

13.2 CHECK YOUR Understanding

1. With 1×10^{22} stars in the sky, list several factors that limit us to being able to see only about 2000 to 3000 (Figure 7).

Figure 7

2. Why are the distances to the planets given in kilometres, while the distances to stars and galaxies are given in light years?
3. The Milky Way galaxy is approximately 1.0×10^5 light years across. Using correct scientific notation, express this distance in astronomical units and kilometres. (Hint: 1 light year = 9.46×10^{12} km and 1 AU = 1.5×10^8 km.)
4. What is the current estimate for the number of galaxies in the universe?
5. What is the estimated volume of our universe?
6. What is a baseline? What baseline is used in astronomy? Why do we need to vary the length of the baselines we use?
7. When you line up your thumb with an object in the distance and see your thumb "jump" compared with the object, what did you do and what baseline did you use?
8. Explain why parallax only works for stars that are less than 200 light years away.
9. When using triangulation to determine distances indirectly, what can you do to improve the accuracy of your measurements?
10. What is a Cepheid variable star, and what makes it variable?
11. Why is a Cepheid variable star referred to as a standard candle?
12. Explain the difference between absolute magnitude and apparent magnitude. Refer to Figure 5 on page 422.
13. How does the brightness of a light source change with distance?
14. What is the connection between a Cepheid variable star's pulse and its brightness?
15. Observations of a pair of Cepheids reveal that Cepheid A is pulsing faster than Cepheid B. Which of the two has a greater absolute magnitude?
16. What two conclusions can an astronomer make about a galaxy with a slight red shift and a galaxy with a large red shift? Refer to Figure 6 on page 422.
17. (a) The closest star to our solar system, Proxima Centauri, is 4.2 light years away (Figure 8). What is the distance to Proxima Centauri in kilometres?
    (b) How many hours would a spacecraft travelling at 40 000 km/h take to reach Proxima Centauri?
    (c) How many years would the spacecraft take?
    (d) If we consider a human generation to be roughly 50 years, how many generations would pass during the trip?

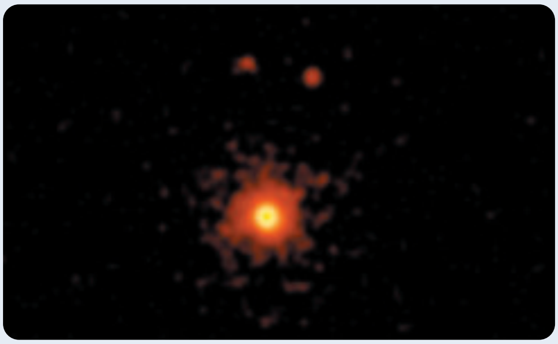


Figure 8

13.3 The Birth of Stars, and the Sun

Stars have a life cycle: they have a beginning (birth), a midlife, and an end (death). The Sun, our closest star, has been around for 5 billion years, and it will be around for another 5 billion years, so we are in no rush to find a new home. But what is a star? A study of our Sun provides some answers.

Stellar (Star) Birth

Stars are formed when nebulas collapse in on themselves. Small amounts of matter collide and stick together, becoming larger masses with increasingly stronger gravity. The increased gravity may be the trigger for a nebula to collapse. Another trigger could be the impact from a shock wave of gas and other matter from a supernova.

Regardless of how the nebula begins to collapse, it will form regions of greater density. One region that is slightly denser than the rest of the nebula will pull more of the gaseous hydrogen to itself, and it will begin to grow. This is the protostar. As the protostar becomes denser, it will draw more material to itself. As the material speeds into the centre of the protostar, its thermal energy (heat) becomes great enough to start the process of nuclear fusion, which releases an enormous amount of energy. The star ignites.

Nuclear Fusion

In the core, where temperatures and pressures are high enough, hydrogen nuclei fuse to form helium nuclei, with a small loss of mass, in a process called **nuclear fusion**. The fusion of six hydrogen protons produces one helium nucleus with two protons and two neutrons. The reaction releases an enormous amount of energy in the form of heat, light, X-rays, gamma rays, and energetic particles such as positrons and neutrinos, as well as two free protons (Figure 1).

LEARNING TIP

Diagrams show written information in a simplified way. To prepare for reading Figure 1, survey the diagram as a whole and then read the key. What does the diagram show? Read the caption, and follow the path of the arrows. What do the arrows tell you?

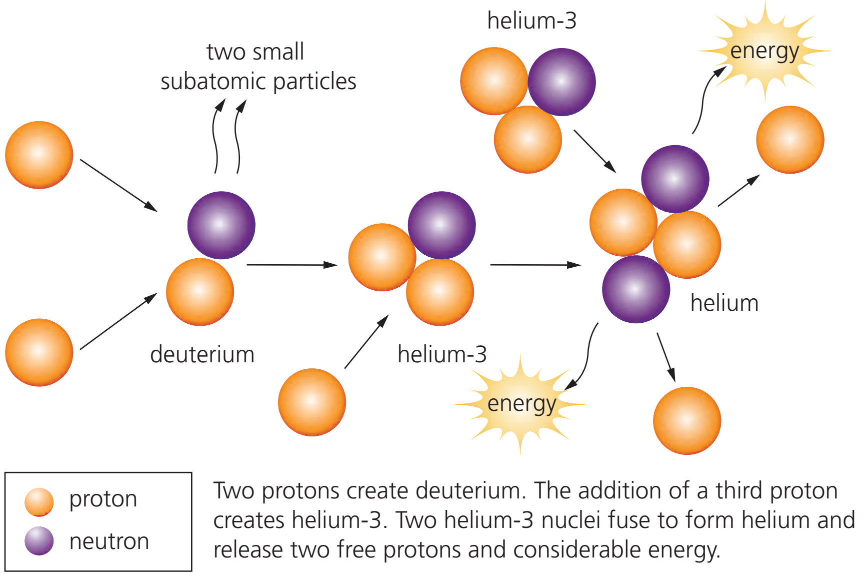
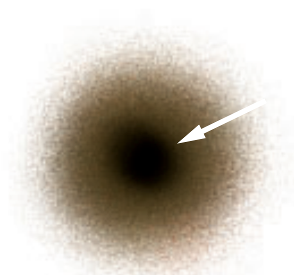


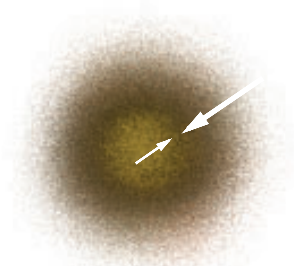
Figure 1 This is a simplified diagram of nuclear fusion in stars, including the Sun. Six hydrogen protons fuse in a series of steps to become one helium nucleus. The process releases an enormous amount of energy.

(a)



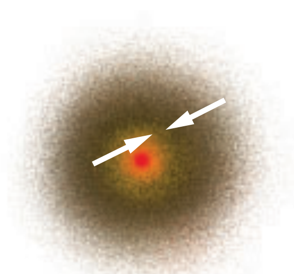
Gravity collapses a nebula into a protostar.

(b)



Fusion begins in the core, and thermal expansion pushes outward.

(c)



Thermal expansion and gravity balance each other out, and the size of the star is set.

Figure 2 The beginning of a protostar

Nuclear fusion at extreme temperatures in the core produces helium, which concentrates in the core. Nuclear fusion also releases massive amounts of energy and subatomic particles, which rush outward from the core of the star. This outward flow or thermal expansion counteracts the force of gravity, which is pulling inward on the star, and it stops the gravitational collapse that brought the young star to life. The young star stabilizes at a particular size (Figure 2). Our Sun went through this process, probably taking 30 million years to condense and ignite.

Stellar Midlife

The Sun works the same way as all the other stars. Every second, the Sun fuses hundreds of millions of tonnes of hydrogen into helium, with a small loss in mass in the process. The difference in mass is converted into an enormous amount of energy. This energy may take hundreds of thousands of years to travel through the outer layers of the Sun to reach the surface, where it is released as light.

Solar Anatomy

The energy-producing **core** of the Sun, at 1.5×10^7 °C, has a radius of 1.75×10^5 km. The next layer, the **radiative zone**, is about 3.5×10^5 km thick. The outermost layers of the Sun are the 2×10^5 km thick **convective zone** at 2×10^6 °C, followed by a 300 km thick **photosphere** at 5500 °C. The photosphere is the visible part of the Sun (Figure 3). The different layers of the Sun all rotate but at different speeds.

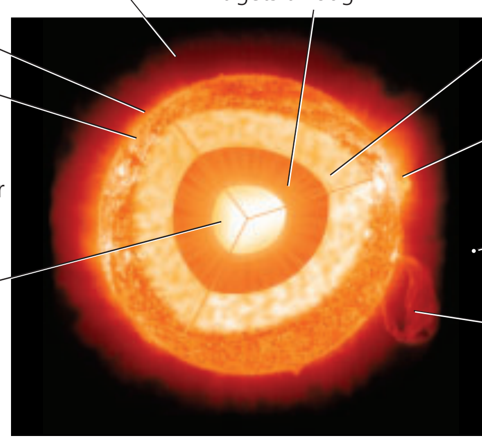


Figure 3 The structure of the Sun

Once in the convective zone, the energy is carried upward by moving streams and eddies of gas in a process called convection. The energy takes considerably less time to pass through the convective zone than it does to pass through the radiative zone. Eventually, the energy reaches the photosphere. Outward from the photosphere is the **chromosphere**, a layer of somewhat thinner gases at 60 000 °C that make up the inner atmosphere of the Sun. Outward from the chromosphere is the **corona**, the Sun's outer atmosphere of thinner gases at a temperature of 2×10^6 °C. Why the corona is hotter than the photosphere is still a mystery that scientists are trying to solve.

The Sun's Surface

Astronomers before Galileo thought that the Sun's surface was smooth and featureless. However, the photosphere is neither smooth nor featureless. Telescopes that can see details as small as 70 km on the photosphere reveal a texture similar in appearance to the surface of a boiling liquid, like tomato soup. As the heated material rises, it reaches the surface, cools, and sinks back inside. Because this happens throughout the liquid, convection cells, or granules, form side by side and give the surface the appearance of a tile mosaic. At the centre of each granule, hot solar gases radiate energy into space. The gases move to the sides of the granule and sink back into the Sun at the darker, cooler boundaries of the granule.

Dark spots, called **sunspots**, have also been identified on the surface of the Sun (Figure 4). Sunspots vary in size and regularity, and they are caused by disturbances in the Sun's magnetic field. The largest sunspot ever recorded was observed in 1947. It covered an area of 18 billion km^2, large enough to swallow Earth many times over.

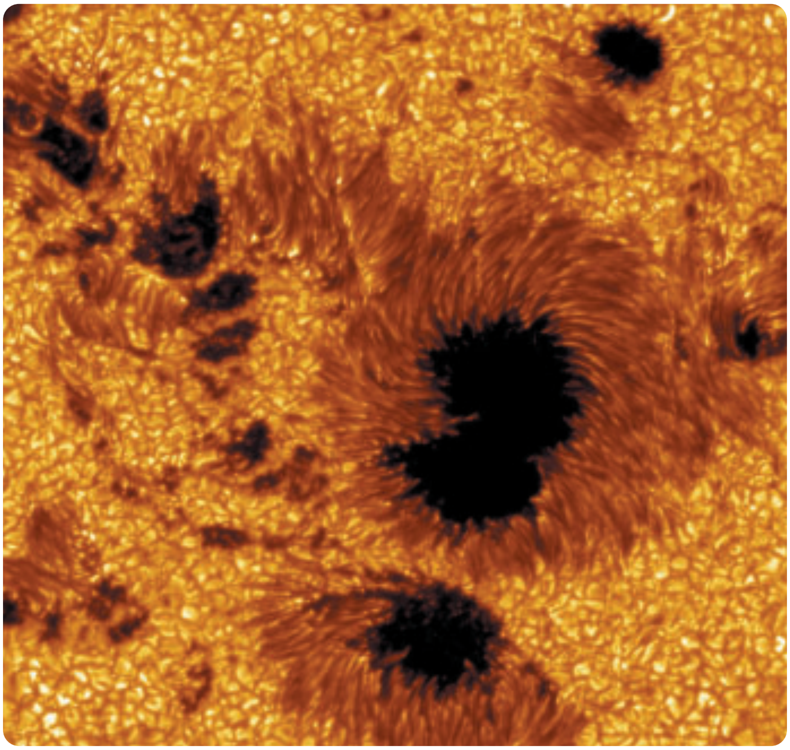


Figure 4 Sunspots consist of a dark central zone, which is large enough to swallow several Earths, and a lighter surrounding border. Also visible in this image are granules, or convection cells, where the Sun's hot gases rise to the surface, bringing heat and light that radiate into space.

Did You KNOW?

***E* = *mc*²**

Einstein's equation, $E = mc^2$, predicts that enormous amounts of energy (E) will be released from very small amounts of mass (m). The amount of energy produced is determined by the amount of mass multiplied by the speed of light, 3.0×10^5 km/s, squared. Even a small mass will release a large amount of energy. For example, 1 g of uranium yields 9×10^7 J of energy.

LEARNING TIP

Scanning allows you to locate a single word, fact, or name in the text or figure. Use this strategy when you are looking for a fact or information to respond to a specific question or to write specific details about something.

13C *Investigation*

A Rotating Sun? Sunspots Provide the Answer

To perform this investigation, turn to page 450.

In this investigation, you will predict how sunspots provide evidence that the Sun rotates.

Sunspots also appear in pairs or groups. An average two-spot group has a regular leading spot and a less regular trailing spot. Many smaller spots often surround the pair. The two sunspots in a pair have opposite magnetic polarities, and the magnetic field lines between the two spots are looped and tangled. Therefore, the Sun's magnetic field is disturbed in an area where there are sunspots. This disturbance in the magnetic field creates active regions, which release solar prominences and solar flares. In time, the magnetic field lines reform a stable pattern, and the sunspots fade until another magnetic disturbance starts the cycle again. **13C** *Investigation*

Prominences and Flares

The Sun's surface is rarely calm. The chromosphere has hundreds of thousands of spicules, narrow vertical gas jets that extend upward 10 000 km to 16 000 km. They last 4 to 5 min.

The Sun regularly releases about 1.0×10^{11} tonnes of glowing hydrogen from the photosphere as **solar prominences** (Figure 5). Twisted magnetic fields, arching into the corona from the photosphere, are thought to trap, hold, and ionize the gas in these huge looping structures for several weeks. An ionized gas is charged, that is, the atoms in the gas have one or more electrons added or removed.

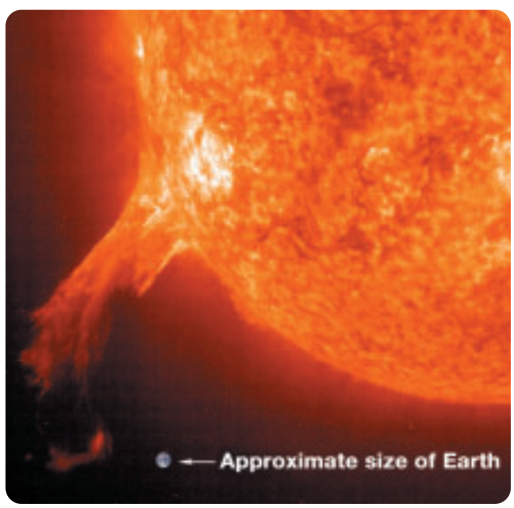


Figure 5 This image, taken by the Solar and Heliospheric Observatory (SOHO) satellite, shows a huge prominence forming out of the photosphere. Prominences often carry solar material vast distances into space. They can last for days or even weeks, and they can grow as high as 400 000 km, which is greater than the distance from Earth to the Moon.

Solar flares, which occur above active sunspots, eject large quantities of gas and charged particles. Solar flares are produced by the rapidly changing magnetic fields around sunspots, and they only last a short time. Solar flares also emit high-energy X-rays and ultraviolet radiation.

The **solar wind**, emitted from the Sun all the time, is ionized gas. The solar wind is strongest when there are solar flares and prominences. As the charged particles race past Earth at 300 to 400 km/s, many are caught in our own magnetic field. Not only do the charged particles create the aurora borealis, but they disrupt our communications equipment and other electronic systems. GO

If you would like to learn more about the surface of the Sun, go to **www.science.nelson.com** GO

13.3 CHECK YOUR Understanding

1. Approximately how old is our Sun?
2. What do nebulas form?
3. Why is hydrogen the most common element in the universe?
4. Describe how a star forms. Use a diagram for each significant stage of your description.
5. What causes a nebula to collapse?
6. Describe the role of gravity in the formation of a star.
7. What is required for nuclear fusion to begin?
8. Fusion produces helium from hydrogen. Consult the Periodic Table at the back of this textbook, and explain why helium concentrates in the core of a star.
9. When fusion occurs in a star, how many hydrogen nuclei are required to create one helium nucleus?
10. At what step in the fusion process to produce helium is energy released? What forms does this energy take?
11. What happens to a star when thermal expansion balances the force of gravity?
12. In a diagram, show the pathway of light from its point of origin through each zone of the Sun. Include labels and a brief explanation of what happens in each zone.
13. Why is a total solar eclipse the best time to view the chromosphere and the corona?
14. What causes sunspots?
15. In a labelled diagram, show the structure of a pair of sunspots as well as the difference in size of the leading and trailing spots. In a second diagram, label the two spots "North" (the leading spot) and "South" (the trailing spot), and include several magnetic field lines running from one to the other.
16. In a diagram, show how convection cells bring heat and light to the surface of the Sun.
17. Using the cross-sectional area of Earth as 5.0×10^8 km^2, calculate how many Earths would have fit into the sunspot observed on April 8, 1947 (Figure 6).

Figure 6

18. Compare a solar prominence and a solar flare, and explain their effects on Earth.
19. What is the solar wind, and what effects can it cause on Earth?
20. The pattern of circulation of heated material in Figure 7 models what happens inside the Sun.
    (a) Which diagram represents the correct pattern of circulation in a heated liquid?
    (b) Use the kinetic molecular theory to explain your choice.

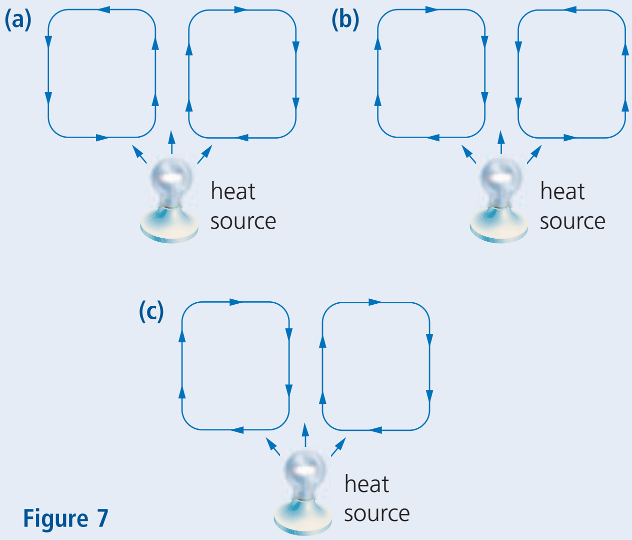


Figure 7

Science
WORKS

SOHO: THE SOLAR AND HELIOSPHERIC OBSERVATORY

Using the Solar and Heliospheric Observatory (SOHO) satellite, solar physicists and astronomers can continuously study the Sun.

Studying the Sun contributes to our understanding of climate, weather, and nuclear power processes. In addition, if we understand why and how the Sun changes, then we can understand and predict how these changes will affect us on Earth. For example, major solar flares can interrupt and sometimes damage our communications equipment.

SOHO was launched on December 2, 1995. Although it was designed to observe the Sun continuously for just two years, it celebrated its tenth anniversary in 2005, and it is still going strong. SOHO's three-fold mission is to study the internal structure of the Sun, the Sun's extensive outer atmosphere, and the origin of the solar wind.

To investigate the Sun's interior and study its behaviour, SOHO has 12 different imaging instruments. Two are particularly interesting: the Extreme Ultraviolet Imaging Telescope (EIT) and the Michelson Doppler Imager (MDI).

EIT is one of three instruments designed to study the inner corona. (Recall that the corona is the Sun's outer atmosphere.) The three instruments measure temperature, density, composition, and speed of ionized particles and gases in the corona. The instruments also provide high-resolution images of the structure of the corona. Figure 1 shows four images of the Sun taken on November 9, 1998, by the EIT. Figure 1(a) shows the corona, at a temperature of 1.0×10^6 °C, and shows the magnetic field lines of several sunspots, flares, and prominences. The other images in Figure 1 were taken within hours of each other and show similar details. Figure 1(b) shows the corona at 1.5×10^6 °C, and Figure 1(c) shows the corona at 2.0×10^6 °C to 2.5×10^6 °C. Figure 1(d) shows the upper chromosphere–lower corona transition layer at a cool 60 000 °C.

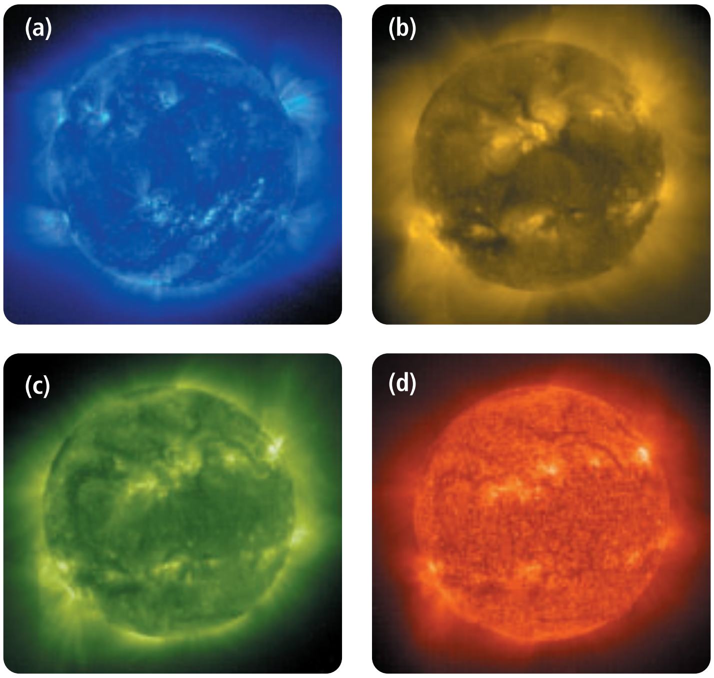


Figure 1 Four images taken by the EIT show the corona at different temperatures and reveal considerable detail about the Sun's magnetic field.

The MDI has opened up a new science called helioseismology, which is the study of the Sun's internal structure. Data collected by the MDI have revealed an internal structure more complex than previously suspected. In Figure 2, the red indicates a layer where sound travels faster than predicted. It does so because the temperature is higher than predicted. MDI has also detected a rapid change in the rotational speeds of the outer faster-moving region and the slower interior. The different rotational speeds cause stress between the layers. It is possible that this stress may cause the disturbances in the Sun's magnetic field that creates sunspots, flares, and prominences at the surface.

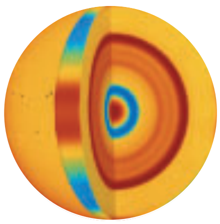


Figure 2 The internal structure of the Sun reveals the possible source of sunspots, flares, and prominences. The different colours indicate the different temperatures of the layers.

13.4

Stars: Old Age, Death, and New Life

All stars age as they use up their hydrogen. After millions or billions of years, a star enters the last stages of its life. It then either fades out of existence or explodes in a stellar life-renewing cycle.

Hertzsprung–Russell: A Life History for the Stars

Keeping track of the life history of a star became much easier when scientists realized that a star's mass determines its brightness, colour, size, and even how long it will live. Astronomers organize much of this information in a diagram called the Hertzsprung–Russell (H-R) diagram, which plots the lives of stars (Figure 1). The astronomers Elnar Hertzsprung and Henry Norris Russell independently developed this system of describing the evolution of stars. An H-R diagram shows the temperature and luminosity of stars. Luminosity is energy output, and the Sun is assigned the value of 1.

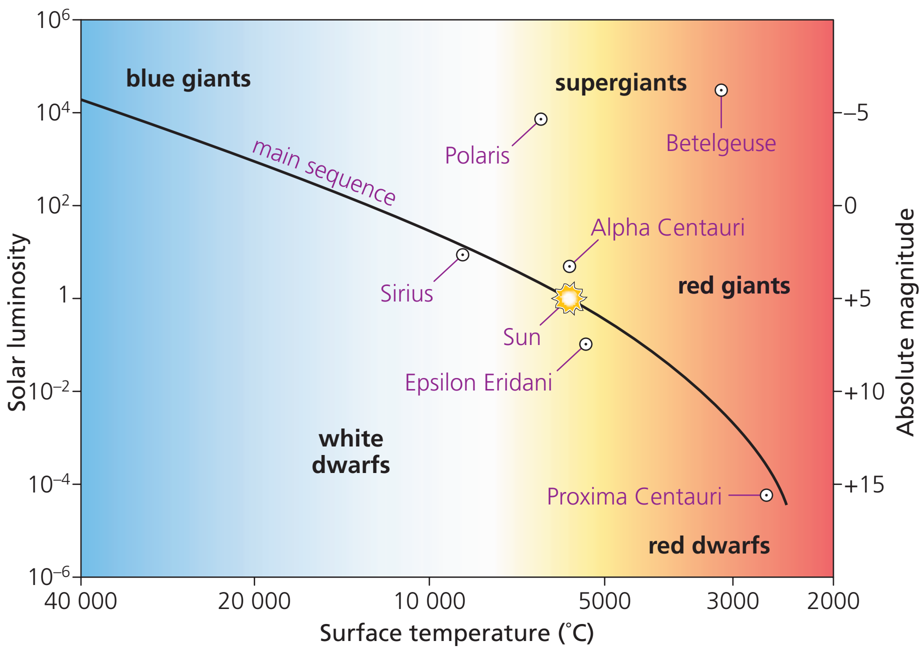


Figure 1 A typical Hertzsprung–Russell diagram shows the main sequence distribution of most stars. Our Sun can be found at a luminosity of 1, a surface temperature of 5500 °C, and an absolute magnitude of about +5. Absolute magnitude is a scale used by astronomers to rate brightness.

Most stars fit into the diagonal band in an H-R diagram called the **main sequence**. Where a star is on the main sequence band depends on its mass. Our Sun, at one **solar mass**, is the standard to which all other stars are compared. In the lower right are the cooler, reddish stars that are small and dim. Moving along the main sequence to the upper left, you pass the Sun. At the end of the main sequence are the massive, very bright, hot bluish stars, the blue giants. The cooler red giants at 0.4 to 10 solar masses and the supergiants at 10 to 70 solar masses are found off the sequence to the upper right. The white dwarfs, which are hot and one third of a solar mass, are off to the lower left.

LEARNING TIP

Check your understanding of Figure 1. What do the vertical axes represent? What does the horizontal axis represent? As you study the H-R diagram, ask yourself, "Is there a predictable relationship between the brightness and size of a star?" Where are the cool dim, bright hot, cool, and hot stars located?

Stars do not move through the main sequence as they age. Once a star is formed with a particular mass, it stays in one place on the main sequence until almost all its hydrogen fuel is used up. Then there is a change in the star's energy production, and it moves off the main sequence to the upper right to become a red giant or a supergiant. The stars in the entire H-R diagram represent different stages in the lives of stars as their fuel is consumed.

LEARNING TIP

Check your understanding. Explain to a partner the life span of the Sun: birth through adulthood, and finally fading into death.

Red Giant to a White Dwarf

After 10 billion years as a main sequence star, fusion will have converted most of the Sun's hydrogen to helium. The helium forms as a core inside a shell of the remaining hydrogen. With less hydrogen to burn, the outward flow of energy slows and the core begins to contract. The contraction heats the core, and the core heats the remaining hydrogen and restarts fusion. While the core contracts and gets hotter, the outer layers of our star expand and then cool. The expanded cooler Sun is becoming a **red giant**.

For millions of years, the Sun will expand, engulfing Mercury, Venus, and possibly Earth. As the Sun consumes its remaining hydrogen, the core will continue to shrink and heat to the temperature where helium fusion begins and continues the expansion. Helium fusion will produce heavier elements up to carbon and oxygen (Figure 2). Our Sun is now a fully formed red giant at several thousand times its original brightness.

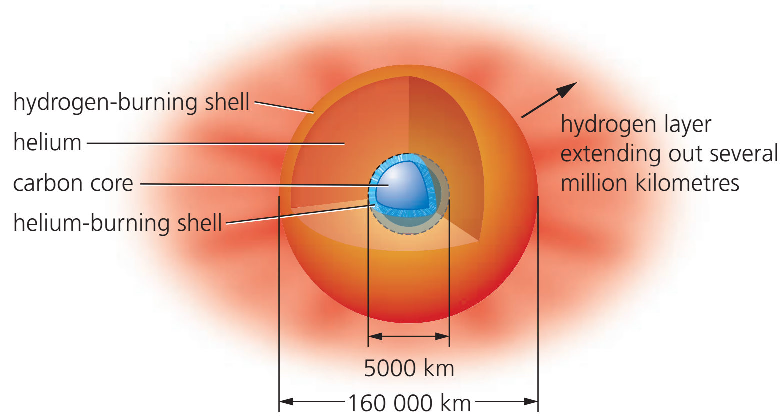
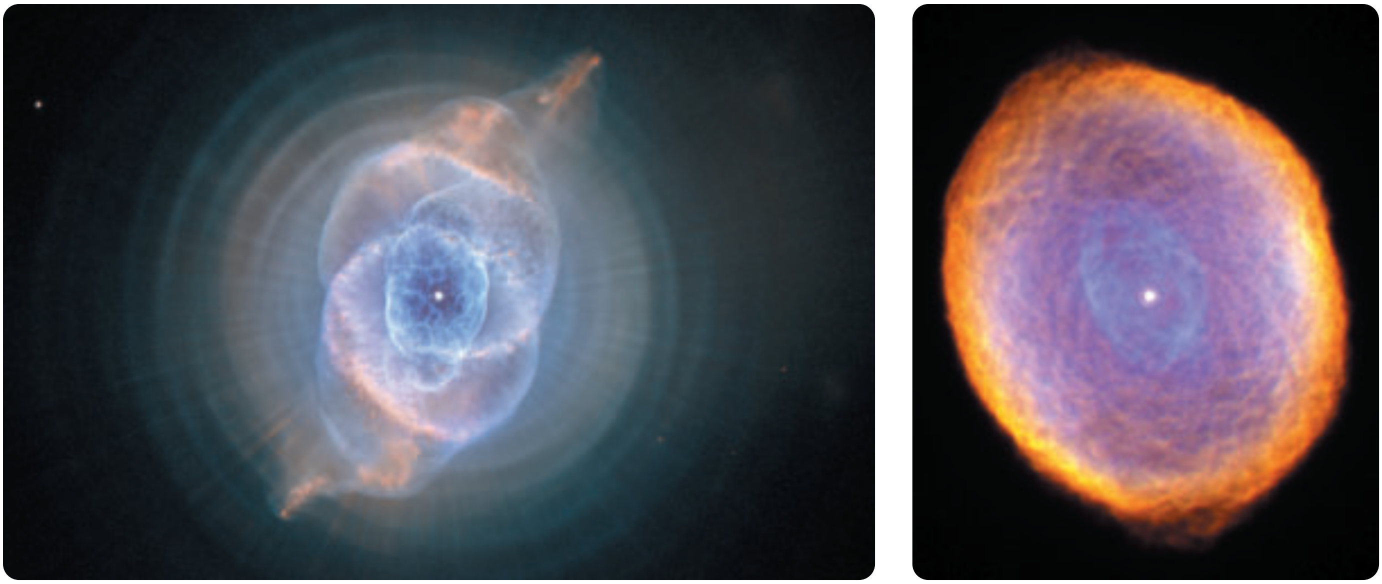


Figure 2 As a star becomes a red giant, the core shrinks while the star swells in size.

As our expanding red giant sends streams of gas and dust into space it begins to lose mass. A star with an initial mass of up to 10 solar masses will lose enough mass that it will become a stable white dwarf. A **white dwarf** is a star whose mass is no more than 1.4 solar masses, compressed to a diameter about that of Earth. A star with an initial mass over 10 solar masses will explode as a supernova (see next page).

Our Sun is one solar mass, so it will become a white dwarf. As it forms, the white dwarf will release a blast of particles that will collide with the matter it shed in the last stages of its life as a red giant. The energy of the collision illuminates these clouds of gas and dust and creates a beautiful celestial object, a nebula. The nebula, illuminated by the white dwarf, is a star-forming body (Figure 3).



(a) (b)

Figure 3 (a) The Cat's Eye nebula with a white dwarf at its centre contains as much mass as all the planets in our solar system. Does it look like a cat's eye to you? (b) The Spirograph nebula shows a complex pattern in the material ejected as the star it came from became a white dwarf.

The white dwarf, the remains of the Sun, will keep its place in the spinning Milky Way galaxy, moving ever onward. Like a dying ember, our white dwarf will radiate its energy into space, becoming cooler and dimmer until its light goes out. When its light goes out, it will become a black dwarf, and it will no longer be visible.

Supernovas, Neutron Stars, and Black Holes

A supernova releases enormous amounts of energy and matter, creating a beautiful nebula (Figure 4). Depending upon the mass of the star, supernovas produce either a neutron star or a black hole.

Figure 4 The supernova that created the Crab nebula was observed in 1054.

Supernovas

Stars over 10 solar masses have enough mass to cause the fusion of carbon nuclei as the star contracts. Carbon fusion will produce iron and nickel, which will not undergo further fusion at these temperatures and pressures. With continuing pressure and temperature changes, the star will collapse catastrophically.

The energy generated is now great enough to drive the fusion and formation of all the elements in the Periodic Table that are heavier than iron. The inward collapsing matter of the star rebounds off the core milliseconds later, with a shock wave that blows off the rest of the star's material. A shock wave is an enormous wave of energy and matter. The explosion scatters through space the elements that will one day be part of a new world. As a famous astronomer, Carl Sagan, once said, we humans are "made of star stuff," the stuff from exploding stars. The dying star will shine, often for only a few months, with a light equal to billions of stars.

TRY THIS: *Modelling a Supernova Explosion*

Skills Focus: creating models, predicting, evaluating, communicating

Materials: basketball, tennis ball

When the core of a star collapses, it does so with such an enormous force that it rebounds. As the core collapses, all the outer atmospheric layers are also collapsing and following the core. The less dense outer layers are still falling in toward the core when the core rebounds. The rebounding core collides with the outer layers with enough energy to blow the atmospheric layers away from the star. This is the supernova explosion. In this activity, the basketball models the core, and the tennis ball models the star's outer atmospheric layers.

1. Drop the basketball and then the tennis ball. Record your observations.
2. Place the tennis ball on top of the basketball, and hold them out in front of you. Predict how each ball will bounce.
3. Let go of both balls at the same time so they fall to the floor together. Record your observations.

A. How far above the floor did each ball rebound in step 1?

B. What did you observe when both balls hit the floor?

C. What is the source of the extra energy that caused the result you observed?

D. How is this model like a supernova explosion?

E. What parts of this model are not like a supernova explosion?

Did You KNOW?

Jocelyn Bell

In 1967, Jocelyn Bell was a graduate student at Cambridge University. In the process of her research, she discovered the first pulsar. Initially, pulsars were thought to be signals from little green men (LGM), and Bell's discovery was the first signal, or LGM1. The idea of LGM was quickly ruled out, however. Eventually, the true nature of the steady signal from space that Bell discovered was determined.

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Neutron Stars

If a star's initial mass is between 10 and 50 solar masses, the supernova will produce a **neutron star**. The core of a neutron star is mostly made of neutrons that are so tightly packed that 250 mL of the core would have a mass of millions of kilograms. A **pulsar** is a type of neutron star that sends out light and a beam of very high-energy radio waves. A pulsar rotates while giving off this beam of energy, much like a lighthouse. If the neutron star is small, less than two solar masses, it will slowly release its energy and fade into oblivion.

Black Holes

A star with an initial mass over 50 solar masses will become a supernova and produce elements that are heavier than iron and nickel. However, if the mass of the material left behind is greater than four solar masses, the core will collapse in on itself. The object's mass is still immense, so its gravitational pull is also immense. Not even light can escape. No longer a star, the object has become a **black hole**.

A black hole of 10 solar masses would be only 60 km in diameter. Trying to find an object this small that is not giving off light is very difficult. Many stars, however, exist as binaries, two stars circling each other. The first black hole was discovered by studying a binary star, a blue giant and its invisible companion, an X-ray source, in the constellation Cygnus (Figure 5). The invisible companion—the black hole—pulls gas from the blue giant. The gas heats up and emits X-rays, which allows the black hole to be detected (Figure 6). The blue giant is a very hot giant star, with a solar mass of 27. The black hole, called Cygnus X-1, has a solar mass of 14.

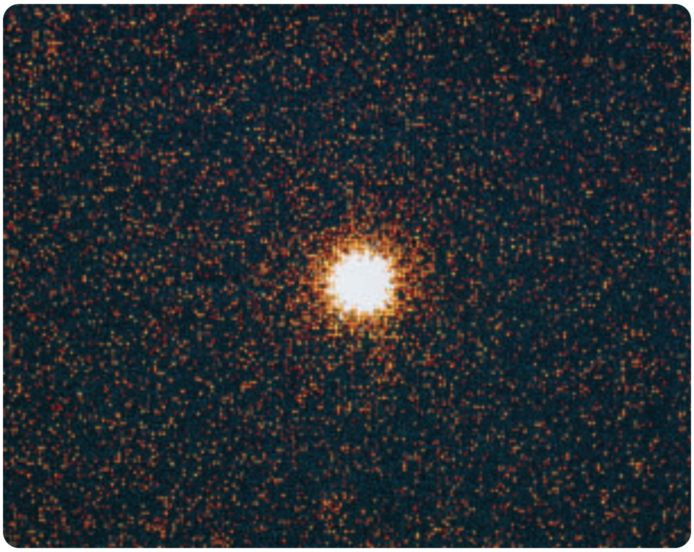

Figure 5 This is an X-ray image of the blue giant in orbit around the black hole called Cygnus X-1. It takes 5.6 days for the star to orbit the black hole.

Figure 6 This image is an artist's impression of a black hole drawing material from its companion blue giant.

TRY THIS: Black Holes: Gravity's Relentless Pull

Skills Focus: recording, communicating

1. Log on to the Nelson website, and follow the links to "Black Holes: Gravity's Relentless Pull."

   www.science.nelson.com GO

2. Click on "Journey to a Black Hole." Find and record the information given about six black holes in "Finding the Invisible."
3. Take "The Voyage" to either Cygnus X-1 or Andromeda. Record the speeds and time you take to reach each milestone.
4. Create your own diagram of either Cygnus X-1 or Andromeda. Record the information about the black hole, the accretion disk, and the jet, if present.
5. Get "Up Close and Personal" with a black hole, and explain what a black hole does to the surrounding space. What is Einstein's cross?
6. Perform each experiment, and report on one you have discussed with your teacher.

Did You KNOW?

First Black Hole Candidate

In 1971, Tom Bolton, an astronomy professor at the University of Toronto, began observing a star thought to be connected with the X-ray source in the constellation Cygnus. Using the university's David Dunlap Observatory, Bolton confirmed that the star is in orbit about the X-ray source and that the X-ray source is probably a black hole. This was the first observational evidence for the existence of black holes.

13.4 CHECK YOUR Understanding

1. Describe how the main sequence stars of the Hertzsprung–Russell diagram are arranged in the diagonal band pattern.
2. Using the Hertzsprung–Russell diagram (Figure 1 on page 431), list some properties of the stars called red giants.
3. In the early years, astronomers thought stars moved along the main sequence from their formation until their end. Describe what astronomers think today.
4. Define "solar mass."
5. As a main sequence star ages, why does gravity at its core begin to increase?
6. If you have ever held onto a bicycle pump as you pumped up a tire, you know that the pump gets hot as more and more air is forced into the tire.
   (a) Use the kinetic molecular theory to describe why the bicycle pump gets hot.
   (b) Use the kinetic molecular theory to describe why the contracting helium core of a star heats up before it becomes a red giant.
7. The nuclear fusion that powers a star takes place in its core. Describe how the expanding outer layers of a red giant begin to cool.
8. What are the heaviest elements that can form in a red giant?
9. Describe how a red giant creates elements such as carbon and oxygen.
10. Using a diagram, describe how the Sun will become a red giant in another 5 to 7 billion years.
11. Describe how a red giant becomes a white dwarf.
12. Under what circumstances does a white dwarf become a black dwarf?
13. What characteristics of the Spirograph nebula suggest that it is the birthplace of new stars? (Hint: See Figure 3 on page 433.)
14. (a) If a star's initial mass is greater than 10 solar masses, what two types of "star" will evolve?
    (b) What are the mass boundaries for each type?
15. List some of the elements in the Periodic Table that are heavier than iron. Under what circumstances do these heavy elements form?
16. (a) What is a neutron star?
    (b) What is a pulsar?
17. A star has a mass that is greater than 50 solar masses. Describe the process that this star goes through to become a black hole.
18. Why is the evidence we use to identify a black hole considered to be indirect evidence?
19. Arrange the following terms in their correct sequence: red giant, nebula, formation of helium, white dwarf, main sequence star, formation of clumps of matter, formation of carbon, hydrogen.
20. Stars over 10 solar masses begin the fusion of carbon and can produce nickel and iron. However, using iron as a fuel has been said to be as efficient as using a rock as a fuel. Explain why.

13.5 Galaxies and Our Home: The Milky Way

Our home is the Milky Way galaxy. Filled with over 200 billion stars, it is a classic example of an average galaxy. It is part of a neighbourhood of galaxies called the Local Group.

Our Local Group

The Milky Way galaxy has neighbours in space that are not moving away from each other as the rest of the universe expands. The Local Group of over 24 other galaxies and smaller systems includes our neighbours to a distance of 2.5×10^6 light years from the Milky Way (Figure 1).

The members of the Local Group have many spectacular features. The great nebula in Orion's sword in our own Milky Way is a stellar birthing ground, producing some immensely powerful stars. At 1500 light years, it is quite close and easily visible with binoculars. One of our satellite galaxies, the Large Magellanic Cloud, houses the bright Tarantula nebula (Figure 2). 13D Investigation

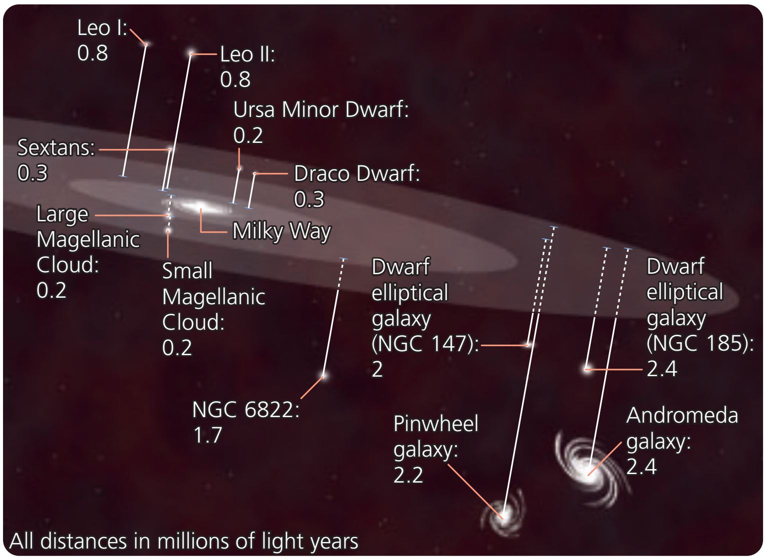

Figure 1 The Local Group, with the Milky Way in the centre. The Large Magellanic Cloud and the Andromeda galaxy are part of the Local Group.

13D Investigation

Hunting for Galaxies

To perform this investigation, turn to page 452.

In this investigation, you will classify galaxies according to their physical characteristics.

Figure 2 The Tarantula nebula is a vast stellar nursery. At 1.6×10^5 light years from us, it is one of the largest and brightest nebulas known.

Classifying Galaxies

Edwin Hubble classified the galaxies he saw according to four basic shapes: elliptical, spiral, barred-spiral, and irregular (Figures 3 to 6).

LEARNING TIP

As you study Figures 3 to 6, ask yourself, "Why did Hubble choose to classify the galaxies by their shape, rather than by their size or colour?"

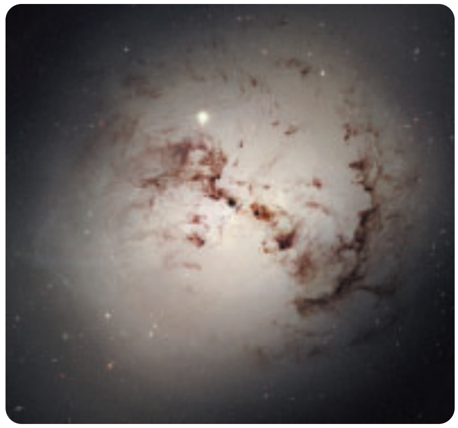

Figure 3 Hubble arranged **elliptical galaxies** according to how spherical they looked. He called the roundest E0 and the most elliptical E7. Elliptical galaxies have little interstellar matter. They are thought to be quite old, and they rarely form new stars.

Figure 4 **Spiral galaxies**, like our own Milky Way and the neighbouring Andromeda galaxy, have a spiral shape. Hubble called a tightly wound spiral Sa and a loose spiral Sc. Spiral galaxies have interstellar matter and are full of new and young stars.

Figure 5 The **barred spiral galaxies** have a well-defined bar of stars running through their middle. Hubble named these the SB galaxies. If they are tightly wound, they are called SBa. If they are loosely wound, they are called SBc.

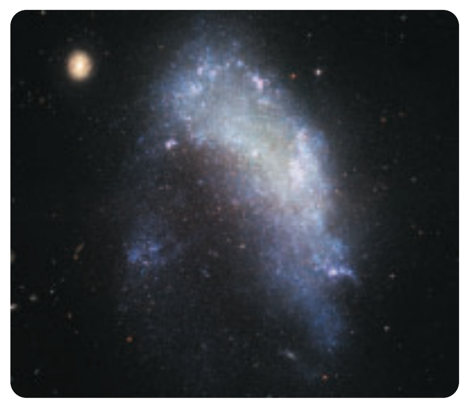

Figure 6 **Irregular galaxies** have no definite outline. They are neither elliptical nor spiral. They are believed to be the result of a collision of two or more galaxies.

In the modern version of Hubble's system of classifying galaxies there are S0 galaxies. These galaxies have a central bulge and a disk but no spiral arms (Figure 7).

Figure 7 An S0 galaxy

The Milky Way

You can describe your home and your neighbourhood because you have seen them and travelled through them. How do you figure out the shape of something as vast as the Milky Way, especially when you are inside it and you can't travel through it? Astronomers have been trying to determine the shape and structure of our galaxy since the 1940s.

Our galaxy is a typical spiral with 200 billion stars. It is about 1.0×10^5 light years across. A bulge at the centre of our galaxy measures 10 000 light years in thickness. Estimates on the number of arms in our galaxy range from four to six (Figure 8). The Sun, at approximately 27 000 light years from the centre, takes 2.00×10^8 to 2.25×10^8 years to go around the galaxy once.

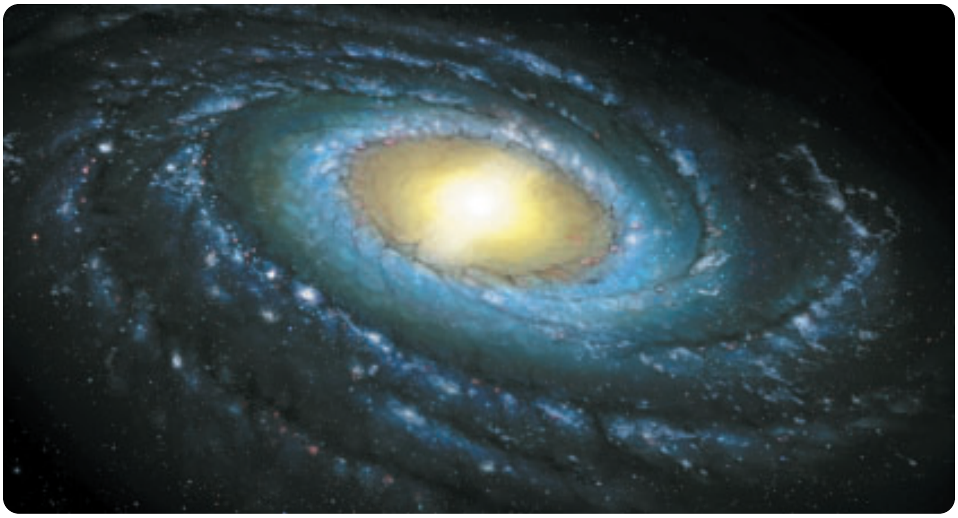

Figure 8 The Milky Way galaxy is a typical spiral galaxy. The core is visible as a glowing mass of stars. The arms are shown in blue because of the many blue giants, thousands of times brighter than our Sun, that colour their surroundings. (Artist's rendition)

The number of stars in our neighbourhood of the Milky Way is relatively low. This leaves our night sky somewhat empty and dark, even if it does not seem that way on a dark, moonless night. However, if we could travel 6000 light years toward the centre, the night sky would be considerably brighter. From the inside of the innermost arm, the galactic core would appear as a wall of stars across the night sky. The older stars of the core glow red, orange, and yellow, giving the central bulge a warm glow as opposed to the harsher blue light of the spiral arms.

The Galaxy's Centre

The centre of our galaxy lies behind clouds of gas and dust in the direction of the constellation Sagittarius. What is behind this warm glow? Optical telescopes cannot see through the dust clouds. Infrared imagery located our galactic core in 1983. In 2002, the VLT (Very Large Telescope) Yepun confirmed that a black hole, given the name Sagittarius A* (The A* is pronounced "A star."), is the source of X-rays and radio waves coming from the centre of the Milky Way. Sagittarius A* is a supermassive black hole, with a mass of over 2×10^6 solar masses and a diameter that is 15 times the diameter of the Sun (Figure 9).

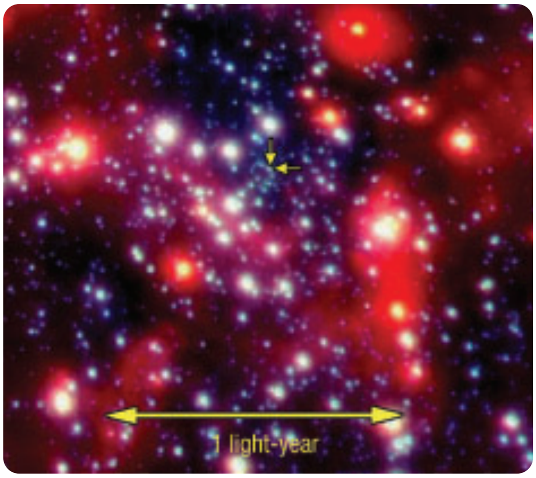

Figure 9 The two yellow arrows in the centre point to the position of Sagittarius A*, our galaxy's supermassive black hole. Hot blue stars and cooler red stars surround it.

Quasars and Galaxy Clusters

There are galaxies larger than the Milky Way. Supermassive black holes of about 1.0×10^9 solar masses power quasars. **Quasars** (**quas**i-stel**lar** radio sources) are starlike objects that emit powerful radio waves. Quasars pump out trillions of times the energy of our Sun concentrated in an area only 10 times the size of Earth's orbit. Quasars are found in the centre of distant galaxies and are thought to have formed when two galaxies collided. GO

If you would like to learn more about quasars, go to **www.science.nelson.com** GO

The largest black holes, about tens of trillions of solar masses, are found in the centre of galaxy clusters. Their enormous home galaxy consumes other galaxies, and their intense gravity holds the cluster together.

Star Clusters

Star clusters are groups of stars that are bound together by gravity and travel together through space. All the stars in each star cluster are thought to be at the same distance from Earth, and formed from the same material and at the same time. Therefore, studying star clusters helps astronomers study stellar evolution. There are two different types of star clusters: globular and open.

Globular clusters are spherically shaped, tight groups of thousands to millions of very old stars (Figure 10). All the stars in a globular cluster are concentrated in a swarm that is about 10 to 30 light years across. They are all the same age, usually only a few hundred million years younger than the universe itself. Because they are so old, most of them are yellow or red, relatively cool, and small, at under two solar masses. All of their hotter more massive siblings have either exploded as supernovas or have become white dwarfs. Our own Milky Way galaxy has about 150 globular clusters scattered spherically around the galactic centre, like a halo.

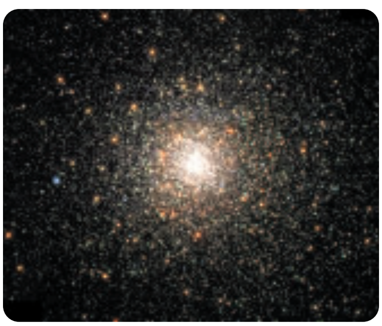

Figure 10 This ancient globular cluster, one of the densest known, is 28 000 light years away.

Open clusters usually contain only a few hundred stars. Open clusters are nearly always in the spiral arms. Open clusters typically contain young stars, 10 to 30 million years old. They have a diameter of about 30 light years, so they are much less densely packed than the globular clusters and much less tightly held together by gravity. Open clusters, therefore, disperse easily when influenced by the gravity of large, neighbouring galaxies. The Pleiades, with its hot, young blue stars, is one of the most well-known open clusters (Figure 11).

Figure 11 The Pleiades star cluster has several bright stars easily seen by the unaided eye, although the cluster actually contains about 1000 stars. Located at 440 light years from Earth, the Pleiades star cluster is located in the constellation Taurus.

13.5 CHECK YOUR Understanding

1. What is meant by the Local Group of galaxies?
2. Give two reasons why elliptical galaxies are thought to be older and more evolved than spiral galaxies.
3. Explain the difference between a spiral galaxy and a barred spiral galaxy. Include a diagram with your explanation.
4. How do astronomers think irregular galaxies form?
5. The arms of a spiral galaxy are thought to have formed as the result of density or pressure waves sweeping into the galaxy at a speed faster than the stars themselves travel. In Figure 12, you can see that the arms are concentrations of dust, gas, and stars. When these pressure waves collide with the dust and gas, what will form within the arms? (Hint: If necessary, review Section 13.3.)

Figure 12

6. (a) The mass of Sagittarius A*, the Milky Way's black hole, is 2.6×10^6 solar masses. Express this number as kilograms in scientific notation. The mass of the Sun is 2.0×10^{30} kg.
   (b) The diameter of Sagittarius A* is 15 times the diameter the Sun. The Sun's diameter is 1.4×10^6 km. Calculate the diameter of Sagittarius A* in kilometres.
7. Describe what the Milky Way might look like if our solar system were located
   (a) on the inner edge of the innermost arm
   (b) in the core itself
8. Describe how two galaxies in collision could produce a supermassive black hole or quasar.
9. Develop a concept map about the Milky Way to help you understand its structure and composition.
10. Refer to Figure 13. Explain why hot stars are blue and cooler stars are red.

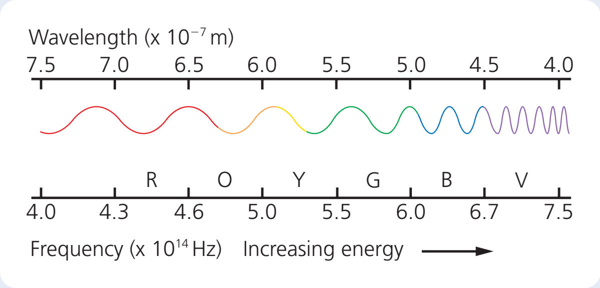

Figure 13

11. Would life as we know it be able to exist on a planet circling a star in the galactic core? Give reasons why or why not.
12. What type of signal is given off by a quasar?
13. Explain what a galaxy cluster is and what keeps it together.
14. Copy and complete Table 1.

Table 1 Comparison of Star Clusters

Cluster	Number of stars	Age of stars	Shape and size of cluster	Location in galaxy
Globular				
Open				

13.6 Dark Energy and the Expansion of the Universe

Starting from the Big Bang 13.7 billion years ago, the universe is estimated to be expanding in volume by about 1×10^{12} cubic light years a minute. Is this expansion destined to continue? From the 1920s, when Edwin Hubble first proposed that the universe is expanding, scientists have expected that the combined gravitational pull of all the galaxies plus whatever other matter existed in the universe would be great enough to slow down that expansion or even reverse it. This was often referred to as the oscillating theory.

In the 1970s, the oscillating theory ran into problems when astronomers discovered that clusters and superclusters of galaxies, which clearly existed, did not contain enough mass to produce the amount of gravity needed to hold them together (Figure 1). The galaxy clusters and superclusters, therefore, should not exist. Galaxies should be spread evenly throughout the universe! Where was the mass that was the source of the gravitational force needed to hold the clusters together?

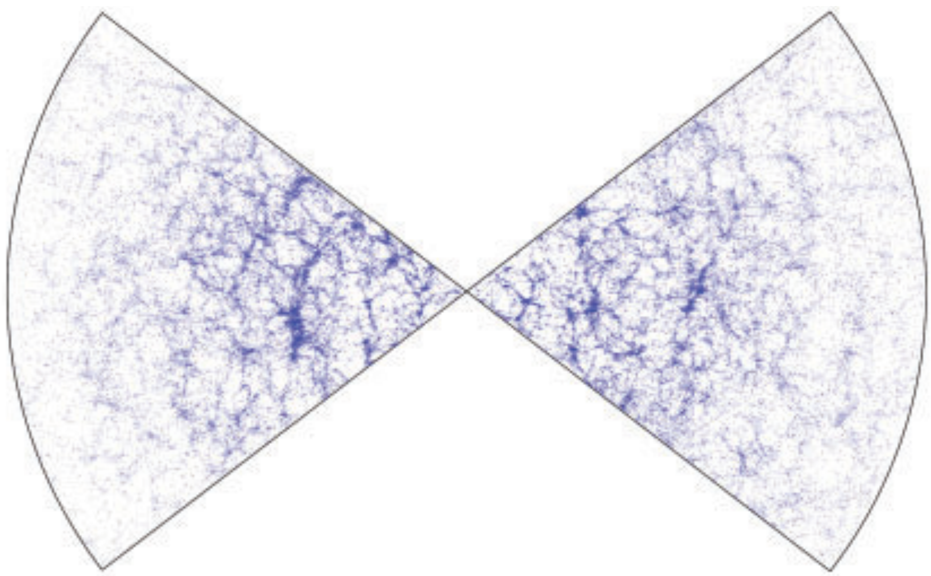

Figure 1 The 2dF Survey, completed in 2002, plotted the positions and distances of galaxies that stretch out in a wedge 2 million light years from Earth. Each dot represents several galaxies. There are huge clusters of galaxies and considerable voids, or blank spaces, as well.

Dark Matter

In the 1970s, the missing mass that is responsible for the gravity needed to hold the galaxies together was theorized to exist in the form of dark matter. What is dark matter? At the start of the 21st century, the best theory is that **dark matter** may be some form of particle yet to be discovered (Figure 2). So where is this dark matter found? The speed of rotation of a spiral galaxy such as the Milky Way provided a clue.

Although the number of stars in the outer fringes of a galaxy decreases, observations showed that the amount of mass did not. The outer fringes of spiral galaxies should not rotate as fast as they do, given the amount of visible matter in them. Astronomers concluded that this missing mass, or dark matter, had to exist in the outer fringes of a galaxy.

Figure 2 This is an image of galaxies colliding. It has been coloured to indicate the visible matter (red) and the dark matter (blue).

Despite not being able to identify dark matter, continuing research supports its existence. We know it behaves like normal matter, clustering in some places but not others. Until 1998, most astronomers agreed that there was enough matter and dark matter, and therefore sufficient gravity, to slow the expansion of the universe and perhaps, someday, to even reverse this expansion.

Dark Energy

In 1998, astronomers determined that the expansion of the universe was not slowing. Instead, observations of very distant supernovas indicated that the universe had increased its rate of expansion. The expansion of the universe seems to have increased, starting about 5 billion years ago. What could be causing the increased expansion and working against the force of gravity, which should be slowing down the expansion? The answer to this question was a surprise. We appear to be living in a universe that contains energy in empty space. This energy, part of space itself, is speeding up—not slowing down—the expansion of the universe. Many scientists consider this energy to be the biggest mystery facing science today, and they have called it **dark energy**.

LEARNING TIP
Check your understanding. Explain to a partner why dark energy is the biggest "unknown" facing astronomers as they adjust to a new view of the universe.

The recent WMAP survey and other experiments support the idea that dark energy is a stabilizing force in the universe. However, it is not an antigravity force because its strength increases with distance, while the strength of gravity weakens with distance.

How much of the universe is dark energy? The best estimate of how all the mass and energy of the universe are distributed is as follows:

- 73 % dark energy
- 23 % dark matter
- about 3.6 % atoms of normal matter; mostly hydrogen gas between the galaxies
- 0.4 % visible matter; stars and galaxies

The visible universe where we live is less than half a percent of all that exists.

TRY THIS: *Testing the Big Bang Model*

Skills Focus: conducting, recording, analyzing, evaluating, communicating

Hubble's early work on the red shifts of galaxies showed that not only were the galaxies moving away from us, but the galaxies farthest away were moving the fastest. Even with the recent discovery of dark energy, Hubble's observations still hold true. However, his observations seemed to point to the idea that we are the centre of the universe because all the galaxies he observed were moving away from us. Is this correct? Moreover, why were the more distant galaxies moving away faster? The following raisin-bread dough model of the universe simulates the expansion that Hubble discovered.

1. Bread dough has raisins scattered through it at different distances from each other (Figure 3(a)).

(a)

(b)

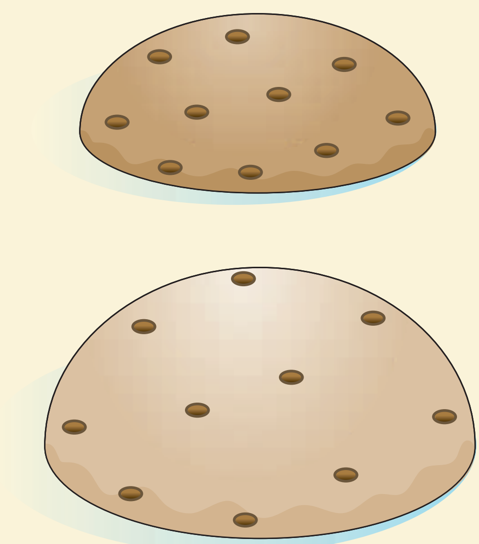

Figure 3 (a) Bread dough with raisins before the dough rises. (b) When every part of the dough expands by the same amount over the same time, the expansion models Hubble's predictions.

2. When placed in a warm location, the dough rises. As it rises, the dough expands relatively evenly to double its original size. It carries the raisins along with it (Figure 3(b)).
3. As the dough rises, each raisin/galaxy would "see" the other raisins moving away.
4. The circles in Figure 4 represent four raisins/galaxies. Copy Figure 4 into your notebook, and then redraw it with each distance doubled.

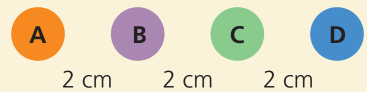

Figure 4

5. Complete Table 1.

Table 1

Raisin	Original distance (cm)	Final distance (cm)	Difference (final − original) (cm)
A to B			
A to C			
A to D			

A. What does the warmth that makes the dough rise in this model represent in the expanding universe?
B. What does the dough represent in the expanding universe?
C. What do the raisins represent in the expanding universe?
D. As the dough rises, what does each raisin "see" happening to all the other raisins? Where does this seem to place each raisin/galaxy?
E. Is the Milky Way or any of our neighbouring galaxies at the centre of the universe? Explain.
F. Which galaxy shows the greatest expansion from Galaxy A?
G. Are galaxies moving through space, or are they being carried with it as space itself expands? Explain.
H. How is this model like the universe? How is it different?

13.6 CHECK YOUR Understanding

1. (a) In your own words, explain the oscillating theory of the universe.
   (b) Compare the oscillating theory with the expanding universe theory.
2. What is the expansion rate of the universe?
3. What force is causing the continued expansion of the universe?
4. In the oscillating theory, what force was supposed to slow the expansion of the universe and even reverse it?
5. Why did the discovery that galaxies have less mass than expected create a problem for the oscillating model?
6. What is dark matter? What is it supposed to add to the universe?
7. If there were not enough mass to hold the galaxies and galaxy superclusters (Figure 5) together, how would the distribution of stars in the sky appear?

Figure 5

8. (a) What evidence supports the idea that dark matter is found in the outer fringes of a galaxy?
   (b) If dark matter did not exist, what would happen to the outer arms of a spiral galaxy?
9. Examine Figure 6. What evidence in this figure supports the idea that dark matter may have been responsible for the formation of galaxies and galaxy superclusters?

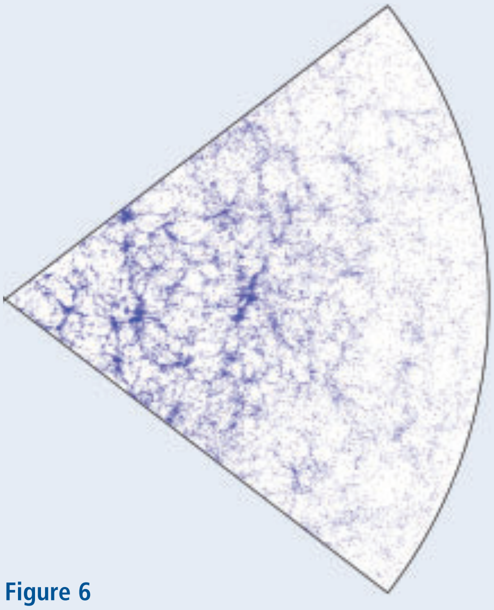

Figure 6

10. Why did the discovery of dark energy cause scientists to abandon the oscillating theory?
11. Why is dark energy not considered to be an antigravity force?
12. Create a circle graph to represent the distribution of all the matter and energy in the universe. In which part of the circle would we be found?

13A Investigation

Bright Line Spectra

Scientists use a spectroscope attached to a telescope to look at the light from stars or galaxies. From this light, they can determine which elements are present in the star or galaxy, what the proportions and temperatures of the elements are, and how fast the star or galaxy is moving away from Earth. To determine the elements that are present, scientists compare the line spectrum from the star or galaxy with the line spectra from known elements.

In this Investigation, you will use a spectroscope to observe the spectra of a variety of light sources.

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	● Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

Question

Do different light sources emit different line spectra?

Hypothesis

If each light source emits different wavelengths of light, then a spectroscope should show a different spectrum for each light source.

Prediction

Write a prediction about the characteristics of different light sources when viewed through a spectroscope.

Design

You will examine a variety of light sources using a spectroscope and observe their spectra.

Materials

- spectroscope
- assorted light sources (such as candles, light bulbs, heat lamp, bug light, and natural light from the Sun)
- coloured pencils
- gas discharge tubes

Procedure

1. Examine your spectroscope carefully. Your teacher will explain how to use it.
2. Use the spectroscope to examine the light from an incandescent bulb and the natural light from a window (Figure 1). Draw sketches in your notebook or on the sheet supplied by your teacher. Include the colour and relative thickness of each spectral line you see.

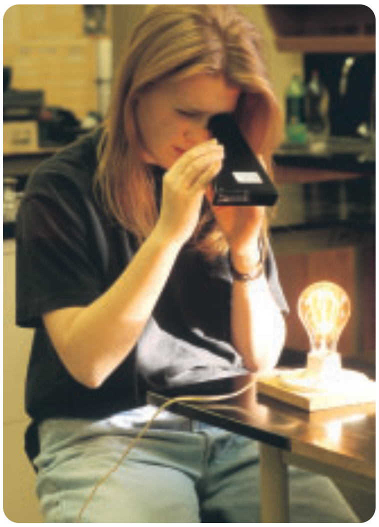

Figure 1 Step 2

Do not look at the Sun with a spectroscope. You will damage your eyes. Set the candle on a stable base, and do not bring the spectroscope too close to it.

3. Observe the spectra of light from other common sources, such as a fluorescent tube (with the protective diffusion cover removed), a heat lamp, a candle, or a yellow bug light. Draw the spectrum, in colour, for each light source and identify it with a label.

4. Observe and record in colour the spectra produced by a variety of gas discharge tubes. Each discharge tube contains a single element. Label each spectrum. See Figure 2 for a sample spectrum.

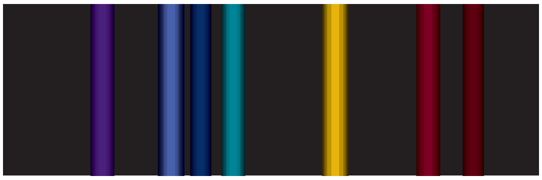

Figure 2 A sample spectrum

Analysis

(a) How are the spectra of the light sources in step 3 similar to the spectrum of sunlight or an incandescent bulb? How are they different?

(b) Compare the spectra of the gas discharge tubes with the spectrum of sunlight. How are they similar? How are they different?

(c) Compare the spectra of the gas discharge tubes with each other. Are any of them similar?

(d) Do various sources of light emit different line spectra? Do any light sources emit the same or similar spectra?

(e) Gas discharge tubes emit light when an electric current passes through the gas. The electrons of the element inside the tube are bumped outward to a higher energy level, and they emit light when they fall back to the level where they belong. Review the Periodic Table at the end of this textbook, and hypothesize how many different spectra you would expect to find.

(f) Did your observations support the Hypothesis? Explain.

Evaluation

(g) Was your prediction accurate? Explain your answer.

Synthesis

(h) Forensic scientists, or crime scene investigators, often use a spectroscope in their investigations. For example, paint chips are often found embedded in the clothing of a hit-and-run victim. A paint sample is also taken from a suspect's car (Figure 3). What has to be done to both paint samples before the spectroscope can reveal the chemical composition of the paint (the elements that the paint was made from)?

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Figure 3 A forensic officer is using a scraping tool to remove paint that was transferred to the car from another vehicle when they collided.

13B **Investigation**

Triangulation: Measuring Distances to the Stars

One important method used to measure the distances between objects in the universe is parallax, the apparent motion of a nearby star against the background of more distant stars that do not appear to be moving.

In this Investigation, you will measure distance indirectly by triangulation.

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ○ Synthesizing
- ● Communicating

Question

If you cannot directly measure how far it is to a distant object, can you determine the distance indirectly?

Prediction

Predict whether angles close to 0° or 90° will give better results with triangulation than angles that are not closer to 0° or 90°.

Design

You will build an instrument to measure the angles from a baseline to an object. You will then use your instrument to measure the angles. Using a scale diagram, you will indirectly determine the distance to the object.

Materials

- cardboard
- angle measurer template
- glue stick
- scissors
- split pin
- protractor
- pencil
- string and tape
- metre stick
- paper
- centimetre ruler

Procedure

Part 1: Make an Angle Measurer

1. Your teacher will give you a template of the angle measurer. Glue the template to the cardboard. When it is dry, cut out both parts.
2. Cut and remove the interior of the small window in the pointer.
3. Fold the arrows on the base plate and on the pointer until they are perpendicular to the base.
4. Connect both parts with a split pin in the centre of the grey spots, so the pointer can turn around the centre point of the grey spots (Figure 1).

Figure 1 Step 4

Part 2: Measuring Distances

5. Select an object within the science room (or gymnasium), that is a distance away from you. For example, a doorknob, window latch, or flower vase. Estimate the distance to the object, and record your estimate.
6. At the distance you chose, mark off two points, A and B, that are 5 m apart (Figure 2). The distance between A and B is the triangle baseline, and point C is your distant object. Record the length of the baseline. As Figure 2 shows, there may be room for only one baseline and triangle in your classroom.

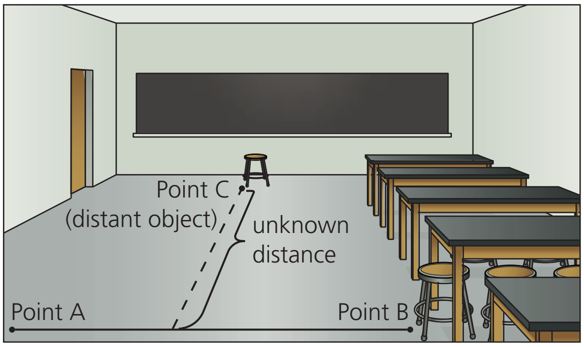


Figure 2 Step 6

7. Hold the angle measurer directly above point A, with its baseline aligned with the triangle baseline (Figure 3). Move the pointer until it lines up with the distant object, point C. Carefully measure the angle formed, angle A, and record the value.
8. Repeat step 7 from point B, and record the value of angle B.

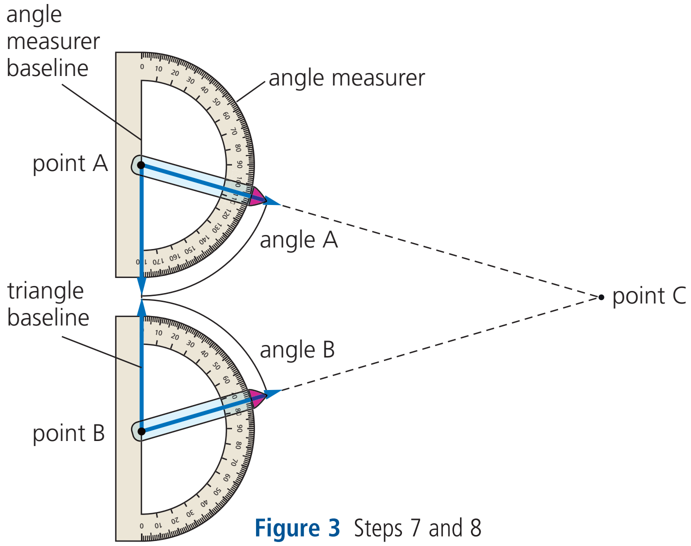


Figure 3 Steps 7 and 8

9. On a piece of paper draw a diagram of your setup (Figure 4). Use a scale of 1 cm = 1 m, and start your diagram with the triangle baseline. Label all the points, and carefully draw angles A and B.

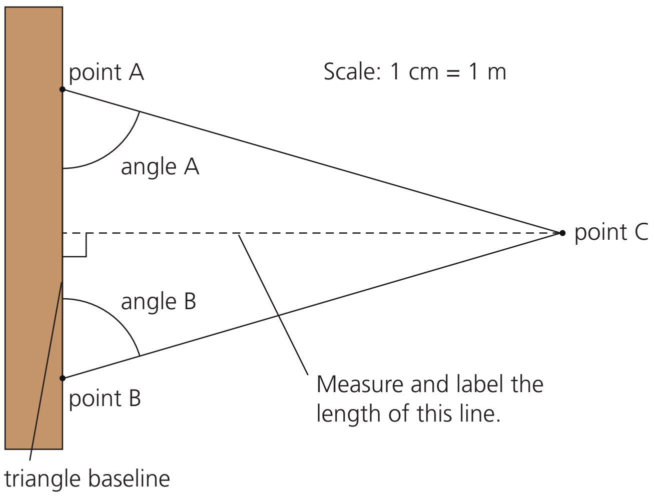


Figure 4 Steps 9 and 10

10. Extend the lines from angles A and B until they meet at the object, point C. From point C, draw a line back to the baseline that meets the baseline at a 90° angle. Measure the distance from the baseline to point C, and record your measurement. Use the scale to convert your measurement back to metres and centimetres. This is the calculated distance from your baseline to the object.
11. Carefully measure the actual distance from your baseline to the object, and record this measurement.

Analysis

(a) Why is this method referred to as "indirect"?

(b) As you look at stars that are farther and farther away, what happens to the angle measured at Earth? At what point will this method no longer work?

(c) Would the measurements you made be more accurate with longer baselines or shorter baselines? Explain your answer.

(d) In step 5 you estimated the distance to the object. Compare your estimated distance with the calculated distance and with the actual distance. Which is more accurate, your estimated distance or your calculated distance? Explain.

(e) In step 11, you used direct measurement to measure the actual distance to the object. Calculate the percentage of error in your measurements using the following formula:

$$\%\ \text{error} = \frac{(\text{calculated distance} - \text{actual distance})}{\text{actual distance}} \times 100\ \%$$

(f) Write a conclusion based on the results of this Investigation.

Evaluation

(g) Identify the possible sources of error.

(h) Evaluate how carefully your group measured angles A and B. How does the accuracy of the angles measured affect the calculation of the distance to an object?

(i) What could you have done to improve the accuracy of your results?

13C Investigation

A Rotating Sun? Sunspots Provide the Answer

Perform this investigation with strict safety precautions.

Observations made since the 1700s have revealed that spots appear on the Sun. These sunspots can be used to demonstrate that the Sun rotates.

Never look directly at the Sun, and never look through binoculars or any other instrument at the Sun. The energy in sunlight is strong enough to permanently damage your eyes.

Question

Does the Sun rotate?

Prediction

Make a prediction about how sunspots will provide evidence that the Sun rotates.

Design

Using binoculars, create a projection system to safely view features on the Sun's surface. Observations over a period of hours through one day or over several days will reveal any rotational motion of the Sun.

Materials

- binoculars focused for distant viewing
- tripod or other mounting system to secure the binoculars
- masking tape
- cardboard or Bristol board at least 216 mm × 279 mm
- scissors
- screen (sheet of smooth white paper attached to cardboard)
- clock or watch
- logbook or notebook

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Procedure

1. Before mounting the binoculars on a tripod, look through them at an object. Practise forming an image of an incandescent light bulb. Note whether the image of the light bulb is right side up, upside down, reversed, or both upside down and reversed. Make a note of what you see.
2. Mount the binoculars on the tripod or another system, and secure them with masking tape (Figure 1).

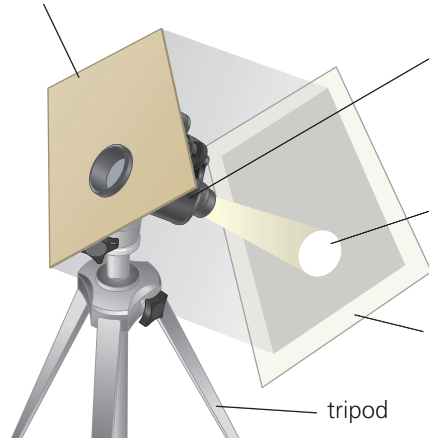


Figure 1 Steps 2 and 3

3. Use scissors to cut one or two holes in the cardboard to pass the binocular lens(es) through. If you cut two holes, use a lens cap to cover one lens. Use masking tape to seal any holes that leak light past the cardboard and to keep the cardboard shield from moving. Draw a circle about 10 cm in diameter on the screen.

4. Aim the binoculars at the Sun. It will take a little effort to find the Sun, and some adjustment of your projection system may be necessary. Place the screen below the eyepiece of the binoculars. Move the screen or adjust the binoculars until a clear image of the Sun fills the circle on the screen.

Do not look through the binoculars at the Sun.

5. Record a starting time in your notebook. Now draw a diagram of the image on the screen in your notebook. Show any lighter or darker details and any features you see. Recall from step 1 how your binoculars project an image onto a screen, and label your diagram of the Sun as to North, South, East, and West. Record when you stopped observing.
6. Give the binoculars a cooling period every 20 min. Block the Sun from shining through the objective lens to keep the internal lenses from overheating and separating.
7. Repeat your observations on two to three more sunny days. Always draw the image of the Sun the same size, and describe what happens to any features you see on the Sun's surface.

Analysis

(a) Was the image of the Sun reversed on the screen, upside down, or in the correct orientation? How did this affect your labelling of the diagram?

(b) Describe the features of the Sun that you observed.

(c) Over a period of several days, did the features change? Describe any changes you saw.

(d) The Sun rotates once every 25.4 days. If you spent one full hour observing the Sun, what fraction of the Sun's rotation would you see? Approximately how many degrees of rotation does this represent?

(e) Why is it important to carry out your observations over several days? Would your observations need to be at exactly the same time of day? Explain.

(f) Answer the Question. What evidence supported or refuted your answer to the Question?

Evaluation

(g) Explain how the evidence enabled you to answer the Question.

(h) How would you modify the Procedure to make it easier to do?

Synthesis

(i) Sunspots appear in cycles of maximum activity and minimum activity (Figure 2). The predicted years of maximum sunspot activity are 2012 and 2023. The years of minimum activity are 2007 and 2018. How did what you observed compare with these predictions?

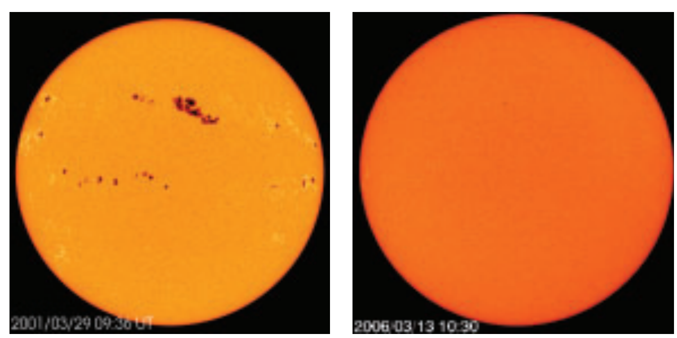


Figure 2 The image on the left shows the Sun during a time of maximum sunspot activity, in March 2001. The image on the right shows the Sun, in March 2006, approaching a year of minimum sunspot activity. (Images taken by SOHO)

(j) Why is it important for a technological society such as ours to study the Sun?

(k) What would a colony on the Moon need to prepare for in terms of solar activities (that is, sunspots, flares, and prominences)?

13D Investigation

Hunting for Galaxies

Galaxies exist in all shapes and sizes. Some galaxies are close to us, and others are at the limits of our ability to detect them. As Edwin Hubble did, you can examine the sky and classify the galaxies by their shapes. Unlike Hubble, you will use images from his namesake, the Hubble Space Telescope.

Question

Will an examination of star field images allow you to classify and sort galaxies by their physical characteristics?

Prediction

Predict how you may be able to classify galaxies using their physical characteristics.

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	○ Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

Materials

- galaxy shapes handout
- Hubble galaxy classification handout

Design

Using the Hubble Deep Field and Ultra Deep Field images shown in Figures 1 and 2 and an illustration of galaxy shapes, you will identify a variety of galaxies. You will then sort the galaxies according to their physical characteristics.

Figure 1 The Hubble Deep Field

Procedure

1. Working with a partner, describe the difference between a star and a galaxy.
2. Examine the galaxy shapes on the handout from your teacher. Write an explanation of how you will classify the galaxies.
3. Study Figures 1 and 2. Review each image, and locate as many different galaxy shapes as possible.
4. Using the characteristics you outlined in Step 2, create a labelled diagram that reflects your classification system.

Analysis

(a) Why do some galaxies look so large and others appear to be so small?

(b) Can you classify galaxies by their physical characteristics? Explain.

(c) Do all the galaxies you observed and recorded fit neatly into Hubble's classification? Why or why not?

(d) What can you conclude from this investigation?

Evaluation

(e) Your teacher will provide you with a copy of Hubble's classification system. Compare your diagram with Hubble's classification system.

Figure 2 The Hubble Ultra Deep Field

CHAPTER 13

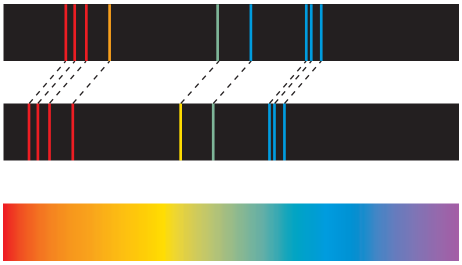
Review

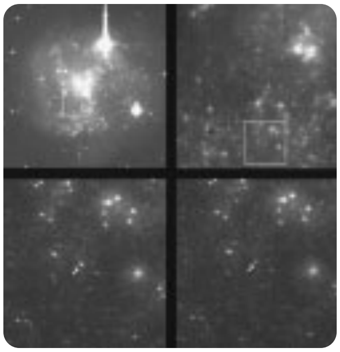
The Universe and Its Stars

Key Ideas

Technology has advanced our understanding of the universe.

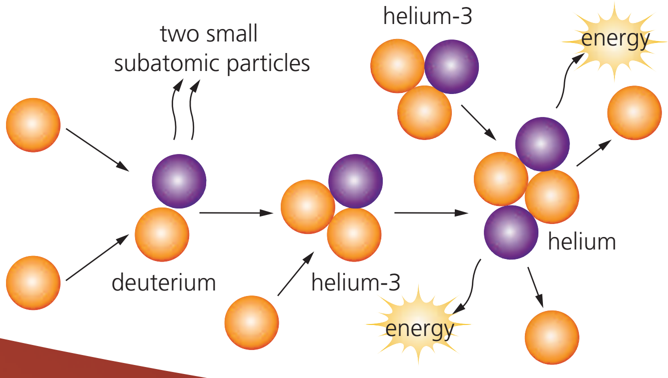
- Spectroscopes show a shift to the red (or longer wavelength) end of the spectrum for galaxies moving away from us.
- The red shift was early support for the theory of an expanding universe.
- COBE and WMAP revealed a structure in the early universe that led to the formation of the galaxies.
- Vast distances in space are measured using parallax, Cepheid variables, and red shift.





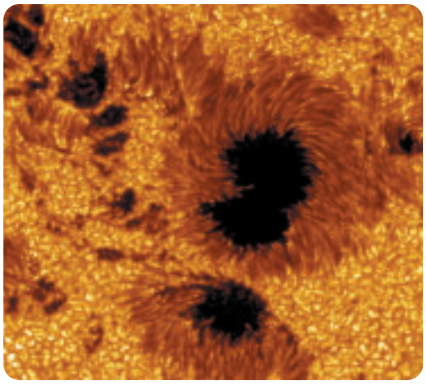
Nuclear fusion powers stars and is the force behind flares, prominences, sunspots, and the solar wind.

- The fusion of hydrogen to helium powers every star.
- As a result of nuclear fusion in the core, heat and light move outward through the Sun's layers.
- From the photosphere, light and heat pass to the chromosphere and then the corona, the Sun's atmospheric layers.
- Magnetic disturbances in the solar surface trigger sunspots, flares, and prominences.
- The solar wind is continuously emitted by the Sun.



Vocabulary

expanding universe, p. 414
red shift, p. 415
Big Bang theory, p. 416
light year, p. 419
parallax, p. 420
baseline, p. 421
standard candles, p. 421
absolute magnitude, p. 422
apparent magnitude, p. 422
nuclear fusion, p. 425
core, p. 426
radiative zone, p. 426
convective zone, p. 426
photosphere, p. 426
chromosphere, p. 427
corona, p. 427
sunspots, p. 427
solar prominences, p. 428

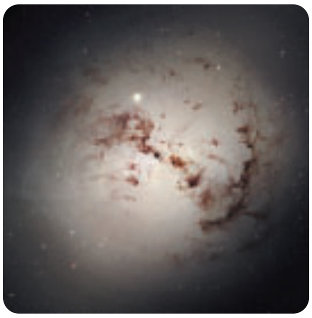


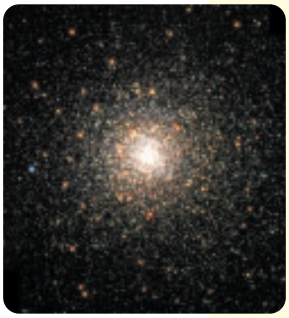
A star's mass determines the stages of its life cycle.

- The Hertzsprung–Russell diagram shows the various stages in the life cycle of stars.
- A star's mass determines its brightness, colour, size, and how long it will live.
- After forming from a nebula, a star spends most of its life in the main sequence.
- Low-mass stars become red giants and fade to white dwarfs.
- High-mass stars pass from giants or supergiants to neutron stars or black holes.

Galaxies, star clusters, and nebulas can be distinguished by their structures and characteristics.

- Hubble classified galaxies by their shape: elliptical, spiral, barred spiral, and irregular.
- Our spiral galaxy, the Milky Way, has a massive black hole at its centre and billions of stars arranged in arms.
- Black holes at the cores of galaxies emit enormous amounts of radiation.
- Globular star clusters consist of tight groups of hundreds of thousands of very old stars. Open star clusters consist of only a few hundred very young stars.





solar flares, p. 428
solar wind, p. 428
main sequence, p. 431
solar mass, p. 431
red giant, p. 432
white dwarf, p. 432
neutron star, p. 434
pulsar, p. 434
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irregular galaxy, p. 438
quasar, p. 440
globular cluster, p. 440
open cluster, p. 440
dark matter, p. 442
dark energy, p. 443

Review Key Ideas and Vocabulary

1. State Edwin Hubble's two major discoveries.
2. Complete the following sentences.
   (a) The wavelength gets shorter as an object moves ___?___ the observer.
   (b) The wavelength gets longer as an object moves ___?___ the observer.
3. Copy the following distances into your notebook. Beside each number, indicate whether the distance would be described as intergalactic, interstellar, interplanetary, or between students.
   (a) 1.0×10^{-3} km
   (b) 1.0×10^{18} km
   (c) 1.0×10^{8} km
   (d) 1.0×10^{13} km
4. Explain the concept of a standard candle.
5. How does apparent magnitude differ from absolute magnitude?
6. Explain the relationship between gravity and mass.
7. Identify and describe the reaction that produces light and energy in the form of heat in stars.
8. Why is our Sun considered to be a main sequence star?
9. What opposes gravity to keep a star from collapsing?
10. What factor brings a star's main sequence time to an end?
11. Why will the Sun not become a supernova?
12. List the three defining characteristics of a globular cluster.
13. Compare the distribution of globular clusters with the distribution of open clusters in a galaxy such as the Milky Way.
14. Explain why dark energy is considered to be the biggest mystery facing science today.

Use What You've Learned

15. Research the expansion of the universe on the Internet. Create a diagram to represent the stages the universe has passed through. Give the duration of each stage, and briefly explain what occurred during this stage.

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16. The mental model of local space in Section 13.2 places Proxima Centauri 2000 km away. If you walked the distance that this model suggests, starting in Vancouver and heading east, roughly where would you end up?
17. An astronomer uses the diameter of Earth's orbit as a baseline to estimate the radius of Saturn's orbit. As shown in Figure 1, the angles to Saturn, taken six months apart, are both 84°. Use a scale diagram to find the distance from Saturn to the Sun.

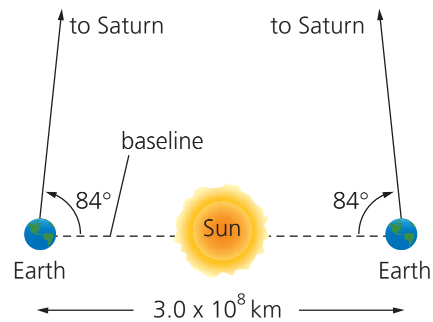

Figure 1

18. The Sagittarius dwarf galaxy (Figure 2) is a satellite galaxy of the Milky Way. At 78 000 light years from us, the Milky Way's gravity is ripping it apart.
    (a) Calculate the Sagittarius dwarf galaxy's distance in kilometres.
    (b) If you were visiting the Sagittarius dwarf galaxy, at what speed would you have to travel to be back before school gets out for the day?

Figure 2

19. Research Type Ia supernovas on the Internet. Explain why they can be used as standard candles.

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20. During nuclear fusion, six hydrogen nuclei are involved, but only four hydrogen nuclei are needed to create a single helium nucleus. Why? For simplicity, compare the mass of both hydrogen and helium.

21. (a) Give the name of the process shown in Figure 3.
(b) What powers this process in the Sun, and where in the Sun does this process occur?
(c) What is each circulating system called?
(d) Viewed from above, what do astronomers call each circulating system?

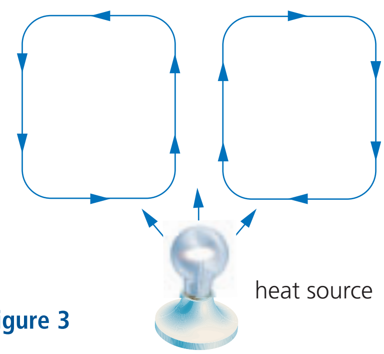

Figure 3

22. Research the solar wind on the Internet. Draw a diagram that shows the effect of the solar wind when it strikes Earth's magnetic field.

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23. Explain the reasons for the following safety procedures in Investigation 13C:
(a) not looking at the Sun through binoculars
(b) not focusing the Sun's image to a point on the screen
(c) letting the binoculars cool down occasionally by blocking the lens

24. "Human beings are made of star stuff." Explain what this statement means in relation to a supernova.

25. Using Hubble's classification system, classify the three galaxies shown in Figure 4.


(a) (b) (c)
Figure 4

Think Critically

26. The element sodium has a simple bright line spectrum (Figure 5). It consists of two closely spaced lines in the yellow portion of the spectrum. Using colouring materials of your choice, create a visible light spectrum. Above your spectrum, create the pattern for sodium as imaged at rest. Beneath your spectrum, create another diagram to show these two lines shifted well toward the blue end of the spectrum. Is the star that emitted this pattern moving toward or away from the observer? Explain.

Figure 5

27. Research the concept of a flat universe and the support that dark energy lends to this concept. Prepare a report outlining your findings, and present it to the class.

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28. Research the Doppler effect on the Internet, and answer the following question. At a railway crossing a student hears the whistle on a train. The whistle starts off sounding shrill and high-pitched and becomes deeper sounding and low-pitched. Is the train moving toward or away from the student? Explain your response, and compare the behaviour of sound with the behaviour of light. How are both light and sound similar?

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Reflect on Your Learning

29. Think about the questions in the Chapter Preview. How will you answer these questions now? What other questions do you have about the formation of the universe?

Visit the Quiz Centre at
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CHAPTER

14

The Tools of the Astronomer

KEY IDEAS

- The astrolabe and the star map were tools used by early astronomers to chart the heavens and navigate the globe.
- Astronomers use different types of telescopes to study a variety of objects in the sky.
- Computers are essential to the astronomer.
- Space probes are sent into space to explore planets and other objects.

Chapter Preview

The view of Earth from the International Space Station (ISS) on these pages is one that many people dream of experiencing first-hand. One of the goals of the ISS is to learn how humans can survive in space so that we may one day inhabit other worlds. However, before we are able to leave Earth as our primary home, we must learn more about the nature of the universe, its forces, and the objects that exist there. As you learned in the previous two chapters, astronomers have already gained substantial knowledge about the universe. What tools have astronomers used to gain this knowledge? What do astronomers see when they use different telescopes? How do astronomers gain information about the universe when they use specialized instruments such as telescopes and space probes? These instruments are valuable because they allow astronomers to see the universe with new eyes and to make discoveries that would otherwise not be possible.

TRY THIS: A Different View

Skills Focus: recording, classifying, communicating

In this activity, you will examine a list of familiar instruments that are used by scientists to view objects. Some of these instruments you will have used yourself. Others you will have learned about in Grade 8 science.

1. Copy Table 1 into your notebook.

Table 1

Instrument	Examples of objects viewed	Approximate size of objects

2. Arrange the following list of instruments in terms of the relative size of the objects they allow us to view, from smallest to largest objects. Write your list in order in the first column of your table.

   Instruments: hand-held magnifying lens, binoculars, transmission electron microscope, optical telescope, scanning electron microscope, compound light microscope, dissecting microscope

3. In the second column, write the names of at least two objects that each instrument would be used to view.
4. In the third column, state the approximate size of these objects, using scientific notation if appropriate. Refer to the Skills Handbook for reference if necessary.

A. Which instruments have you already used?

B. Which instruments do you think are used by astronomers?

14.1 Ancient and Modern Tools

(a)

(b)

Figure 1 The two images of the Crab nebula illustrate the different views that new technologies provide astronomers. The image in (a) was taken by the Hubble Space Telescope (HST) in 2000 and is the largest image taken by the HST. It provides the highest resolution image of the Crab nebula taken to date. The image in (b) was taken in 1973 by NOAO, a 4 m Earth-based telescope located at Kitt Peak in Tucson, Arizona.

After reading Chapters 12 and 13, how do you think scientists have learned so much about the objects in the universe? To perform any investigation, specific tools are required. For example, if you want to examine microscopic organisms in a drop of pond water, you do not use binoculars. A microscope is the best tool for this job. What tools are used to study distant objects, such as planets, stars, and galaxies? What exactly do you see when you look at images that were created using cameras and computers?

As technology advances, astronomers can view objects in the universe with increasing clarity. Today's instruments have enabled astronomers to see parts of the universe in such detail that 30 years ago they would have appeared to us as mere blurs of light. Figure 1 shows the difference between two images of the Crab nebula that were taken almost 30 years apart. Thirty years from now, today's state-of-the-art technology will be obsolete.

Ancient Tools

One of the earliest tools used by astronomers was the astrolabe. You learned about the astrolabe in Section 12.5. It is the simplest of all the instruments used to study the sky. First designed by the early Greeks, the astrolabe helped astronomers calculate the distance to and between stars by measuring the angles from two positions to create a scale drawing. This method is called triangulation, and it is used in other fields as well. In land surveying, for example, the triangulation method is used to calculate the distance across a valley. The astrolabe is also known as a sextant and was used in early navigation.

Another simple tool that was used by early Aboriginal and Indigenous peoples, astronomers, and mariners (ocean travellers) is the star map. Star maps show where specific constellations and stars are located in the sky at different times throughout the year. Knowing the date and time of day allows the user to orient the star map so that these constellations are positioned the way they can be seen in the sky. The user's position on the globe can therefore be determined. Star maps are a great way to learn about the night sky. See "Using Star Maps" on page 533 in the Skills Handbook.

Modern Tools

To learn about the modern tools of the astronomer, you must first appreciate what these instruments actually measure. The universe is primarily made of matter that emits significant amounts of energy, called radiation. Radiation comes in many different forms. Together, these forms of energy are called the **electromagnetic (EM) spectrum** (Figure 2). A thorough understanding of the energies that radiate from objects is necessary for astronomers to view celestial objects in different ways and obtain new information. The EM spectrum is a spectrum, or range, of energy that results from both the electric and magnetic

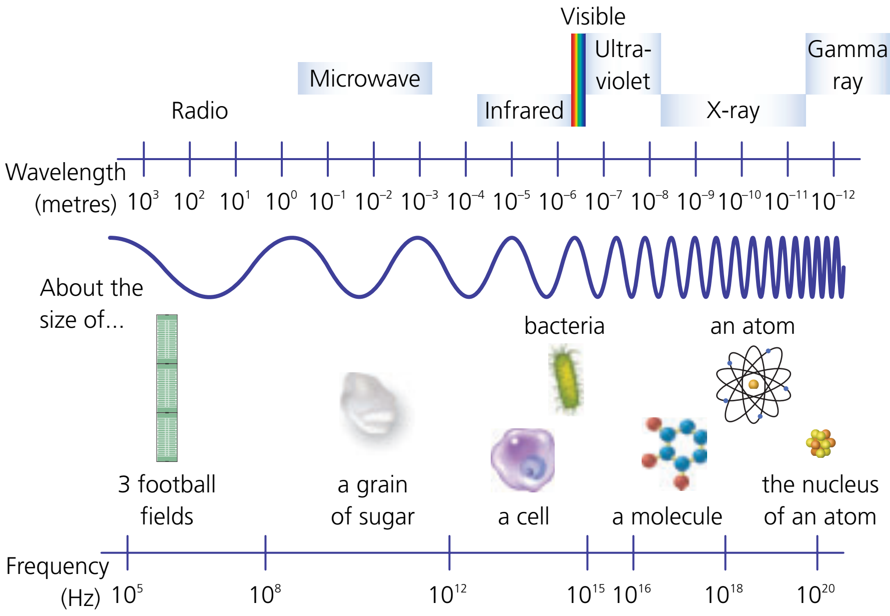


Figure 2 The electromagnetic spectrum. Which frequencies do you think cause the most damage to the human body? Why? (Wavelengths are not drawn to scale.)

fields generated by atoms. Also referred to as electromagnetic radiation, this spectrum behaves like waves of light that travel through space at the speed of light with varying wavelengths and associated amounts of energy. One end of the EM spectrum is characterized by long, low-energy waves called radio waves. The other end features high-energy rays, called gamma rays, with very short wavelengths. Most telescopes can detect visible light; however, there is only a small number of telescopes that observe at wavelengths other than visible light.

Probably the most familiar part of the EM spectrum is the band of wavelengths called the visible spectrum. These are the wavelengths that our eyes can see. Humans are blind to all other parts of the EM spectrum. When sunlight passes through raindrops, the raindrops act as a prism, separating the visible spectrum into the recognizable ROYGBV (red, orange, yellow, green, blue, violet) pattern. Red light has the longest wavelengths (and lowest energy) of the visible spectrum, and violet has the shortest wavelengths (and highest energy) of the visible spectrum. The relationship between wavelength and energy is seen throughout the entire EM spectrum. Scientists use a spectroscope to study the visible spectrum of unique bands of colours from stars and to compare these bands with known sample of elements to determine the composition of stars. Recall from Chapter 7 that each element has its own emission spectrum.

Radio Telescopes

Radio waves, the longest wavelengths of the EM spectrum, are easy to detect. Unlike visible light waves, radio waves travel undisturbed through clouds and rain and can pass through buildings. Astronomers use radio telescopes when they want to receive radio waves emitted from a distant object such as a star. Radio telescopes look like large satellite dishes. They are made of metal or wire mesh. The parabolic, or curved, surface collects radio waves that have travelled from space to Earth and focuses them to a single point, where the receiver is located (Figure 3). The radio signals are amplified and transmitted

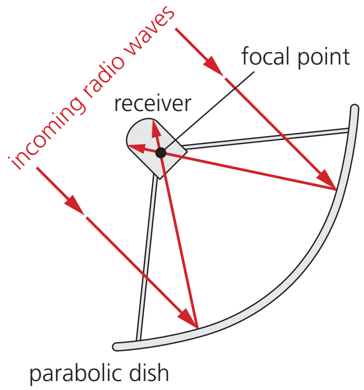


Figure 3 A radio telescope dish

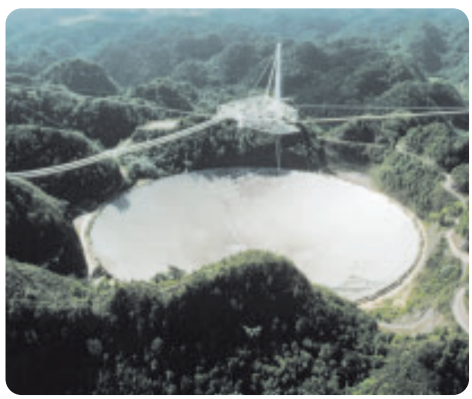
to a computer, which processes the information. Radio astronomers simply tune into the appropriate frequency, much like you would tune your radio to the frequency of your favourite radio station.

As a general rule, the instrument that is used to measure a specific band of the EM spectrum needs to be much larger than the wavelength it detects. Therefore, a telescope's resolution increases as its size increases. Since radio waves have the longest wavelengths, radio telescopes are large. Some are quite large. The radio telescope at Arecibo, Puerto Rico, has a diameter of 300 m (Figure 4(a)). As you can see, this telescope uses the curve of a natural valley between the mountains. Several smaller radio telescopes can be combined to work together. These are called arrays. They are usually placed in Y-formations that span many kilometres and are used instead of a much larger, single radio telescope. The Very Large Array (VLA) in New Mexico covers a distance of 36 km (Figure 4(b)). The advantage of using arrays is the increased resolution they provide.

Did You KNOW?

Radio Wave Interference

The ignition of the spark plugs in gasoline-powered engines interferes with the radio waves collected at radio telescopes, much like running a vacuum cleaner can interfere with TV reception. Scientists who drive to work at radio telescope observatories use diesel-powered vehicles because these vehicles don't have spark plugs.



(a)

(b)

Figure 4 (a) The radio telescope at Arecibo, Puerto Rico (b) The VLA near Socorro, New Mexico

Figure 5 The Dominion Radio Astrophysical Observatory, Penticton, British Columbia

The Dominion Radio Astrophysical Observatory (DRAO) in Penticton, British Columbia, has a relatively small radio telescope, with a diameter of 26 m (Figure 5). The DRAO also has a seven-dish array and a program that monitors the Sun. DRAO has been in use since 1960. In 1967, the DRAO and the Algonquin Radio Observatory in Ontario were linked, forming the first very long array. The resolution provided by this array equalled the resolution of a radio telescope with a diameter of 3000 km.

By studying radio waves that originate from distant sources such as galaxies and stars, astronomers can learn about the composition and movement of these objects. Astronomers also study radio wave emissions when searching for evidence of extraterrestrial life. Perhaps beings from other parts of the universe, if they exist, create radio waves with transmitters like humans do. An example of one of these projects is the Search for Extra-Terrestrial Intelligence (SETI). GO

If you would like to learn more about SETI, visit
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Microwave Technology

Microwave wavelengths range from approximately one millimetre (the thickness of pencil lead) to 30 cm. Microwaves are used primarily to transmit information from one city to another. However, microwaves are also emitted from Earth and from objects such as cars and planes. These microwaves can provide important information, such as the temperature of the object that emitted them. In fact, if you had a sensitive microwave telescope in your home, you could detect a slight signal leaking from a microwave oven in your kitchen. If you pointed your microwave telescope away from the kitchen, you would still detect a faint signal coming from all directions. This is the cosmic microwave background radiation mentioned in Chapter 13.

Infrared Telescopes

Infrared (IR) radiation is the part of the EM spectrum that we feel as heat, or thermal energy. While we cannot see IR radiation, we can detect it instantly. Special instruments aboard satellites such as IRAS measure incoming IR radiation from objects such as Earth, the Sun, and galaxies (Figure 6).

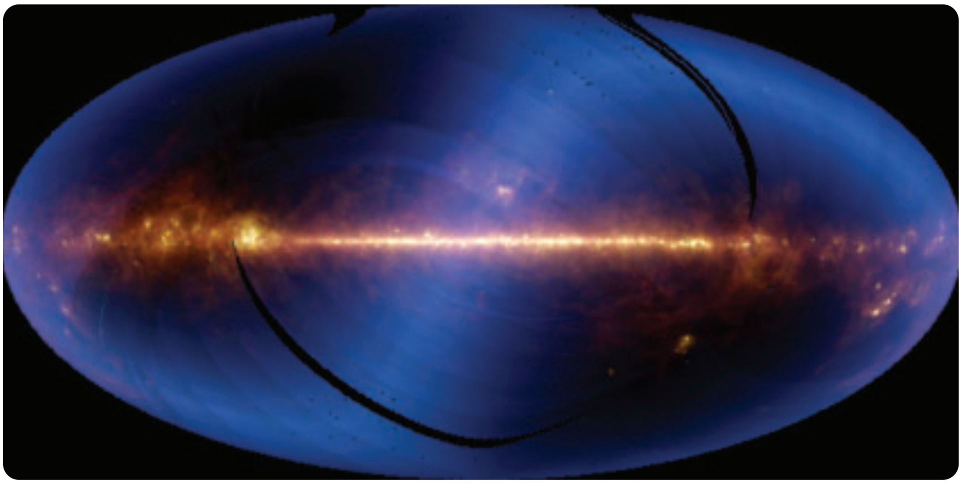


Figure 6 The centre region of the Milky Way galaxy, taken by IRAS

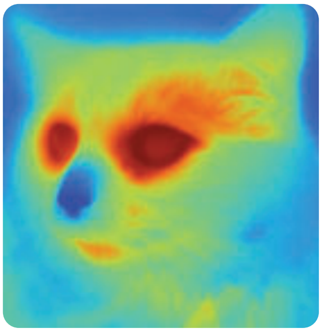
The specific frequency (or wavelength) of IR radiation that is emitted from an object is just one way that astronomers determine the temperature of the object. Look at the subtle differences in the cloud cover surrounding Earth in Figure 7. The darker clouds are warmer and lower than the brighter clouds. Clouds nearer the surface are warmed by the ocean below.

Figure 7 Image of Earth through IR-enhanced telescope

Did You KNOW?

A Snake's-eye View of the World

Some snakes, such as the pit viper, "see" only IR radiation. Their eyes are adapted with special sensory receptors that locate prey by detecting moving sources of heat. This view of a domestic cat in IR is how a pit viper would see it. The yellowish orange areas are the warmest, and the bluish white areas are the coolest.



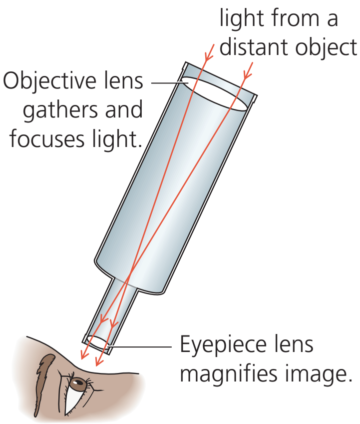


Figure 8 the light entering a refracting telescope refracts as it passes through the objective lens

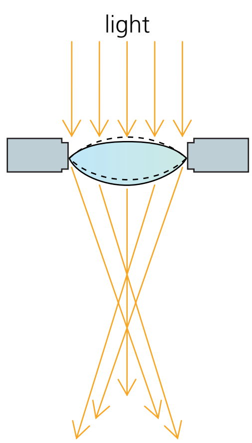


Figure 9 A large-mass glass lens will start to sag over time, under the force of gravity. The sag distorts the lens and, therefore, blurs the image.

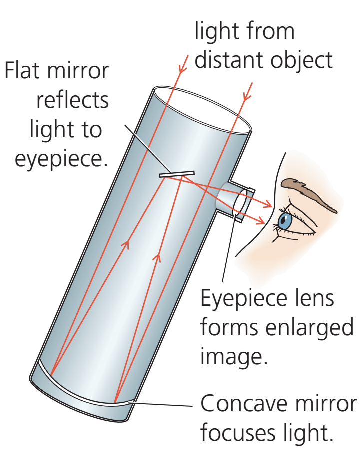


Figure 10 reflecting telescopes are used in many observatories around the world

Optical Telescopes

Instruments that gather and focus visible light so that our eyes can view distant objects up close are called **optical telescopes**. The first optical telescope, called the refracting telescope, was invented in 1608 by Hans Lippershey. The first person to use a refracting telescope for astronomy was Galileo, in 1610. A refracting telescope uses glass lenses to refract and focus light from distant objects (Figure 8). The images produced by refracting telescopes are crisp and clear. The larger the lens, the more light the telescope can gather, and the greater the resolution of the image. Resolution is the ability of an instrument to separate two images that are close together. Unfortunately, the diameter of refracting telescopes is limited to 1.2 m. Glass lenses that are beyond this size are too heavy and begin to sag under their own weight, resulting in blurred images (Figure 9).

In 1668, Isaac Newton designed what he thought was a better telescope. In place of a lens it had curved mirrors. It is called a reflecting telescope (Figure 10). The reflecting telescope could be made less expensively and still achieve images in sharp focus.

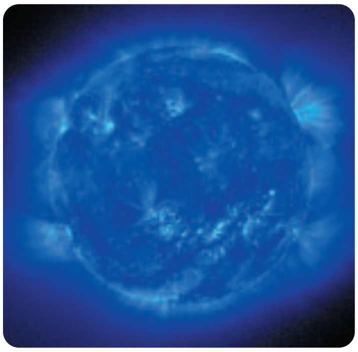
Although the small, portable refracting and reflecting telescopes are ideal for amateur astronomers to view the night sky, professional astronomers require telescopes with far greater light-gathering abilities. Larger telescopes are placed in permanent buildings called **observatories**. Observatories are expensive to build, so astronomers need to ensure they are built in places that will provide the best viewing.

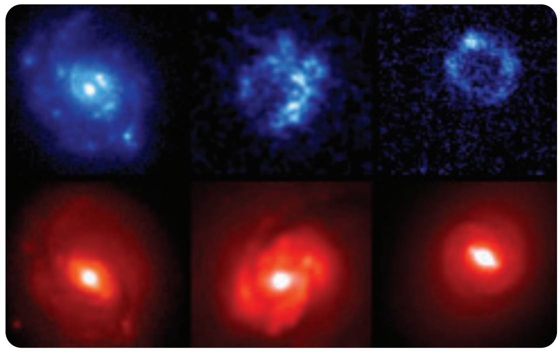
As light from space reaches Earth's atmosphere, it scatters, or diffracts. Atmospheric diffraction is responsible for the blurring and twinkling of celestial objects viewed from Earth. The less atmosphere through which light rays travel to an observatory, the less the effect of atmospheric diffraction and the clearer the images. Astronomers look for sites on mountains that are at least 3000 m high and above the clouds, away from light pollution. They also look for sites in areas where the atmosphere is dry. Because it is an advantage for the length of the night to be as long as possible throughout the year, observatories are often located near the equator. Locations near the equator also allow astronomers to see more stars in both the northern and southern hemispheres of the celestial sphere.

Ultraviolet Telescopes

Ultraviolet (UV) telescopes are designed to detect UV radiation. Since Earth's atmosphere blocks most UV radiation, these telescopes need to be placed on satellites in orbit. Scientists have used UV telescopes to predict when the Sun's UV emissions will be the greatest. Based on this, they have devised a system called the UV index, which can be used as a guide for people to protect their skin from the damaging effects of UV radiation. Since UV radiation exists at such a narrow wavelength, it can penetrate our cells and damage our DNA, causing cells to mutate and grow into tumours. Lucky for us, most UV radiation is blocked by the ozone layer in our atmosphere. Since the hottest and most active objects in the universe (such as newly formed stars) emit large quantities of UV radiation, many astronomers are interested in studying the invisible, or ultraviolet, universe.

Figure 11(a) shows what our Sun looks like in UV radiation. Computers interpret the UV data to make an image we can see. Figure 11(b) shows a comparison of three different galaxies in visible light and in UV radiation.





(a) **(b)**

Figure 11 (a) An image in UV from SOHO provides astronomers with new information about our Sun. (b) These images illustrate the difference between UV and optical telescopes. Three different galaxies are shown in UV light (top) and visible light (bottom). The UV images were taken by NASA's Ultraviolet Imaging Telescope.

Did You KNOW?

Bumble Bees See in UV

The bumble bee's compound eyes are specialized to detect wavelengths that are part of the UV spectrum.

X-Ray Telescopes

Black holes, neutron stars, binary (two) star systems, stars, and even some comets are among the many objects in the universe that emit X-rays. These high-energy waves do not make it to the surface of our planet. The Chandra X-ray Observatory, named after astronomer Subrahmanyan Chandrasekhar, has been orbiting Earth since 1999. Some events generate extremely high temperatures. One example is a binary star system, in which two stars are connected by a gravitational pull of matter from the smaller star to the much more massive neutron star (Figure 12). When objects reach more than a million degrees Celsius, they emit X-rays.

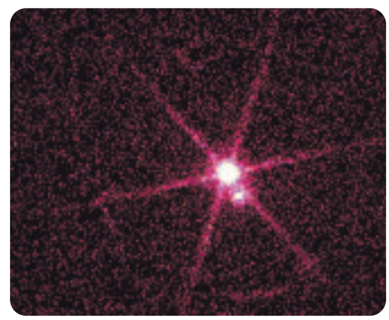


Figure 12 This Chandra X-ray image shows the double star Sirius A (lower right) and Sirius B (upper left).

Gamma Ray Telescopes

At the opposite end of the EM spectrum from radio waves are the gamma rays. They have the shortest wavelength and the highest associated energy of the EM spectrum. Gamma rays are produced by the hottest objects in the universe, such as the violent nuclear explosions of supernovas. Gamma rays are also produced by some radioactive materials when the nuclei of their atoms begin to decay (break down). Once again, our atmosphere protects us from gamma rays that travel vast distances from objects such as black holes, neutron stars, and pulsars.

Gamma ray telescopes detect radiation that is so energetic it simply passes through most of the telescopes mentioned in this section. That is, the radiation is not reflected by a mirror or stopped by a lead plate as in optical and X-ray telescopes. We detect the presence of gamma rays by their effects on electrons, as seen in the bubble chamber image in Figure 13. When gamma rays enter the atmosphere, they interact with particles, which take on some of the gamma rays' energy, much like an 8-ball moves when you hit it with the cue ball in a game of billiards. In fact, a chain reaction of energy transfer takes place through

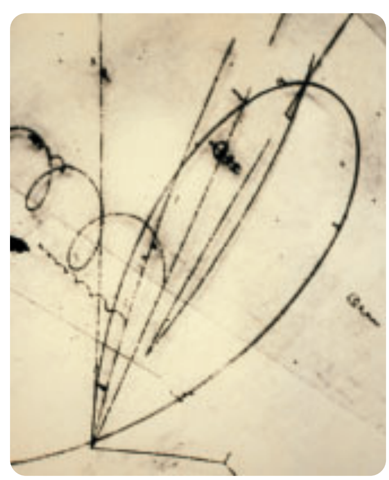


Figure 13 When electrons are hit by high-energy gamma rays, they scatter to make these beautiful patterns.

LEARNING TIP

To help you organize the information on the different telescopes make a six-column table with the following headings: Infrared, Optical, Ultraviolet, X-Ray, Gamma Ray, and Hubble. Reread pages 461 to 466 and record important information in point-form notes under the appropriate headings.

If you would like to learn more about TRIUMF, go to **www.science.nelson.com** GO

the atmosphere along the path to the ground. The altered particles in the atmosphere can be detected by devices called cosmic ray detectors, like the one shown in Figure 14 used at TRIUMF (Tri-University Meson Facility). TRIUMF is a world-renowned research site for particle physics. TRIUMF is operated by a number of universities across Canada, including the University of British Columbia and the University of Victoria. GO

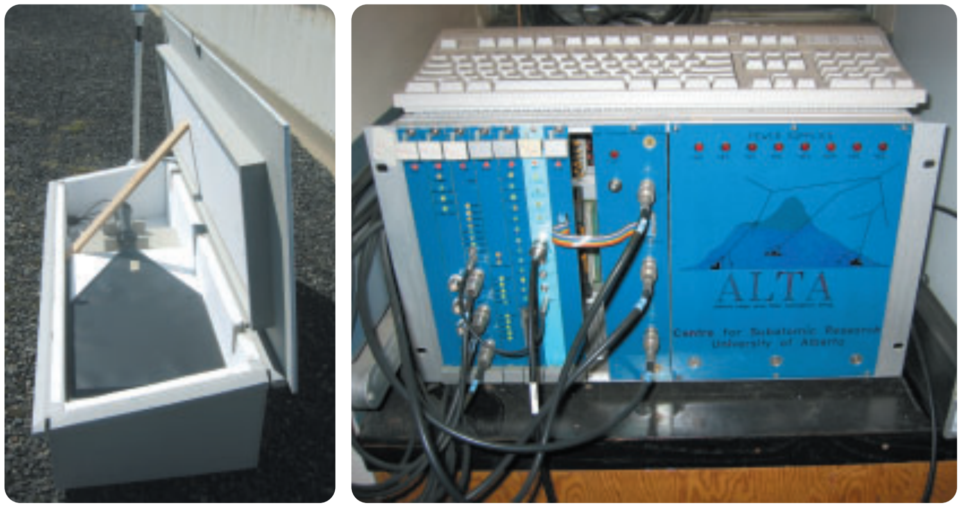
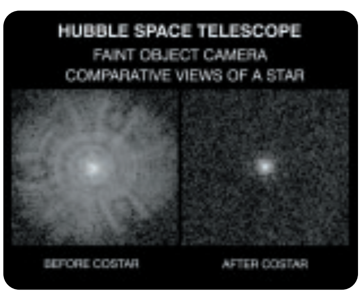


Figure 14 A cosmic ray detector at TRIUMF, University of Victoria. The black paddle-shaped device in the box (left) catches cosmic rays. These rays are then sent to a terminal that reads the signals (right).

Did You KNOW?

Little Room for Error

The optical portion of the HST consists of a very large mirror that was manufactured with a slight defect in the curved surface, one-fiftieth the diameter of a human hair. The defect was not detected until after the HST was launched on April 24, 1990, when the first few images were not as clear as scientists had hoped. Astronauts corrected this problem in 1993 by adding a secondary mirror. The image on the left shows a star before the defect was fixed. The image on the right shows the same star after the defect was fixed.



Hubble Space Telescope

An alternative to building an observatory above the clouds is to place a telescope in space as a satellite, above the atmosphere. The Hubble Space Telescope (HST), named after the famous astronomer Edwin Hubble, is approximately the size of a school bus and orbits Earth every 90 min at an altitude of about 500 km (Figure 15). This multitasking tool allows astronomers to view objects at distances far greater than they could with other telescopes without the negative effects of atmospheric diffraction. The HST has a variety of other telescopes aboard, besides the optical telescope. Figure 16 shows just one example of the brilliant photographs taken by the HST.

Figure 15 The Hubble Space Telescope. Many images used in this unit were taken by the HST.

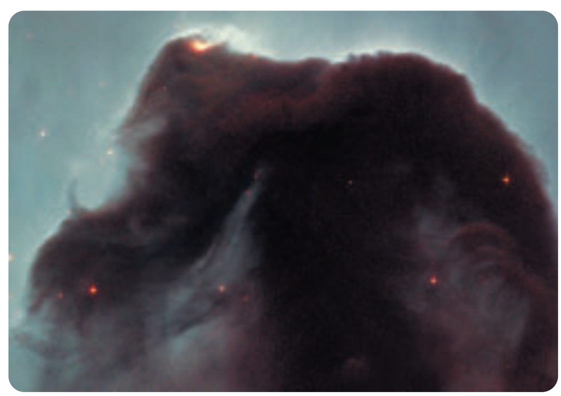


Figure 16 The Horsehead nebula, one of the most photographed objects in the sky. The bright region near the top left is a young star in the earliest stages of its life cycle.

14.1 CHECK YOUR Understanding

1. What is an astrolabe, and how is it used?
2. (a) What is the electromagnetic spectrum?
   (b) Explain why the electromagnetic spectrum is important to astronomers.
3. Compare radio waves and gamma rays.
4. Why do astronomers study radio waves?
5. Why are radio telescopes sometimes arranged in arrays?
6. What is an advantage of using a radio telescope rather than an optical telescope?
7. (a) What are optical telescopes?
   (b) Compare refracting and reflecting telescopes. You may want to include a diagram in your answer.
8. What is atmospheric diffraction, and how does it affect the images from optical telescopes?
9. Why do the mountains in British Columbia not provide suitable locations for optical observatories?
10. According to Figure 17, which part of the EM spectrum would require the smallest instruments for detection?

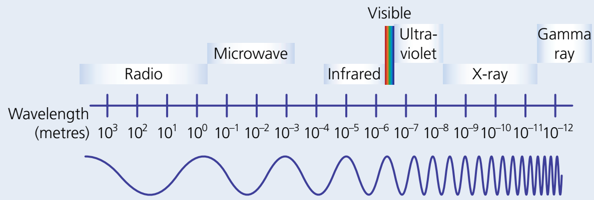


Figure 17

11. How do astronomers use UV radiation to study certain objects?
12. List the forms and approximate wavelengths of energy that is blocked by our atmosphere.
13. How are all the telescopes mentioned in this section similar? List two ways in which they differ.
14. If you wanted to study the variations in temperature on the surface of a star, which instrument(s) would you use?
15. What type of telescope would you use to detect each of the following wavelengths of light?
    (a) 1×10^4 m (10 000 m)
    (b) 1×10^{-2} m (0.01 m)
    (c) 1×10^{-6} m (0.000 001 m)
    (d) 1×10^{-14} m (0.000 000 000 000 01 m)
16. Identify and describe the wavelengths of the electromagnetic spectrum detected by each instrument in Figure 18.

(a)

(b)

Figure 18

14.2 Explore an Issue

DECISION MAKING SKILLS

- ○ Defining the Issue
- ● Researching
- ○ Identifying Alternatives
- ● Analyzing the Issue
- ● Defending a Decision
- ● Communicating
- ● Evaluating

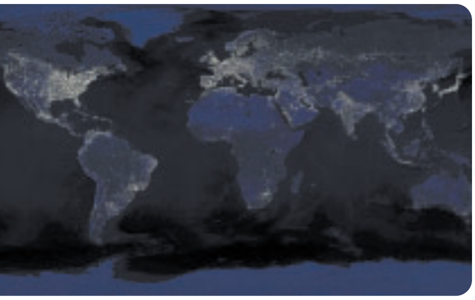


Figure 1 This composite of satellite images shows the areas of the world where population is concentrated. Light pollution is a global problem.

Light Pollution Solution

Depending on where you live in the province, you may not be able to see the same number of stars that people were able to see only a generation ago. On any given evening someone in a rural location will be able to see a greater number of stars than someone in or near a city. In fact, the city dweller will only be able to see the brightest of stars and planets in the sky. Why? This is because of the artificial light that surrounds us during the night. Every light source emits light directly where it is needed, but some of the light shines upward where it is not needed and indirectly illuminates the night sky (Figure 1). The indirect light that is wasted is called light pollution.

The Issue: The Impact of Light Pollution

Most of the wasted light shines upward and reflects off hard surfaces and clouds. The wasted light is then scattered by molecules and dust in the atmosphere. This causes even more of the city's skyline to glow at night, further reducing the number of stars visible from the streets and homes below (Figure 2). Urban areas may experience a night sky that is up to 100 times brighter than a night sky in an unpopulated or unlit rural location.

Figure 2 The Vancouver skyline at night is so bright that apartment dwellers often suffer from interrupted sleep cycles.

Statement

Municipalities across British Columbia should be concerned about light pollution and take steps to reduce it.

Background to the Issue

Astronomers and other observers are frustrated by the amount of artificial light that enters their eyes or telescopes as they attempt to study the night sky. It is almost impossible to study the smaller and more distant stars through the glowing atmosphere caused by the light from nearby towns and cities.

There is considerable energy wasted through light pollution. If 30 % of light output from outdoor lighting goes up into the sky instead of down onto the street, then we are using 30 % more energy than is necessary to light our towns at night. Wasted energy also means wasted money.

LEARNING TIP

Before beginning this activity, read over the headings to become familiar with the different parts.

Different Perspectives on the Issue

- Astronomers need light pollution to be reduced to make research easier.
- Environmentalists are concerned about excessive light for birds and other wildlife. Many migratory birds are killed when they fly into lit windows. Turtles, insects, and other nocturnal animals such as owls depend on the natural rhythm of light and darkness.
- Environmentalists are also concerned about the wasted energy.
- Business people need light to keep the company signs and logos well lit at night as a way of advertising to people who pass by at night.
- Citizens, in particular senior citizens, need well-lit streets at night for protection.
- The city council says that funding is not available to implement necessary steps to reduce light pollution.
- Some taxpayers say that reducing light pollution saves money in the long term.
- Some taxpayers say that the costs associated with reducing light pollution should be the responsibility of those who want light pollution reduced.

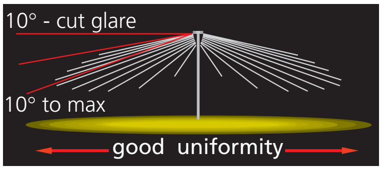
LEARNING TIP

When taking a perspective on an issue, it is helpful to step into the person's shoes, and imagine what it is like to be him or her.

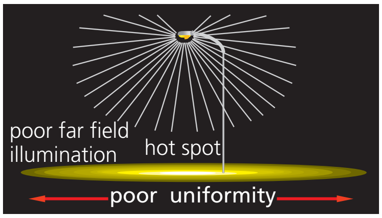
What Can Be Done?

Council members at your City Hall may not be aware of this issue or may have other priorities and costs to manage. Installation of streetlights with better shielding so that more light is directed down to the street and not up to the sky is one measure that could help reduce light pollution.

Designs may be required for a new lighting system that would produce uniform illumination (Figure 3) so that less energy is wasted. These new designs may solve the problem, but they are costly to produce and install.



(a)



(b)

Figure 3 Modified lighting technology can reduce light pollution. (a) Sharp cut-off illumination reduces upward glare and provides better uniformity to the light cast below. (b) By contrast, the standard cobra illumination has poor illumination and causes upward glare.

Make a Decision

1. Research the issue for additional background information and perspectives.

   www.science.nelson.com GO

2. Decide which perspectives are the most important. Explain or justify your position.
3. As a group, decide whether or not you agree with the statement. Provide support for your position.

Communicate Your Decision

4. As a group, prepare a presentation that summarizes your position on the issue. Base your presentation on a staged debate, which you will act out in front of the class, or on a written position paper. If you choose to enact a debate, be sure to finish the session with a conclusion. If you choose to write a paper, be sure to support your position.

14.3 Computers and Probes

LEARNING TIP

Set a purpose for your reading. Preview Section 14.3 by noting the headings and figures. Predict what you will learn in this section.

When you think of an astronomer at work, you may imagine someone who spends a lot of time looking up at the stars, searching for new discoveries through an optical telescope. In fact, the modern astronomer spends far more time in front of a computer interpreting data that has been collected by many of the instruments discussed in this chapter.

Computers

As you have learned, many of the instruments discussed in this chapter have to be placed on satellites outside Earth's atmosphere in order to receive the radiation. The data gathered by these telescopes is then analyzed by computers, which translate the data into images we can see. The images produced appear as we would see them if our eyes were adapted to pick up other wavelengths of the EM spectrum. Therefore, most of the photographs taken by these specialized telescopes are enhanced by false colour (Figure 1). False colour is produced by a computer program, which assigns a colour to a specific wavelength in the image. Since we cannot actually see these wavelengths, false colour is essential when astronomers want to create detailed images of a star's ultraviolet or radio wave emissions. Our eyes cannot store light over time so we may not necessarily see an object's true colours. However, cameras attached to optical telescopes can take long exposures, thus enhancing the true colours for us.

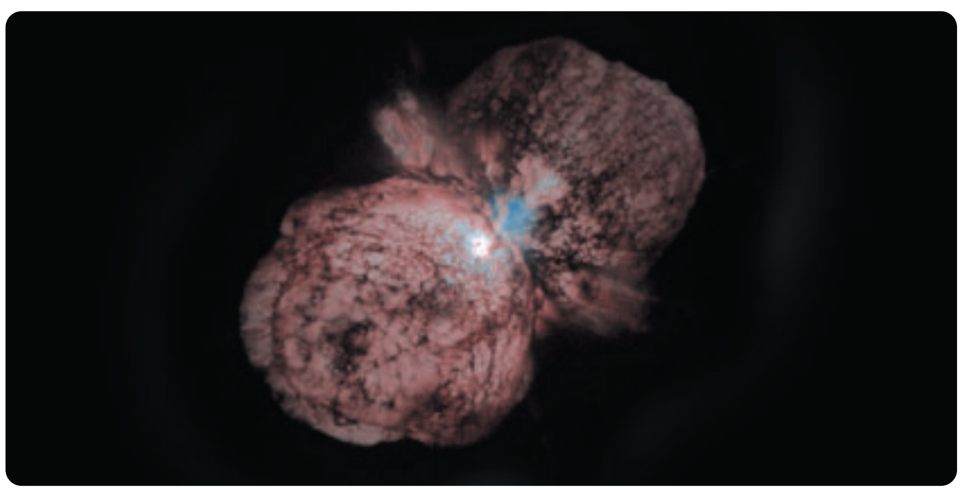


Figure 1 This picture of a dying star, Eta Carinae, was taken by a series of radio telescopes. A computer creates the radio wave image of what you would see if you had eyes that could see radio waves. Images like this have given astronomers a new view of the universe.

Computers on the HST transmit data from many types of telescopes to allow astronomers on Earth to analyze certain features, display images, make calculations, and store data for future reference. These computers also enable Earth-bound astronomers to control the instruments aboard the HST.

Scientists also use computers when they want to test their models through simulations. Computers can perform many calculations based on parameters set by the scientist. The effect of different conditions can be simulated by changing the parameters or by adding and removing variables in the system.

Computers record and analyze huge amounts of data, produce images, and perform complex mathematical calculations, and operate and monitor intricate instruments. Computers allow us to peer into the past, examine the present, and make reasonable predictions for the future. One of the most important functions of computers is that they allow scientists all over the world to share scientific information and collaborate in their investigations.

Probes

Another valuable instrument in the astronomer's tool box is the space probe. A **space probe** is an unpiloted spacecraft that leaves Earth's orbit. The first successful space probe to leave Earth's gravity was the Soviet *Luna 1*, launched in 1959, 10 years before humans took the first steps on the surface of the Moon. Since then, hundreds of space probes have sped through our solar system in an attempt to acquire new short-range data. Often samples are collected and analyzed onboard, so the findings can be sent back to Earth by radio signals. Much of what you have learned about the planets and other objects in our solar system has come from data collected by numerous space probes.

Space probes enable scientists to learn more about our own planet as they observe other planets. For example, the space probe *Magellan* helped scientists learn about the effects of greenhouse gases on Earth when they observed the same phenomenon in the dense atmosphere of Venus.

One of the most successful space probes is *Voyager 2* (Figure 2), which was launched in 1977 to study Jupiter, Saturn, Uranus, and Neptune. *Voyager 2* sent back amazing images of the planets and their moons as well as detailed information about the composition of their atmospheres. *Voyager 2* and *Voyager 1* (launched the same year) discovered that Jupiter has rings, a magnetic field, and that Io, one of Jupiter's moons, has active sulfurous volcanoes at its surface.

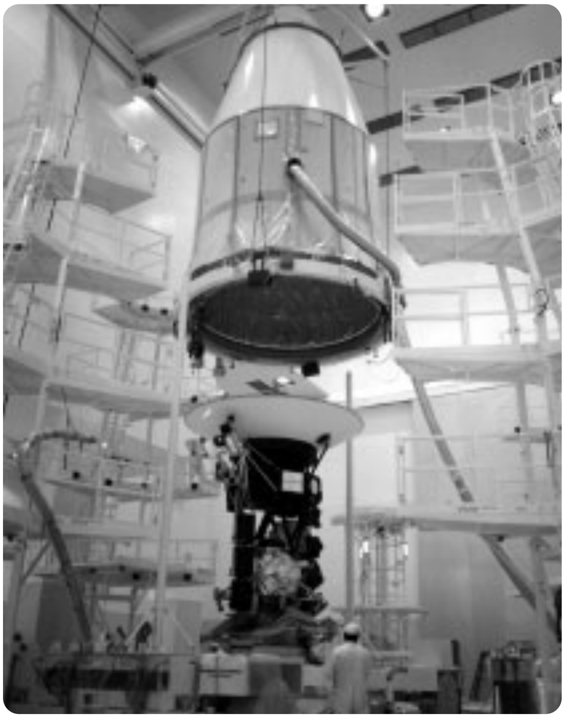


Figure 2 The *Voyager 2* spacecraft

Did You KNOW?

Voyager Slingshot

Probes can travel great distances using very little fuel. They are launched in such a way that their paths are influenced by the gravitational pull of the planets along their route. *Voyager 2* took advantage of a rare alignment of the outer planets that only happens once every 189 years. This special circumstance provided sufficient force to sling-shot the probe beyond the outer edge of our solar system!

Figure 3 The Mars rover *Spirit* (Artist's rendition)

If you would like to learn more about the Mars rover expeditions, go to **www.science.nelson.com** GO

LEARNING TIP

Check your understanding. Explain to a partner how computers and probes have given astronomers a new view of the universe. What role does false colour play in computer programs?

There are many other space probes:

- In 1995, the space probe *Galileo* released a probe into Jupiter's atmosphere and discovered that Jupiter had winds that extend thousands of kilometres into its interior.
- In 2003, NASA sent two probes, the two robotic rovers called *Spirit* and *Opportunity*, to Mars to explore the surface and geology (Figure 3). One of the mission's goals has been to search and characterize a variety of rocks and soils that hold clues to past water activity on the red planet. Such information may help scientists determine whether life has ever existed on Mars and may even help them unveil the mysteries of life's origin on Earth. GO
- In 2004, the space probe *Cassini* was the first probe to orbit Saturn. During its four-year mission, *Cassini* will make 74 revolutions of the planet and 44 fly-bys of Saturn's moon Titan. In 2006, Cassini captured images of the Sun from behind Saturn, allowing scientists to view a new ring and one of the planet's moons passing through the outer ring (Figure 4).

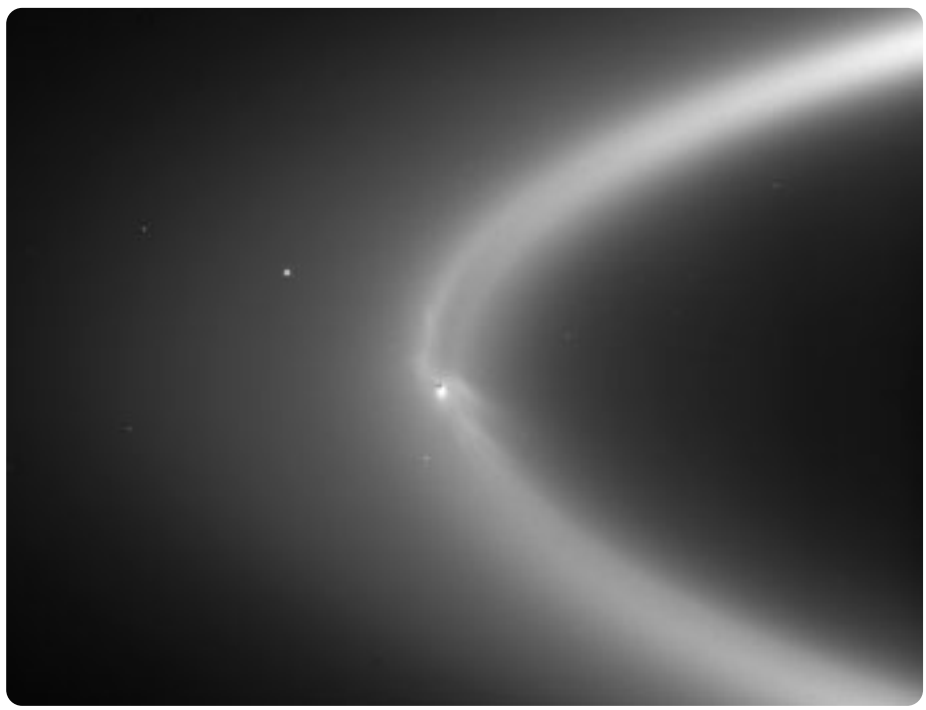


Figure 4 With light from the Sun behind Saturn, the moon Enceladus is seen passing through Saturn's outer ring, sending a bright streak of icy material tens of thousands of kilometres into space.

- In 2004, NASA launched the space probe *Messenger* (Figure 5) to study the planet Mercury. When it does reach Mercury, *Messenger* will take colour images of most of the planet. *Messenger* will also collect data to analyze the composition of the surface, the planet's atmosphere, and its magnetic field.

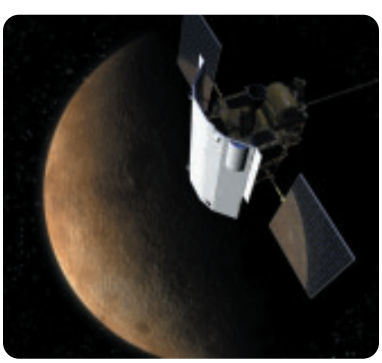


Figure 5 The *Messenger* space probe will enter Mercury's orbit in 2011.

- The European Space Agency (ESA) probe *Huygens* hitched a ride on *Cassini* and landed on Titan in 2005. The *Huygens* landing marks the farthest touchdown of any probe sent to land on another celestial body.
- Later in 2005, an impactor spacecraft the size of a coffee table, which was sent out from the space probe *Deep Impact,* slammed into Comet Tempel 1 at a speed of more than 14 000 km/h. Analysis of the cloud of material that blasted into space revealed water and ice on the comet's surface and interior (Figure 6).

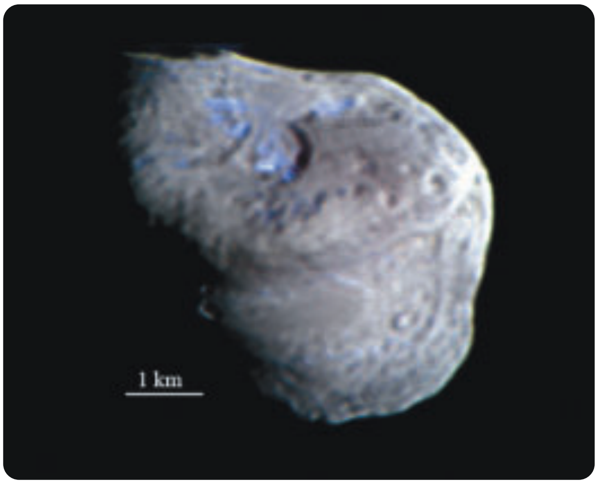


Figure 6 Ice deposits (shown in blue) on Comet Tempel 1

LEARNING TIP
Summarize what you have read. What do you recall about the successes of the different space probes?

- In 2006, NASA launched the *New Horizons* probe. *New Horizons* will explore Pluto and Charon, one of Pluto's moons. Charon is quite large, compared with Pluto. It is half Pluto's size. Pluto and Charon form a binary dwarf planet. *New Horizons* will be the first probe to explore a binary system. After this encounter, *New Horizons* will explore Kuiper belt objects. GO

If you would like to learn more about probes and other unpiloted missions, go to **www.science.nelson.com** GO

Amateur Astronomers

Amateur astronomers also contribute data to professional astronomical organizations. In fact, the American Association of Variable Star Observers (AAVSO) relies on the contributions from amateur astronomers worldwide to collect, evaluate, and publish data from variable star observations. This data is referenced by hundreds of professional astronomers as they study stellar activity.

Sometimes an object such as the Moon, a planet, or an asteroid passes between an observer and a star. This is called an occultation. Another way amateur astronomers contribute to professional organizations is by observing occultations. Astronomers with the International Occultation Timing Association (IOTA) are interested in occultations. If several observers situated kilometres apart all accurately record the time that a star disappears behind an asteroid, for example, then IOTA can use this information to determine an accurate size and shape of the asteroid. GO

If you are interested in learning more about the AAVSO and IOTA, go to **www.science.nelson.com** GO

14.3

CHECK YOUR Understanding

1. List five ways that astronomers use computers.
2. The false-colour images in Figure 7 show Earth and Mars and their axes. The false colours represent heights above and at sea level.
   (a) Study the false-colour image of Earth on the right. Which colours represent sea level, and which colours represent high altitudes?
   (b) Using what you have deduced about the false-colour image of Earth, what can you tell about the surface of Mars?
   (c) What is the predominant landscape in the southern hemisphere of Mars?
   (d) Do you find anything misleading in the false-colour image of Mars? Explain your answer.

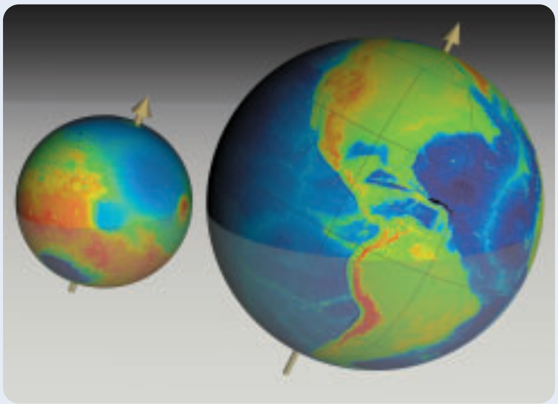


Figure 7

3. How are land-based telescopes different from orbiting instruments?
4. Create a concept map that shows astronomers' use of computers to understand space.
5. What is a space probe?
6. State at least two differences between space probes and instruments in Earth orbit.
7. Describe two advantages of using space probes to study distant objects.
8. Space probes have been sent to explore asteroids (Figure 8) and comets. How does this exploration help in the study of the origin of the solar system?

Figure 8

9. What are some reasons why space probes are unpiloted?
10. Why is launching the space probe *Messenger* to go into orbit around Mercury like trying to stop suddenly while running downhill?
11. How can amateur astronomers contribute to the research done by professional astronomers?
12. Why are contributions by amateur astronomers considered to be a tool of the astronomer?

Awesome **SCIENCE**

THE INTERNATIONAL SPACE STATION

Is it a bird? Is it a plane? Well, it might be the International Space Station (ISS). Visible from Earth, the ISS is the most complex technological project ever built by humans. It required the co-operation of space agencies from 16 countries, including Russia, Canada, Germany, France, Italy, Japan, and the United States.

Construction of the ISS started in 1998, and its first crew reported for duty in 2000 (Figure 1). Since that time, there have always been at least two people living onboard the ISS.

Although over 400 people have already been sent into space, scientists know very little about the long-term effects of continuous free fall (sometimes incorrectly called weightlessness) on the human body. For this reason, much of the work that takes place on the ISS is medical research conducted by scientists. Areas of research include studies on the human nervous, cardiovascular, respiratory, and immune systems. In addition, biopsies of the crew's calf muscles are taken to learn more about physiological changes in the metabolism of cells. Behavioural issues related to isolation and confinement are also closely monitored through crew journals and surveys.

Medical research is not the only work that is done on the ISS, however. Experiments in materials research, crystal growth, chemical reactions, the environment, and much more take place. For example, studies of plant and microbial life are conducted. In one such experiment, scientists hope to determine the genetic effects on microbial life on the ISS—whether the free-fall environment causes harmful strains of mutant bacteria to develop. Scientists also want to learn how plants function because plants could serve a vital role on future space stations, converting excess carbon dioxide into oxygen that humans can breathe.

In addition to conducting research, the astronauts must exercise on a regular basis and complete complex tasks, such as repairing equipment outside the space station.

Two of Canada's major contributions to space technology are the Canadarm (Figure 2) and its successor, the Canadarm2. Most space shuttles have a Canadarm. The Canadarm2 is used on the ISS to assist in the construction of the ISS, to move cargo in and out of the station, and to help astronauts who are working outside the station. The Canadarm can handle masses of up 266 000 kg in space, while the Canadarm2 can handle masses of up to 116 000 kg. Canadarm2 is equipped with a sophisticated vision system and a touch sensor system, which allow the astronauts more precision when using it.

Figure 1 The International Space Station, with the Canadarm2 extended

Figure 2 The Canadarm

CHAPTER 14

Review

The Tools of the Astronomer

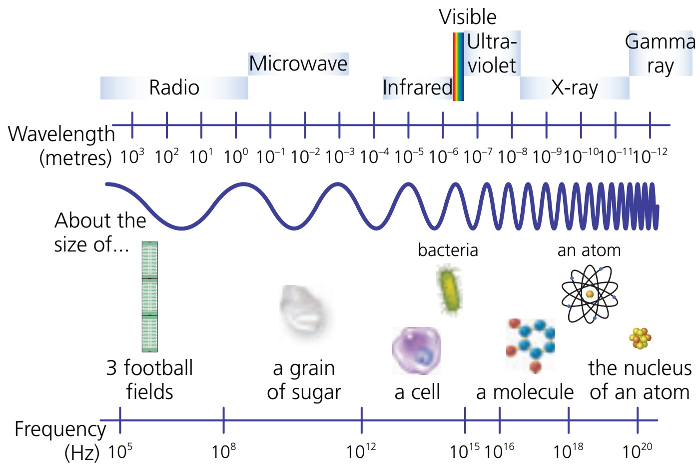
Key Ideas

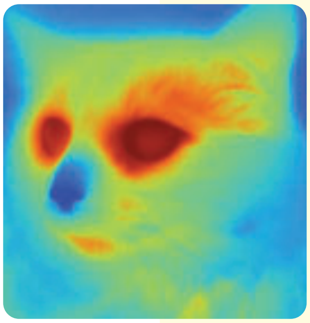
The astrolabe and the star map were tools used by early astronomers to chart the heavens and navigate the globe.

- The astrolabe is an instrument that is used to calculate the distance to and between stars by measuring the angles from two positions and creating a scale drawing. This method is called triangulation.
- Star maps help observers locate objects in the sky.

Astronomers use different types of telescopes to study a variety of objects in the sky.

- The electromagnetic spectrum is the total spectrum of radiant energy. Parts of the EM spectrum are emitted by all objects in the universe.
- Telescopes are instruments that allow astronomers to view objects in space, either from Earth's surface or from orbit around Earth.
- Each type of telescope is designed to detect specific wavelengths of the electromagnetic spectrum. For example, radio telescopes detect the radio waves emitted from galaxies and stars and provide clues to their composition.





Vocabulary

electromagnetic (EM) spectrum, p. 460

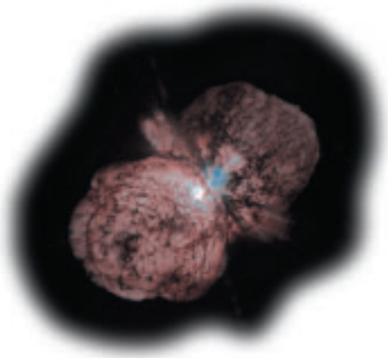
optical telescopes, p. 464

observatories, p. 464

space probe, p. 471

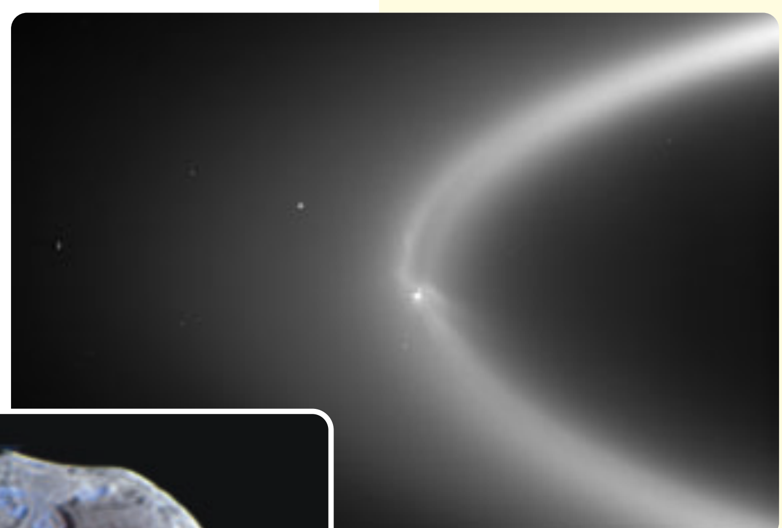
Computers are essential to the astronomer.

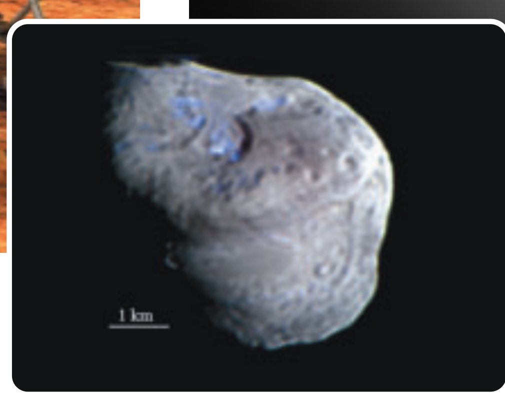
- Computers are used to analyze large quantities of data.
- Astronomical equipment and instruments such as telescopes, on the ground and in space, are controlled by computers.
- Computers translate the information received by telescopes into meaningful images of objects we ordinarily would not see.



Space probes are sent into space to explore planets and other objects.

- Space probes are unpiloted instruments that are sent into space to explore planets and other objects at close range.
- Some space probes use robots that roam the surface of another planetary body and transmit data back to Earth for analysis.





Review Key Ideas and Vocabulary

1. Describe a specific situation in which an astrolabe could be used.
2. What simple tool is used for triangulation?
3. What is the electromagnetic spectrum?
4. How would you explain the term "emit" to a Grade 5 student?
5. (a) What is atmospheric diffraction?
   (b) How does atmospheric diffraction affect observations of celestial objects from Earth's surface?
6. Why are many observatories situated on mountaintops in remote locations near the equator (Figure 1)?

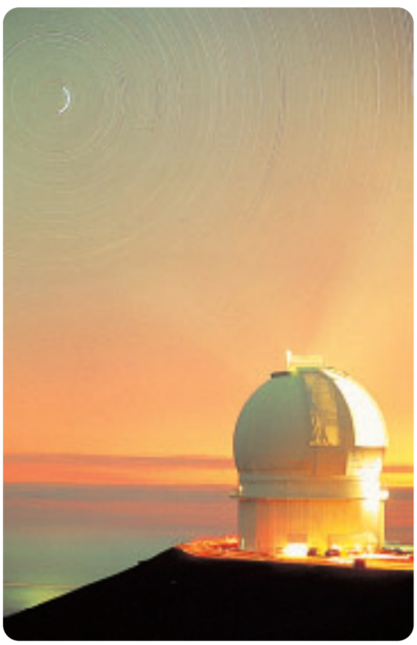


Figure 1

7. How has the Hubble Space Telescope helped astronomers on Earth better view distant objects?
8. What characteristic of ultraviolet light makes it hazardous to living things?
9. How do astronomers detect gamma rays?
10. In your own words, explain why we should be concerned about light pollution. Provide three reasons.
11. Name an instrument other than the Hubble Space Telescope that enables astronomers to overcome the effects of atmospheric diffraction.

Use What You Have Learned

12. Indicate the wavelength on the EM spectrum that corresponds to each of the following objects.
    (a) basketball court
    (b) virus particle
    (c) baseball
    (d) human hair
13. Create a list of tools that astronomers use, and classify them into categories of your own.
14. What kind of telescope would detect the heat emitted from the object in Figure 2?

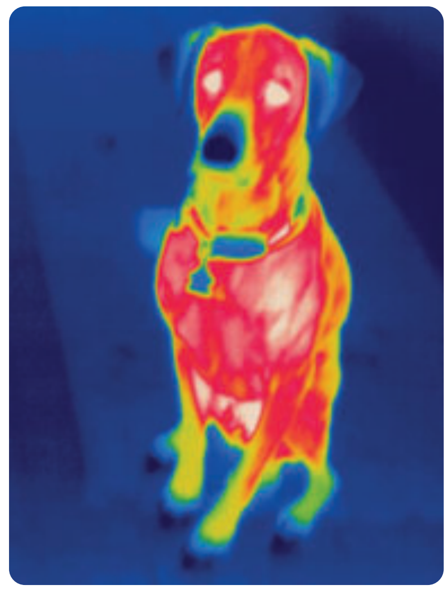


Figure 2

15. Imagine that you had the ability to see only infrared light.
    (a) How would the appearance of the world around you be different than what you are used to now?
    (b) How might infrared vision be an advantage in our world? How would it be a disadvantage?
16. How have space probes improved our knowledge of the universe?
17. Copy and complete Table 1 for three objects from the solar system.

Table 1 Information Gained from Recent Probes

Object 1	
Object 2	
Object 3	

Think Critically

18. Some researchers have suggested that the constant shower of electromagnetic radiation has influenced the evolution of species on Earth. Do you agree or disagree with this statement? Explain your answer.

19. How do you suppose astronomers would differentiate between radio signals that may come from an intelligent source and the natural "noise" of radio waves in the cosmic background? (Hint: Consider how the patterns of radio wave bursts may differ.)

20. Do you think optical observatories use refracting or reflecting telescopes? Defend your answer.

21. Research Earth's atmosphere on the Internet.
(a) How does the atmosphere protect us from harmful cosmic radiation?
(b) In what ways does the atmosphere block radiant energy from space?

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22. The images in Figure 3 show Uranus in true colour (on the left) and false colour (on the right). The false-colour image shows a dark polar region surrounded by progressively lighter concentric bands, which show differences in cloud structure. These structures are barely detectable in true colour. What sorts of questions are raised when astronomers study false-colour images like this one? Do you think false-colour images can help direct the investigations of astronomers? Explain.

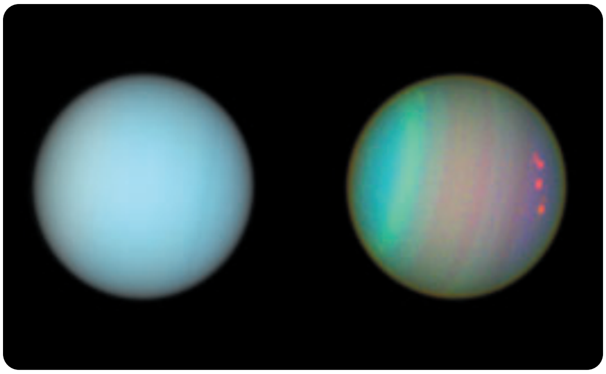

Figure 3

23. When the spacecraft *Pathfinder* landed on Mars in 1997, it bounced 16 times (Figure 4). Research how probes are designed to land safely. Select one of the designs and prepare a brief report, including a drawing.

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Figure 4

24. In 1998, NASA launched the *Mars Climate Orbiter*. In September 1999, the probe burned up while entering the Martian atmosphere. Research the Internet, and determine why this mission failed.

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25. Design your own space probe. What is the destination of your mission? What information do you hope to find? What types of instruments will your probe carry? (The instruments should relate to the information you are trying to obtain.) Sketch and name your probe, and describe the path that your probe will take to its destination.

26. Suppose that you have been asked to interview an astronomer. Write the top five questions that you would like the astronomer to address during the interview.

Reflect on Your Learning

27. Think about the questions in the Chapter Preview. How would you answer these questions now? What other questions do you have about tools that are used by astronomers?

28. What will you look for the next time you gaze at the night sky?

29. In your own words, describe what the expression "the right tools for the job" means to an astronomer.

Visit the Quiz Centre at
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CHAPTER 15

Exploring Space

KEY IDEAS

- The technology required to travel beyond our solar system has not yet been developed, and the ideas are only in the speculation stage.
- New technologies for travelling into Earth orbit are being researched or developed.
- There are ethical issues associated with travelling in space and possibly colonizing other worlds.
- NASA and other space agencies have planned for further exploration of the Moon and Mars in the coming decades.

Chapter Preview

At the dawn of the 21st century, astronomers have discovered over 200 planets circling other stars. But data suggest that these planets are not terrestrial, Earth-like planets. Are there Earth-like planets out there? If life exists on other planets, why haven't we found it? Why hasn't it found us? In a 5-billion-year-old solar system within a 13-billion-year-old universe, shouldn't there be life that is more advanced than we are and capable of travelling the vast distances of interstellar or intergalactic space? If we are alone, and all of space is ours to freely explore, what steps have we taken to do so? What do we need to survive in space? Do we have the right to colonize or mine the worlds we visit? In this chapter, you will learn about some of the current research into technologies that may allow us to travel to, and possibly inhabit, Mars.

TRY THIS: An Earth-Like Planet?

Skills Focus: conducting, recording, evaluating, communicating

To date, astronomers have found approximately 200 planets circling other stars, but they are not Earth-like planets. What makes a planet Earth-like? In the Orion nebula, shown on these pages, astronomers have found many solar systems in the making, but no functioning sun and no planets yet, and certainly no Earth-like planets.

What conditions are required for a planet to be an Earth-like planet and, therefore, capable of supporting life?

1. In a group, describe the conditions that support life on Earth. What do we need to survive?

A. What do you think would happen if our planet was
- closer to the Sun
- farther away from the Sun
- orbiting the Sun in 10 days
- made of nothing but gases

B. In a summary statement, describe the characteristics that an Earth-like planet must have.

C. What assumptions do scientists make about other possible life forms when they search for Earth-like planets?

15.1 Faster Than the Speed of Light

Given the vastness of space and the distances to the closest stars, how long would conventional space travel take us to reach one of those stars? What plans exist to speed up such a journey?

In popular science fiction of the late 20th century, warp travel, or travel at and beyond the speed of light, is commonplace (Figure 1). However, reality is considerably different from science fiction. Three major scientific advancements must be made before we can travel to the stars. We must discover:

- a way to exceed the speed of light
- a system to power a spacecraft without fuel
- a way to take advantage of the energy in space

Figure 1 The spaceship *Enterprise* from the science-fiction television series *Star Trek*

Warp Speed

Table 1 shows how long it would take, at different speeds, to reach Proxima Centauri. At 4.2 light years, Proxima Centauri is our closest star besides the Sun. Clearly, travel to the stars means that we have to figure out how to travel faster than the speed of light.

LEARNING TIP

As you read Table 1, look at the headings. They will help you focus on what is important in the table. How does the middle column help you understand Table 1?

Table 1 Time to Proxima Centauri

Travelling speed	Reference	Approximate time to Proxima Centauri
90 km/h	some highway speeds	50 million years
28 000 km/h	space shuttle speed	163 000 years
60 000 km/h	interstellar probe speed leaving the solar system	80 000 years
300 000 km/s	speed of light	4.2 years

Power without Fuel

Suppose that we could reduce the travel time to Proxima Centauri to 900 years. How much fuel would the best chemical rockets of today need to get a spacecraft the size of a school bus there? The calculations show there is not enough mass in the universe to provide the necessary rocket fuel. Nuclear-powered engines are a possibility, but they, too, need excessive amounts of fuel. The most efficient nuclear fusion rocket, if it existed, would need enough fuel to fill 1000 supertankers (Figure 2(a))! Ion propulsion rockets would be much more efficient; they would need only enough fuel to fill about 10 train tanker cars (Figure 2(b)). Theoretically, any of these systems could get us there, but we would be out of fuel and travelling very fast. How would we stop? How would we get home? Add these considerations to the enormous amount of fuel the spacecraft would have to carry, and it would be impossible.

(a) (b)

Figure 2 (a) A supertanker (b) Train tanker cars

Energy from Space

Scientists need to find a way to control the forces of gravity and **inertia**—the tendency for an object in motion to stay in motion or an object at rest to stay at rest—or to find a way for a spacecraft to push against space itself.

Travelling without fuel still requires energy. The only possible energy source is the energy in the vacuum of space itself. Unfortunately, we are far from using this energy at the present time and in the foreseeable future.

The science, technology, and practical applications required for a form of space travel that could get us to the stars fast enough, with less bulky fuel or no fuel at all, is beyond our reach. Indeed, in a five-part scale of progress two other stages—wishful thinking and speculation—occur before science, technology, and practical application (Figure 3). Wishful thinking is the stage when we know what we would like to have, but we have no idea whether it is possible. Speculation is the stage when we have finally learned enough to know what we do not know. From here, science is often able to ask the right questions to solve a problem.

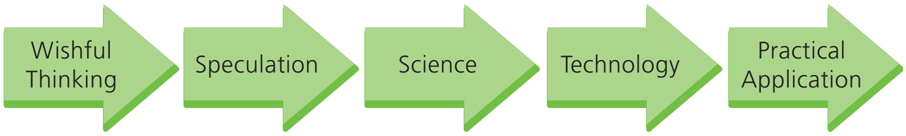


Figure 3 The scale of progress

Warp Drive

Faster-than-light travel powered by a warp drive engine is at the speculation stage. It has barely entered the reality of science. However, most of the scientific data collected so far indicates that faster-than-light travel is not possible. The concept poses many problems:

- Faster-than-light travel is not possible according to current theories about the nature of the universe. To achieve faster-than-light travel, scientists will have to modify or replace existing theories on how the universe works.
- The matter that a spacecraft is made of is held together at the subatomic level by electromagnetic forces. Light is part of the electromagnetic spectrum. How can something travel faster than that which holds it together?
- The speed of light is a constant: no matter how fast you go, the speed of light stays the same.
- The energy required for a spacecraft to travel at the speed of light is infinite.

Gravity

Some researchers speculate that if we could use gravity to our advantage, then we would have made a major development toward moving a spacecraft without a rocket engine. Somehow, the spacecraft would be attracted by the gravity of a star or planet or repelled by this gravity as it moves away. We would also need a new understanding of gravity because, as far as we know now, gravity is a one-way force: it attracts; it does not repel. Fuel would not be necessary, and the spacecraft could have its own gravity to provide a comfortable environment for the crew. Gravity control is at the speculative stage. But unlike warp drive, science has not said that gravity control is impossible.

Antimatter

Antimatter is matter with its electric charge reversed. Protons are positive, and antiprotons are negative. Electrons are negative, and anti-electrons, or positrons, are positive. Some scientists theorize that if matter and antimatter meet, enormous amounts of energy will be released, energy that could power a spaceship at great speeds. However, it takes far more energy to make antimatter than we can get back from it as an energy source. There are also safety and economic concerns. Production of antimatter has the same safety requirements as a nuclear reactor, and producing 1 mg of antimatter would cost over $100 billion (Canadian).

On our scale of progress we are firmly rooted at the speculation stage. For now, interstellar travel belongs in the world of science fiction.

15.1 CHECK YOUR Understanding

1. List the three conditions necessary to travel to the stars.
2. Why must we be able to travel at the speed of light to explore space?
3. Why is a chemical rocket not capable of getting us to our closest neighbour, Proxima Centauri?
4. In the scale of progress model, where do most of our plans for faster-than-light travel fit?
5. Fission and fusion rocket engines need excessive amounts of power to travel to the stars. What is another problem with the concept of a fusion engine?
6. Ion propulsion was tested on the space probe *Deep Space 1*, which tracked an asteroid (Figure 4) and a comet. Why is ion propulsion not a practical system?

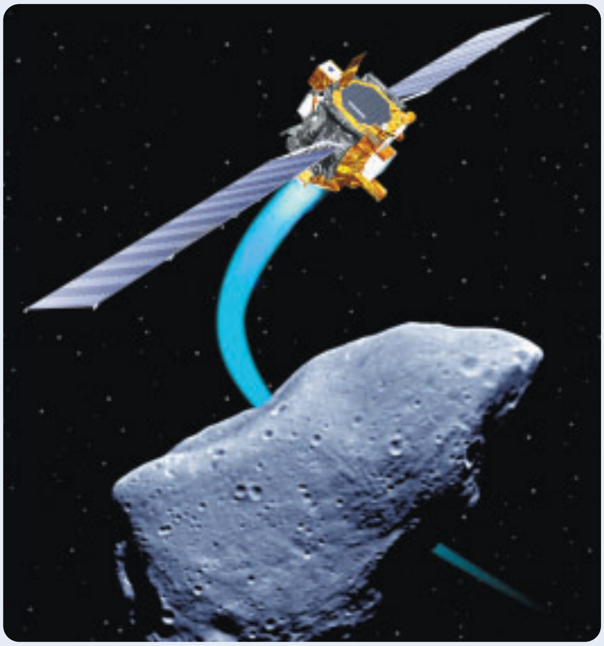


Figure 4

7. Why is antimatter propulsion not feasible?
8. What factors increase the fuel requirements for travel to the stars?
9. What is a theoretical alternative way to travel at the speed of light without fuel?
10. If you could travel at the speed of light without fuel, where would the energy required for the engine come from? Is this possible?
11. Compare gravity control and warp drive.
12. What force holds matter together?
13. Suppose that a galaxy with signs of life is only 75 light years away. How long would you take to get there travelling at the speed of light? Would you live long enough to reach your destination?
14. If you are standing on a crowded bus, what happens to you when the driver suddenly brakes or accelerates (Figure 5)? What would inertia do to you if you were on a spacecraft that accelerated to the speed of light or slowed down from this speed?

Figure 5

15.2 Getting into Space

LEARNING TIP
Skim Figure 1 to get a general sense of what it shows. Match the information in the caption to the letters in the diagram. What do the different letters represent?

Humans are explorers, and our final frontier is space. For humans to survive in the near vacuum of space, we require a spacecraft to meet our needs. We must have a breathable atmosphere at the right pressure and temperature. We must also have the means to meet all of our biological needs. Such a spacecraft has to be launched at a speed that will take it beyond our atmosphere and then reach a speed that will overcome the pull of Earth's gravity. When the pull of gravity and the forward speed are perfectly balanced, the spacecraft is continuously falling toward Earth at the same time as it is trying to speed away from Earth (Figure 1). This continuous falling is **free fall**, and the spacecraft is in orbit around the planet. Everything that is not fastened down inside the spacecraft during free fall is floating, or "weightless" (Figure 2).

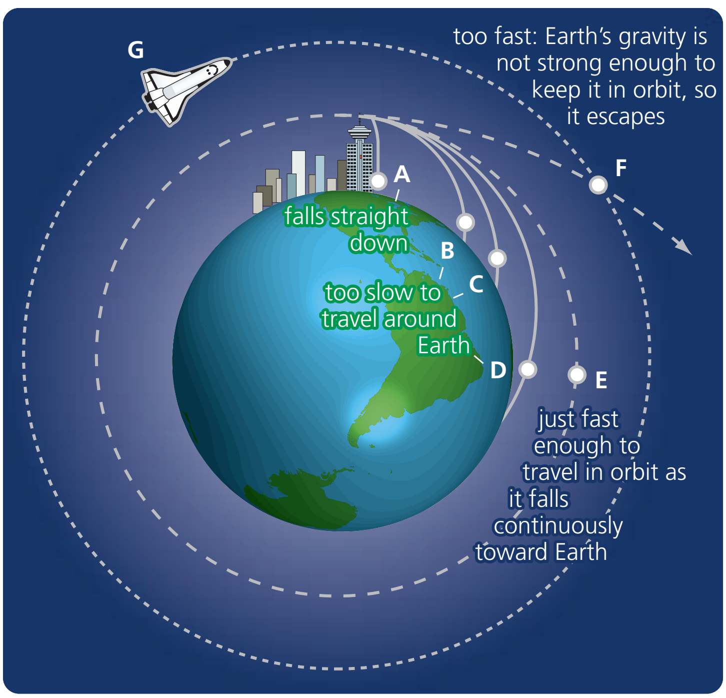


Figure 1 Imagine six steel balls that leave a tall tower. Ball A falls straight down, and balls B to F are shot horizontally. Only ball E has the right speed to travel in an orbit around Earth. It follows a curved path just like the space shuttle at point G. Ball F is moving too fast to stay in orbit around Earth, so it escapes Earth orbit.

Figure 2 Canadian astronaut Chris Hadfield seems to be floating. What causes this effect?

Weight is the force of gravity acting on an object. On the surface of Earth, we have to use our muscles to overcome the pull of gravity. In an orbiting space shuttle or space station, with everything constantly in free fall and moving at the same rate, no upward force needs to be exerted. Things seem to float, or be weightless. The astronauts do not sense the gravity. They float, or free fall, along with everything else, including the spacecraft. However, there is still considerable gravity present. At the altitude of the International

Space Station (ISS), around 330 km, the pull of gravity is 90 % of that at the surface of Earth. It is free fall, not the absence of gravity, that produces the sensation of weightlessness.

In free fall there is no concept of up or down. You could just as easily stand on the ceiling as on the floor. This has an advantage: nothing would ever be out of reach. There are also disadvantages. You could step on a supply cupboard or an important piece of equipment, or you could step on the door to the bathroom and surprise someone. In addition, free-fall conditions create health problems for the astronauts. Their muscles weaken and their spines stretch longer as the joints relax. Sanitation becomes critical because everything is floating and bacteria can get everywhere. Creating artificial gravity where normal gravity does not exist is important for maintaining the astronauts' health on long voyages.

TRY THIS: Artificial Gravity

Skills Focus: conducting, hypothesizing, recording, analyzing, evaluating, communicating

Materials: plastic bucket with a strong handle, water, rubber duck

How to turn up into down is a problem that needs to be solved for comfortable travel in space. Science-fiction television shows and movies show this problem as already solved because filming actors walking around is less expensive than filming them floating from place to place. In this activity, you will model artificial gravity.

This activity should be done outdoors under adult supervision. There is the possibility that you may get wet, so dress accordingly.

1. Half fill the bucket with water, and float the duck on the water.
2. Holding onto the handle, swing the bucket back and forth until you are ready to swing it in a full, vertical circle at a fairly high speed.
3. Bring the bucket to a stop, trying not to spill the water on yourself.

A. Does the water fall out of the bucket when it is swung quickly in a vertical loop? Create a hypothesis to explain why it does not.

B. From the duck's point of view at the top of the loop, how important is Earth's gravity? For the duck, which way is down?

C. Draw a diagram of the bucket and the duck at the top of the loop. Add arrows to show the forces the duck "feels" to stay floating on the water.

D. For the water and the duck to stay in the bucket, what did you have to overcome?

E. In what way is this activity a model for artificial gravity?

F. How could you apply what you have learned in this activity to a space vehicle that takes humans to and from Mars?

Launching into Space

A new generation of spacecraft will go into space on top of a new series of rockets.

Traditional Rockets

To launch any spacecraft or satellite into orbit requires an enormous amount of power. The next generation of NASA launch vehicles (rockets) is the Ares series. The Ares I rocket is the crew launch vehicle, and Ares V is the cargo launch vehicle. Ares I is a single, five-segment, solid fuel rocket that will lift more than 25 000 kg into low Earth orbit. **Low Earth orbit** is an altitude between 200 km and 1000 km. Some satellites travel in low Earth orbit at a

LEARNING TIP

Make connections to what you already know. As you read Launching into Space, compare what you are reading with what you already know. Ask yourself, "How does this information fit with what I already know? Does it reinforce or contradict what I already know, or is it new information?"

Did You KNOW?

Ares

Ares is the Greek name for the planet Mars. Mars is the Roman name.

Figure 3 On the left is the Ares V at 110 m tall; Ares I is on the right. The I and V designations are a tribute to the *Apollo* program's Saturn I and V rockets, which were the first space vehicles built specifically for the piloted flights to the Moon.

speed of approximately 28 000 km/h. At this speed, an orbit of Earth takes 1.5 h to complete. Ares V is a heavy lift launch vehicle that uses a combination of liquid oxygen/liquid hydrogen-fuelled engines and solid fuel rocket boosters (Figure 3). It will be able to lift more than 130 000 kg into low Earth orbit. The payload, or cargo, launched into space by Ares V will be the spacecraft components needed to go to the Moon by 2020 and later to Mars.

Why do rockets need to be so large and powerful? The answer is gravity. Large bodies such as Earth exert a strong gravitational force on nearby objects, including ourselves. The vehicles that will eventually travel to Mars must be able to reach escape velocity. **Escape velocity** is the speed that is needed for a vehicle to travel into deep space without being pulled back to Earth by gravity. Escape velocity decreases as the distance from Earth increases because the force of gravity decreases with distance. For example, on the surface of Earth, escape velocity is around 11.2 km/s (40 320 km/h). At 9000 km from Earth, escape velocity is slightly less than 7.1 km/s (25 560 km/h).

Rocket engines that work in space must carry their own fuel. They must also carry oxygen so the fuel can burn. The burning fuel and its exhaust gases travel rapidly out of the engine's nozzle and create the **thrust**, or the force that moves the rocket forward (Figure 4). If the thrust is large enough, the rocket will reach escape velocity.

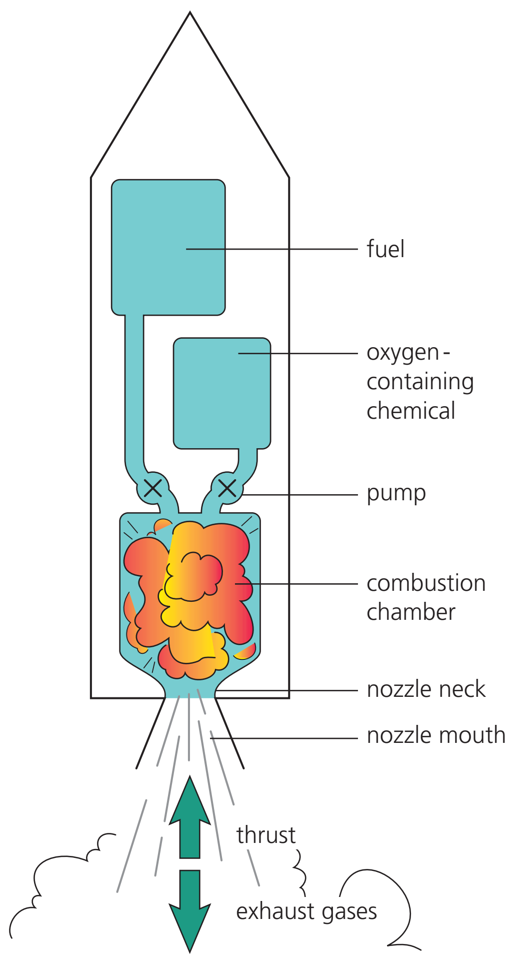


Figure 4 This diagram represents the basic design of a liquid-fuelled rocket engine. Escaping gas molecules exert a force in the opposite direction, moving the rocket along its flight path.

A balloon can be used as a model to demonstrate the principle of rocket thrust. When the air in an inflated balloon is released, the balloon will fly erratically around the room. As the air escapes from the open neck, the balloon will be forced in the opposite direction. This is the same type of thrust that is experienced by a launch rocket (Figure 5). 15A Investigation

15A Investigation

Launching Simple Rockets

To perform this investigation, turn to page 505.

In this investigation, you will model the principle of rocket thrust.

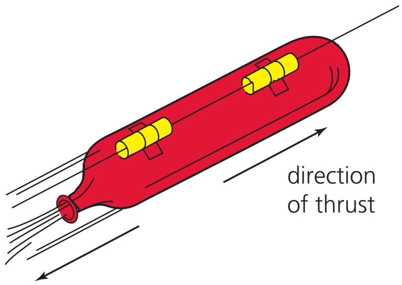


Figure 5 Fishing line threaded through two pieces of a drinking straw, which are taped to a long, inflated balloon, will help guide the balloon. When the balloon is released, air will leave the open neck, creating a thrust on the balloon. The thrust will push the balloon in the opposite direction.

The Space Elevator

Another plan to get people, satellites, cargo, and power to space and back again is to use a space elevator. A space elevator is a long cable, or tether, that would extend from Earth's surface into space, with its centre of mass at a geosynchronous orbit of approximately 36 000 km above the surface (Figure 6). An object or satellite in **geosynchronous** orbit stays in the same position over Earth. Vehicles travelling along the cable could serve as a mass transportation system. One plan calls for four to six elevators that would allow simultaneous travel up and down from platforms or stations at various levels. Electromagnetic vehicles could possibly reach speeds of thousands of kilometres per hour, making each trip relatively short. One early estimate of the cost to travel up and down in a space elevator is $2 per kilogram. Compare this with the estimated cost of $22 000 per kilogram to send cargo up in a space shuttle.

LEARNING TIP

Reinforce your understanding of geosynchronous orbit by examining Figure 6.

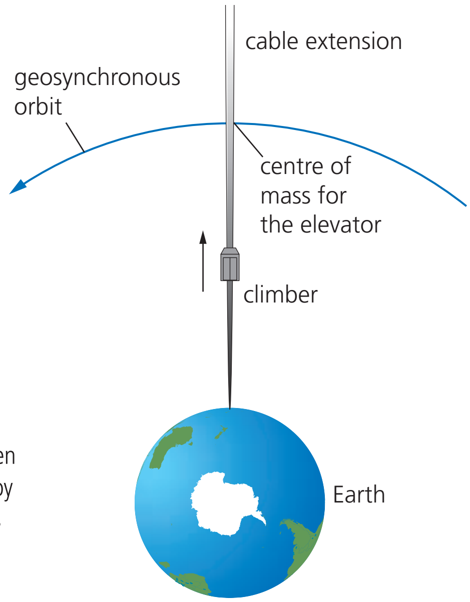


Figure 6 With a counterweight at the end or a further extension of the cable, the interaction between gravity and inertia (the movement given to the cable by the rotating Earth) keeps the cable stretched taut. This effect keeps the elevator in a geosynchronous orbit above Earth. (Diagram is not drawn to scale.)

To keep the cable taut so that is does not fall back to Earth, it would need to be attached to either a heavy counterweight, such as a space station, or a captured asteroid. A simpler proposal is to extend the cable itself well beyond geosynchronous orbit and let inertia from the rotating Earth and gravity keep everything taut. The base station would either be mobile and somewhere in the Pacific Ocean, or stationary and built on a mountaintop. In either case, the location would be at the equator to align with a geosynchronous orbit. Some form of climber would travel up and down the cable carrying the payload (Figure 7).

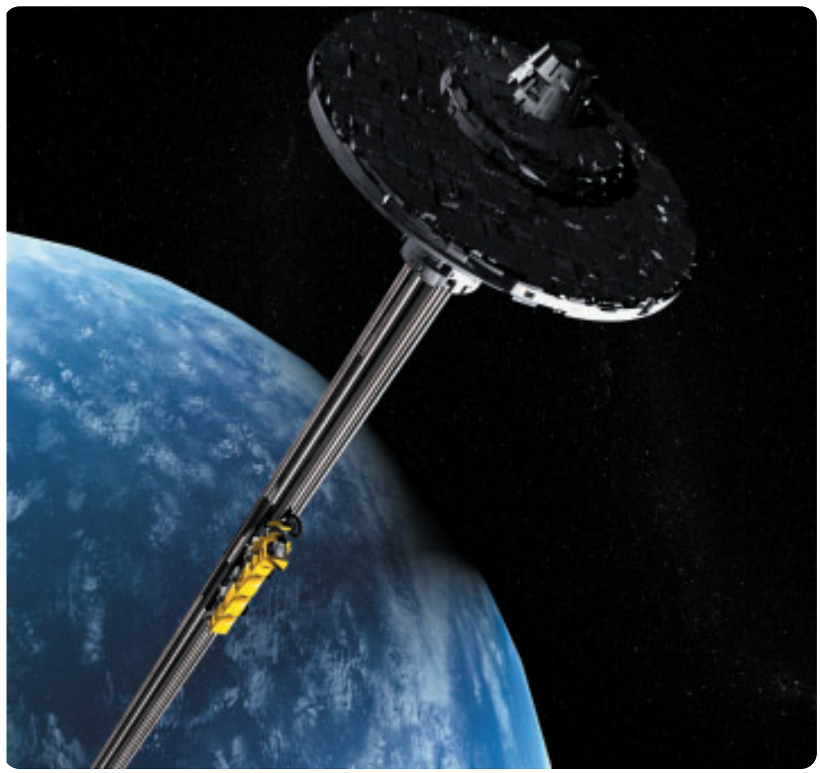


Figure 7 An artist's impression of a space elevator with a space station as a counterweight

When could a structure such as a space elevator be built? Noted science fiction author Arthur C. Clarke once responded to this question: "Probably about 50 years after everybody quits laughing." Is a space elevator a possibility? NASA administrators have held at least one conference on the topic and have published a report indicating that it is a possibility. An American company is currently researching and testing models and materials for a tether made of carbon nanotubes (Figure 8). The company hopes to launch its system by 2018.

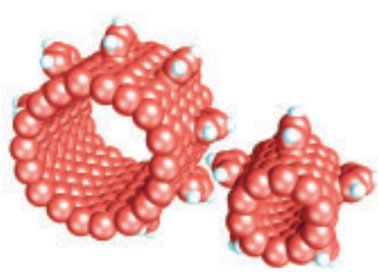


Figure 8 Carbon nanotube is a new form of carbon, similar to a flat carbon sheet rolled into a tube. It is a lightweight material that is at least 25 times stronger than steel. Two different thicknesses are shown.

There are many problems to overcome, especially with the strength of the cable. We may be decades, if not a full century, too early. Some scientists speculate that the plans to build a space elevator will succeed or fail based on our ability to create a material that is both light and strong enough. Even if no one builds a space elevator, the research into carbon nanofibres alone will bring improvements to suspension bridge construction and contribute to lighter aircraft and new composite materials for construction. Car manufacturers are already considering using carbon nanofibres to make lighter-weight automobile bodies. GO

If you would like to learn more about the space elevator and other plans for travelling to space, go to **www.science.nelson.com** GO

15.2 CHECK YOUR Understanding

1. “Space is our final frontier.” Do you agree or disagree with this statement? Explain your response.
2. Name the force that must be overcome to launch a vehicle into space.
3. Describe the concept of free fall.
4. Why are the terms “zero gravity” and “weightlessness” inappropriate when discussing free fall?
5. Why is there no up or down in free fall?
6. Classify each of the following as a payload or as a launch vehicle:
   (a) satellite
   (b) Ares V
   (c) astronaut
   (d) SOHO
7. Describe what would happen if a satellite were launched with too little speed or with too much speed.
8. If astronauts aboard the International Space Station experience 90 % of Earth’s gravitational pull, why do they appear to float (Figure 9)?

Figure 9

9. Outline some of the health problems that are faced by astronauts on a long space voyage.
10. What are the characteristics of a low Earth orbit?
11. Copy and complete Table 1.

Table 1 Comparison of Ares I and V Rockets

Rocket	Design	Type of fuel	Payload capacity
Ares I			
Ares V			

12. Rocket engines that work in space still need oxygen for the fuel to burn. Space is a vacuum. Where does the oxygen come from?
13. Describe thrust, and explain how it causes a rocket to move.
14. (a) Describe the concept of escape velocity.
    (b) Is escape velocity the same for every rocket that is launched from Earth? Explain.
15. What would hold the cable of a space elevator up?
16. Why would the base station for a space elevator be positioned at the equator?
17. For the aircraft industry, what would be the advantages of building airplanes out of carbon nanotube fibres?
18. What advantage might there be to having the base station of a space elevator mobile (Figure 10)? Think about potential hazards of a cable that is 36 000 km long.

Figure 10

15.3 All These Worlds

Did You KNOW?

Future Traveller?

On most space shuttle missions, the average age of the astronauts is about 45 years old. If this pattern continues and the astronauts who go to Mars are 45 years old, then they are about 15 years old today. The future astronauts are in high school. You could be one of them!

If interstellar travel is currently out of reach, will this stop us? Should this stop us? In spite of several serious setbacks, our exploration of space has not stopped. It has slowed, but only to reassess and refocus its goals. NASA's broad goals over the next 20 years include robotic missions within the solar system and beyond, and further human explorations of the Moon no later than 2020, with a permanently occupied base at the Moon's South Pole by 2024. A piloted trip to Mars would follow by 2035. To achieve these goals, scientists must develop the knowledge and technology to complete the missions safely.

Why should humans go back to the Moon? It is close to home. Compared to Mars, the Moon is in our backyard. We can use the Moon to practise living and working on another world, thus making the scientific progress necessary to go on to Mars. Both the Moon and Mars are hostile environments (Table 1). Any new technologies developed will also benefit Earth.

Table 1 A Comparison of Conditions on the Moon and Mars

	Gravity	Temperature	Atmosphere	Atmospheric pressure	Surface material
Moon	$\frac{1}{6}$ that of Earth	−240 °C to +125 °C	none	none	very fine dust
Mars	$\frac{1}{3}$ that of Earth	−90 °C to −5° C	very thin, with little oxygen (0.13 %)	$\frac{6}{1000}$ that of Earth	rock, very fine dust, and clumpy, salty minerals

Once construction of the ISS is complete around 2010, NASA will retire the space shuttles. The successor to the space shuttle as the main vehicle for human space exploration is the new Crew Exploration Vehicle (CEV) named *Orion* (Figure 1). Its first flight to the ISS with a crew of astronauts is scheduled to be no later than 2014, with flights to the Moon by 2020. *Orion* will carry cargo and six crew members to and from the ISS but only four crew members to the Moon. *Orion's* state-of-the-art computers, electronics, life-support, propulsion, and heat-protection systems will get the crew there and back again safely. *Orion* will be 5 m in diameter and 2.5 times the volume of the cramped *Apollo* capsules that went to the Moon in the 1960s and 1970s. Long stays on the Moon will be testing periods for the long trip to Mars.

Figure 1 The *Orion* capsule and a service module are shown in this artist's impression. *Orion* will take humans to the Moon and lead the way to Mars.

Return to the Moon

Among the first steps for returning to the Moon is the launching, in 2008, of the Lunar Reconnaissance Orbiter (LRO) (Figure 2). NASA's plan is to have a crew of four astronauts on the Moon by the year 2020 (Figure 3).

If you would like to learn more about the LRO in orbit around the Moon and its mission, go to **www.science.nelson.com**

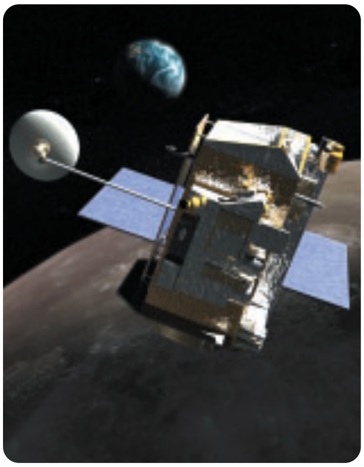
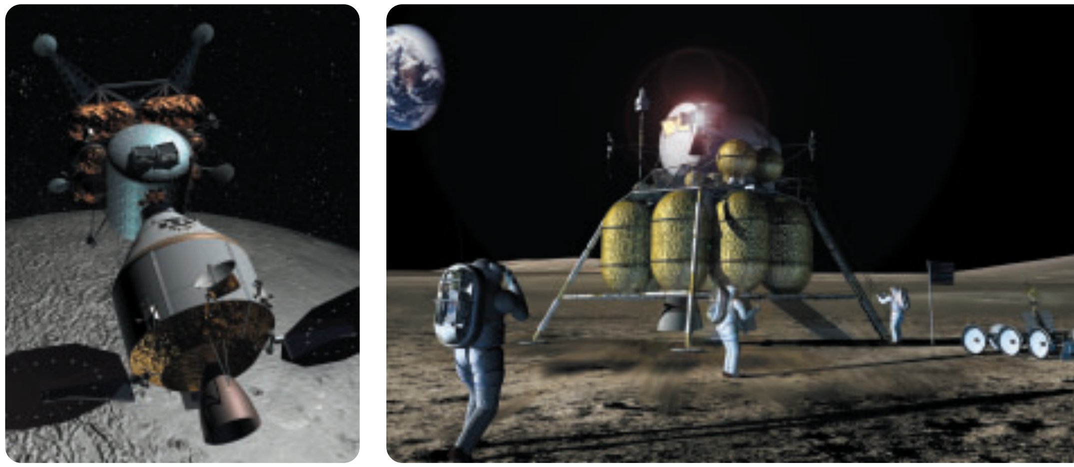


Figure 2 The LRO will gather data on radiation levels on the Moon, topography (shape of the moonscape), temperature, location of water or ice, and potential landing sites.



(a) (b)

Figure 3 (a) Artist's impression of the CEV attached to a lunar lander (b) Artist's impression of three crew members and a lunar buggy on the Moon

Before moving into deep space, humans must be able to survive and thrive on the Moon. This means that we must be able to establish a fully functional habitat, or living quarters, that provides food, water, air, and fuel. We must also be able to protect ourselves from harmful radiation.

Any habitat on the Moon will be constructed with Moon-based materials. Previous expeditions to the Moon discovered the materials to cast basalt (stone), to form metals, and to make concrete, fibreglass, glass, and glass ceramics—all in the lunar soil. These materials will be useful, whether permanent colonies are built above ground or below ground. Building underground will have some drawbacks, but an underground habitat will protect the astronauts from solar and cosmic rays and extreme temperature changes. A form of helium on the Moon, called helium-3, has the potential to be a useful energy source once a fusion reactor can be created to combine the helium-3 with hydrogen.

Did You KNOW?

Helium-3 Power

The estimated helium-3 reserves on the Moon could supply Earth with energy for 1000 years.

Water is another challenge. Astronauts need water to drink and to farm. Water can also be separated into oxygen for breathing and hydrogen (along with oxygen) for rocket fuel. Surprisingly, water is also an effective material for blocking radiation from space. A habitat insulated by a layer of water 1 m thick would block most cosmic rays and solar flare radiation. But is there any water on the Moon? Astronomers believe that comets and asteroids hit the Moon in its earliest years, like they hit Earth, and left water behind. However, water on the surface evaporates in the intense sunlight and reduced atmospheric pressure, and is lost into space. If water still exists, it will be in the shadows of the deepest and coldest craters. One of the many tasks of the LRO will be to look for water.

If you would like to learn more about looking for water on the Moon, go to **www.science.nelson.com**

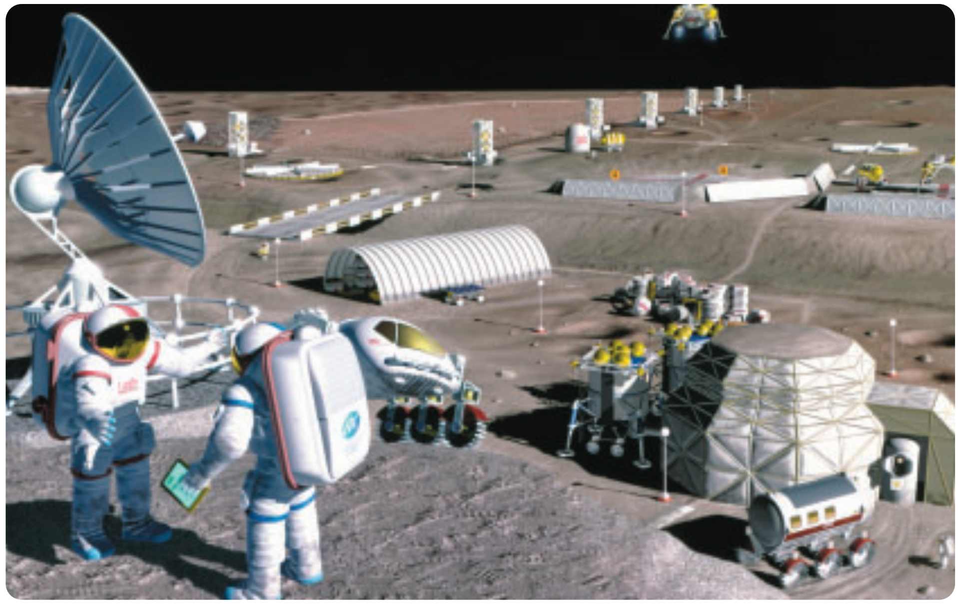


Figure 4 An artist's impression of a mining site on the Moon's surface

Any water existing on the Moon is too precious to convert to oxygen. Fortunately, the lunar soil is rich in oxygen. However, it is found as silicon dioxide (SiO_2), calcium oxide (CaO), iron(II) oxide (FeO), magnesium oxide (MgO), and ilmenite ($FeTiO_3$). Scientists plan to heat these materials until they release their oxygen. The oxygen would then be captured, purified, condensed, and stored as liquid oxygen. The mineral ilmenite may prove to be the best source of oxygen. The metallic material left after removing the oxygen could be used as construction material, radiation shielding, pavement, or even as a metal source for spare parts (Figure 4).

New Spacesuit

The next astronauts going to the Moon will be travelling in new, safer, and "smarter" spacesuits:

- The innermost layer of the new spacesuit will be filled with a thick polymer gel, with an airtight seal. The gel will be sandwiched between two layers of polyurethane, a type of plastic. If something pokes a hole in these layers, the gel squeezes out and plugs the hole. During testing, this system has sealed holes up to 2 mm wide. Larger holes will break current-carrying wires in the suit. If the suit is punctured, sensors in the damaged area will alert a central computer. The computer will inform the astronaut, who will seal the hole.
- Flexible solar cells sewn into the fabric will provide power for the suit's various sensors.
- Layers of silver-coated polyester will slowly release silver ions. Silver ions kill bacteria, helping to keep the suit fresher and more sanitary than the first generation of spacesuit.
- Layers of polyethylene, which contains hydrogen, will absorb radiation. This will provide the astronauts with some protection against the various forms of radiation constantly bombarding them.

LEARNING TIP

When you are reading the bulleted text, stop and restate the points in your own words. Ask yourself, "How is this point related to making a safer and "smarter" spacesuit?"

To Mars

Once the missions to the Moon have tested the spacecraft, the habitat, and the means to obtain fuel, water, and oxygen from the available materials, explorations to Mars can begin. The trips to Mars will pose their own particular problems, and they, too, must be solved.

Protection Against Radiation

Deep space is filled with radiation. This radiation comes in the form of harmful particles and energies, such as protons from solar flares, gamma rays from black holes, and cosmic rays from exploding stars. On the round trip to Mars, which will take 2.5 to 3 years, there is no big planet nearby to block or deflect this radiation. The radiation level is high. How an astronaut's body will react to this much radiation is uncertain (Figure 5).

The average 40-year-old non-smoking male has an unusually high risk of developing terminal cancer—20 %—and this is just from living here on Earth! The cancer risk to a returning astronaut has been estimated to range from 1 % to 19 % beyond the normal Earth risk. If the degree of exposure only increased the astronaut's risk of developing cancer by 1 % to 4 %, then design changes to the spacecraft and its composition can protect the astronauts. But at 19 %, an average healthy, non-smoking male astronaut will face a 39 % risk of developing cancer after he returns home. That is an unacceptable level of risk. A female astronaut has nearly double the risk of developing cancer, particularly cancers of the reproductive system.

Modern medical researchers are not completely sure what long-term exposure to the radiation in deep space will do to the human body. What alternatives exist to make the trip safer?

The aluminum framework of the spacecraft could be augmented or replaced by plastics, like the spacesuits. Plastics, which are rich in hydrogen, absorb cosmic rays. NASA's Marshall Space Flight Center, in Huntsville, Alabama, has developed a reinforced polyethylene that is 10 times stronger than aluminum (Figure 6). It is lighter as well. While the entire spacecraft cannot be made this way, the crew areas could be shielded, as on the ISS.

If the spacecraft is powered by hydrogen, then great quantities would be needed for such a trip. Because of hydrogen's ability to absorb radiation, some designs for spacecraft have even called for the crew areas to be surrounded by the fuel tanks.

On Mars

Once safely on Mars, the crew will explore and begin the mining operations that will produce oxygen to breathe and hydrogen for the fuel required to go home. However, Martian soil is different from lunar soil. New techniques will have to be developed to work the Martian soil. Special vehicles will be needed to move over the Martian surface without getting stuck (Figure 7 on the next page). The Mars rovers *Spirit* and *Opportunity* have already experienced these problems on a small scale. Martian dust storms will drive dust into everything and will be a threat to any habitat.

Did You KNOW?

Radiation in Space

During a trip to Mars, an astronaut could be exposed to an amount of radiation equivalent to approximately 30 000 chest X-rays!

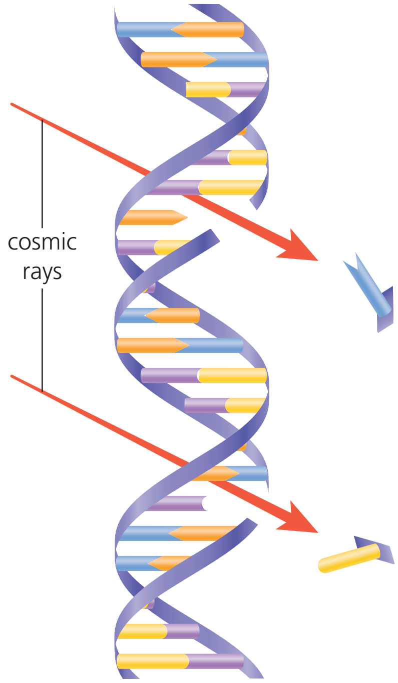


Figure 5 Cosmic rays can cause changes in the genetic code of DNA. Damage to the genes that control cell division can lead to the development of cancer.

Figure 6 Blocks of reinforced polyethylene, like the one shown here, may be an important building material for future spacecraft.

Figure 7 An artist's impression of a Mars lander and a large track-wheeled buggy

Martian explorers will have to grow their own food (Figure 8). Plants grown on Mars will also recycle organic material and replenish the air. At Mars' reduced atmospheric pressure, experiments have shown that Earth plants behave as if they are in a desert and respond as if they are drying out. They go through great quantities of water. Even if they are given all the water they need and are kept moist, the plants' drought response genes have been activated, and the plants begin to die from drought stress. This would not be a good outcome for the Martian farmer. Current research on plant hormones may lead to a solution. To be able to grow Earth plants in Martian soil, the genetics of the plants will have to be manipulated. Genetic engineering and selective breeding will be needed to create a whole new species of plant—possibly the first Martians. GO

If you would like to learn more about recent discoveries of water on Mars, go to **www.science.nelson.com** GO

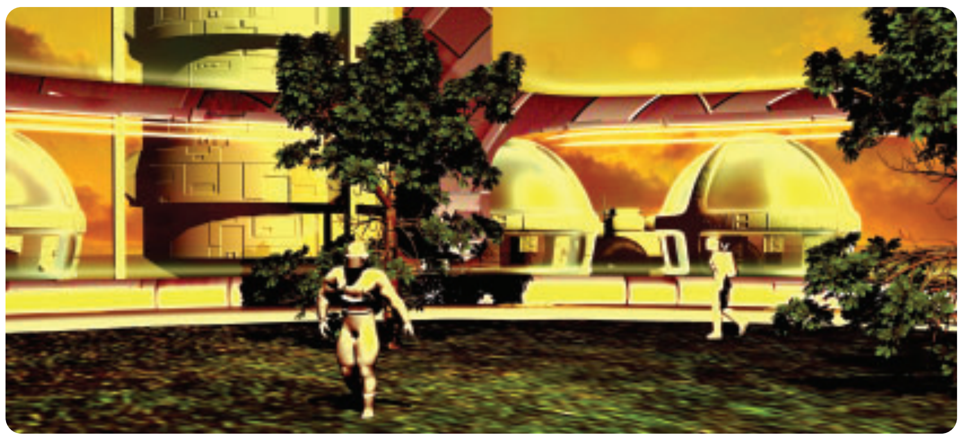


Figure 8 The domed buildings are an artist's impression of Martian greenhouses; the domes are closed

TRY THIS: *A Very Long Trip*

Skills Focus: planning, conducting, recording, analyzing, evaluating, communicating

Materials: 12 metre sticks (or any wooden strips that are 1 m long), masking tape

In this activity, you will identify the entertainment needs for a crew of four on a return mission to Mars, which will take 2.5 to 3 years. All the other needs (for air, food, water, sanitation, warmth, and sleep) have been taken care of. You and three companions will decide what you can bring to pass the time, stay entertained, and remain happy. However, you only have a space of 1 m^3 to store all of your entertainment needs for the voyage.

1. Using 12 metre sticks or wooden strips and masking tape, build a 1 m^3 box framework for the entire class.
2. Once the box is assembled, create your own list of what to bring. Then work out how your group will decide on the final contents. Here are some hints:
   - Sharing objects conserves space.
   - Electronic devices need 2.5 to 3 years worth of dry cells.
   - If something breaks on the trip, it may stay broken.
   - There will be no television, cable, Internet, or phone service on this low-budget trip to Mars.
   - The gravity conditions in the spacecraft and on the surface of Mars are different from Earth's gravity.
3. Bring your final selections to class, on a day set by your teacher, to see if they will fit into the 1 m^3 framework. You can make a cardboard model of any objects you cannot bring to school.

A. How did your group decide what to bring?

B. Were you all willing to give up some things? What did you give up?

C. What got left out? Why?

D. Can four of you be entertained for the voyage with the objects you brought? Explain why or why not.

15.3 CHECK YOUR Understanding

1. Why are scientists planning a trip back to the Moon?
2. Outline the purpose of the Crew Exploration Vehicle *Orion*.
3. Explain the role of the Lunar Reconnaissance Orbiter in the return to the Moon.
4. Why would a Moon colony be built underground?
5. How might a lunar colony (Figure 9) be protected from
   (a) radiation
   (b) meteorites

Figure 9

6. Why is it necessary to build a habitat on the Moon from local materials?
7. Water is an extremely important substance for human survival.
   (a) Why is taking bottled water to the Moon a problem?
   (b) Where might water be located on the Moon?
8. Outline two procedures for producing the heat necessary to extract oxygen from the Moon's rocky soil.
9. Many construction materials required on the Moon can be created from local materials (Figure 10). However, materials such as gasoline, grease, and plastics will have to be brought from Earth. Why?

Figure 10

10. What properties of lunar soil suggest that it could be used as a source of oxygen?
11. What metals are left behind when oxygen is removed from ilmenite?
12. Would someone on the Moon wearing a smart spacesuit be protected during a solar flare? Why or why not?
13. Why does a plant grown under simulated Mars conditions wilt?
14. What characteristics of some types of radiation make the radiation damaging to the human body?
15. Compare the radiation risk on a trip to Mars with the radiation risk on a trip to the Moon. Why are the risks greater on a trip to Mars?
16. What are the advantages of spacecraft being built of aluminum and plastic?
17. The first Martians may be genetically modified plants. Explain why.
19. Electrolysis is the process of using electricity to split water into hydrogen and oxygen. Where will electricity come from on the Moon or Mars?

15.4

Explore an Issue

LEARNING TIP

Before starting this activity, read over the headings to become familiar with the different parts.

DECISION MAKING SKILLS

- ○ Defining the Issue
- ● Researching
- ● Identifying Alternatives
- ● Analyzing the Issue
- ● Defending a Decision
- ● Communicating
- ● Evaluating

Terraforming: Are We Developers or Caretakers?

As early as 1976, a NASA study identified Mars as a planet that could be altered to support life and be habitable for humans (Figure 1). The process of changing a planetary body to create an environment capable of supporting human life is called **terraforming**. Such planetary engineering would change the temperature, the atmosphere, the soil, the amount of water, indeed, every aspect of the planet's ecology. This is not a new concept. However, only now are we capable of beginning the steps that could transform other worlds. Can it actually be done? This has yet to be verified scientifically. We have taken the first steps, but should we be taking these steps to terraform other worlds?

Figure 1 Artist's impression of an early settlement for visitors to Mars

The Issue: Terraforming Mars

There is a philosophical debate among biologists and ecologists as to whether terraforming other worlds is ethically acceptable.

Statement

It is humanity's moral obligation to make Mars suitable for human life.

Background to the Issue

Scientists Robert Zubrin and Richard Taylor argue that it is "humanity's moral obligation to make other worlds suitable for life." This is their extension of the concept that life on Earth has a history of transforming the environment around it. They also point out that Earth will eventually be destroyed as nature runs its course and our Sun becomes a red giant. Thus, in their view, humanity faces an important choice—terraform other worlds or allow life on Earth to become extinct. Another point of view counters their view, however, and argues for the preservation of other world ecosystems and any life that may exist there. After all, how well have we managed our own mineral resources and forests?

Take a Position

Considerable information and opinions about terraforming other worlds, in particular Mars, exist in print and on the Internet. Take one of the following three positions with respect to the statement:

- You support the statement.
- You oppose the statement.
- You take the middle position: Only a planet without life of its own should be terraformed. Otherwise, the planet's environment would have to be engineered for the benefit of its own life forms.

1. Research the issue.

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2. Identify the individuals, organizations, and government agencies that have addressed the issue and the positions they have taken.
3. Identify the major premises of each position on the statement. Create a graphic organizer that arranges the different aspects of each position to clarify your understanding.
4. Within your group, decide your position on terraforming.
5. Create a position paper of not more than 500 words to summarize your group's viewpoint.

Communicate Your Position

6. Within your paper, prepare several arguments to support your viewpoint. You must be prepared to defend your viewpoint against opposing viewpoints.
7. Present and defend your position statement in a classroom debate.

Evaluation

8. How did your group reach a decision about which position to defend?
9. After the debate, did you think of anything you could have done or said differently? Explain.
10. Did the debate solve the issue in favour of one particular position? Did the debate change your opinion on terraforming? Explain why or why not.

15.5 Are We Alone?

LEARNING TIP

Read with a purpose in mind. As you read Section 15.5, ask yourself, "Are we alone?" Look for main ideas, facts, reasons, and examples to answer this question.

Life abounds on our planet. Everywhere we look, from deep oceanic vents to the Alaskan permafrost, we have found life. As you gaze into the universe and see all those stars, do you ever wonder whether we are alone in the universe? With the billions of stars in our galaxy alone, there must be other planets at the right distance from their star, with the right temperature for liquid water, and a protective atmosphere in the habitable zone around their star (Figure 1). This reasoning appeals to many, but it is not hard scientific evidence.

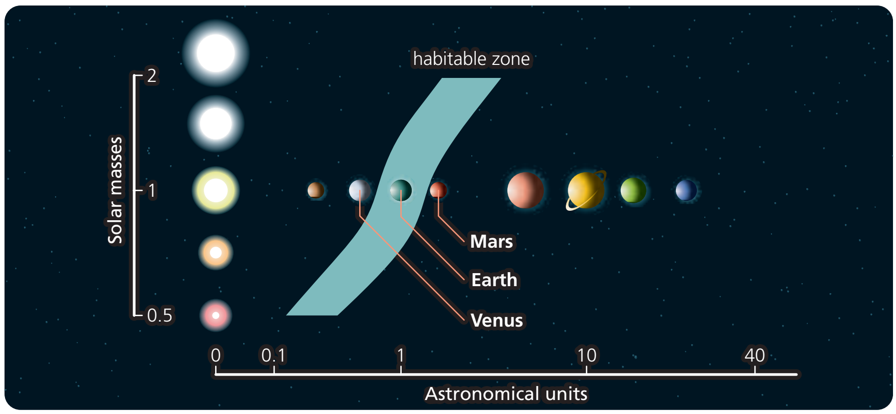

Figure 1 The habitable zone for planets varies with the mass and type of star.

Other Suns, Other Planets

The question of whether it was even worth looking for Earth-like planets was answered in the last decade of the 20th century. Astronomers have discovered protoplanetary disks in nebulae, such as the Orion nebula, and more than 200 planets around other suns, called **extrasolar planets**. Whether life exists on any of these extrasolar planets or elsewhere is yet to be determined.

Detecting Extrasolar Planets

Two methods that are used to find extrasolar planets have been referred to as "wobble" and "wink." The wobble method, also called the **radial velocity method**, is an indirect method that relies on a planet's gravitational pull on its sun. Think of two people on either end of a rope as one runs around the other. The person in the centre wobbles as the runner pulls on the centre. In this same way, a planet tugs on its sun. What observers on Earth see, as a result of this wobble, is an alternating red shift and blue shift as the sun is tugged away from us and toward us. So far, astronomers using this technique have detected several Jupiter-like extrasolar planets. Earth-sized planets do not create enough of a wobble on their suns to be detected.

The wink method, or the **photometric transit method**, measures changes in a star's brightness as a planet crosses in front of it. From year to year, stars do not vary greatly in their brightness. So if an astronomer detects a regularly occurring faint change in a star's brightness, then the astronomer knows that something is crossing in front of it. GO

If you would like to learn more about searching for extrasolar planets, go to **www.science.nelson.com** GO

In 1999, scientists used the wink method on a star in the constellation Pegasus. They discovered that the star known as HD 209458 dimmed by about 2 % every 3.5 days. The star was dimming because a planet was crossing in front of it. This was the first extrasolar planet to be discovered. The planet's orbit is about one-eighth the radius of Mercury's orbit, the planet's surface temperature is estimated to be approximately 700 °C, and its mass is 220 times the mass of Earth. These data suggest that the extrasolar planet is probably a gas giant.

Another planet, known as OGLE-2005-BLG-390Lb, was discovered orbiting a red dwarf star approximately 21 500 light years toward the centre of our galaxy. This planet is 2.6 AU from its star (Figure 2). It is likely the most distant and coldest extrasolar planet discovered so far. At a mass of 5.5 times the mass of Earth, it is the smallest known extrasolar planet orbiting an ordinary main-sequence star. It is also the first near-Earth-like planet found with a wide separation from its parent star. At this distance from a red dwarf, however, its surface temperature is approximately −222 °C, clearly outside the habitable zone.

The search for Earth-like extrasolar planets continues with one group looking at stars that have their equators aligned with Earth's equator. In addition, NASA is planning the *Kepler* (Figure 3) and *Terrestrial Planet Finder* missions. The European Space Agency (ESA) is planning the *Corot* and *Darwin* missions. These missions will launch between 2006 and 2015, and they will examine over 100 000 stars for Earth-sized planets. If any are found, astronomers will examine the planets' atmospheres for life. Both *Kepler* and *Corot* will use the photometric transit method and will be able to detect planets both smaller and slightly larger than Earth.

Figure 2 This is an artist's rendering of the Earth-sized planet called OGLE-2005-BLG-390Lb orbiting its red dwarf sun. At a distance of 2.6 AU from its sun, it would be between Mars and Jupiter in our solar system.

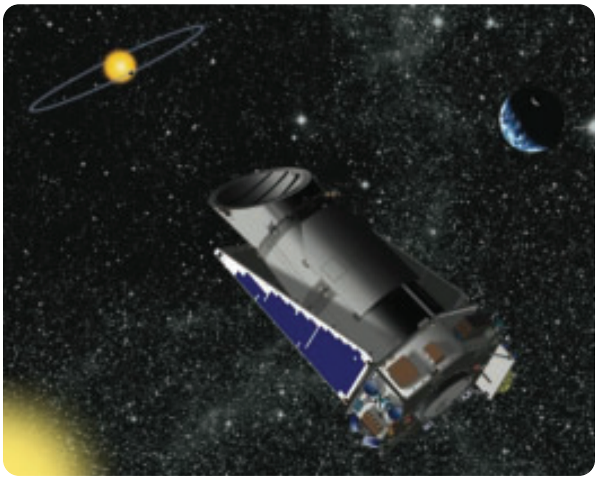

Figure 3 Artist's impression of the *Kepler* spacecraft aiming its telescope at a distant solar system to search for Earth-sized planets

SETI: The Search for Extraterrestrial Intelligence

About 50 years ago, an astronomer named Frank Drake began the first modern SETI experiment with an antenna aimed at the stars. He hoped to hear a deliberate signal aimed our way. To predict the chances of being able to hear a signal, Drake created an equation to estimate the number of planets in our galaxy that could harbour intelligent, technological civilizations. The equation has come to be known as the **Drake equation**. Refinements based on discoveries over the last 50 years have changed some of the numbers, notably the number of stars that could support life and the number of life-sustaining planets. As of 2004, Drake estimated that the number of planets that could harbour intelligent life in our galaxy exceeded 10 000. Although his equation has no right answer, it is still a significant tool for examining the individual factors within the equation and for triggering curiosity about our universe.

TRY THIS: The Drake Equation

Skills Focus: conducting, recording, analyzing, evaluating, communicating

The Drake equation is

$N = N^* \times f_p \times n_e \times f_l \times f_i \times f_c \times f_L$

where N = the number of civilizations with detectable electromagnetic emissions

N^* = the number of stars in the Milky Way galaxy that are suitable for the development of intelligent life

f_p = the fraction of those stars with planets

n_e = the number of planets in each solar system with environments that are suitable for life

f_l = the fraction of suitable planets where life actually develops

f_i = the fraction of life-bearing planets where intelligent beings develop

f_c = the fraction of civilizations with technology that releases detectable signals into space

f_L = the length of time those civilizations release signals into space

1. Go online, and try the Drake equation for yourself.

   www.science.nelson.com GO

2. Follow the directions, and select values for the variables based upon what you think is the best answer from the box. When you have selected all the values, click "Calculate." Record your selections and your final answer.
3. Change the variables several times. Record at least two sets of selections and final answer.

A. In recent years, research has indicated that N^* is a larger value than initially estimated. Increase that factor and observe and record the answer.

B. Why would the factor n_e be low?

C. List at least two possibilities to explain why a civilization would stop releasing signals into space.

D. Does any one variable alter the answer more than another? If so, which one?

E. Is there a single answer to the Drake equation? Why or why not?

Did You KNOW?

Analyze SETI Data

There is so much SETI data to sift through that SETI researchers have asked the public for help. If you have a home computer connected to the Internet, you can download the seti@home screensaver. While your computer is idle, it will analyze a small block of SETI data. If no signal is detected, your computer will alert SETI and ask for another block of data to analyze. If the block of data is of interest, your computer will alert SETI that the signal needs further examination.

www.nelson.science.com GO

SETI has expanded its search over the last 50 years, but still no signals have been received. However, in all those years only about 1000 star systems have been examined, and there are several hundred billion stars in the Milky Way galaxy. The number and speed of the experiments are growing geometrically. Every two years the scope of the search nearly doubles.

One of the most significant SETI projects currently under construction is the Allen Telescope Array. SETI and the Radio Astronomy Lab at the University of California, Berkeley, are building a radio telescope that will consist of 350 separate antennas, each 6 m long. When completed, the array will have a collecting area larger than a 100 m radio telescope. Individually each unit is relatively inexpensive to build. Both SETI and modern radio astronomy research can be done at the same time. The completed array will have 24 h access. The array will be able to search 100 000 to 1 000 000 nearby target stars at once and speed up the search about 100 times over. Using the Allen Telescope Array as a radio telescope, the Radio Astronomy Lab will be able to measure magnetic fields in the Milky Way galaxy and study black holes and star formation.

The SETI project is an ongoing, long-term project. We must view its results from the premise that the "absence of evidence" is not the "evidence of absence." In other words, the fact that astronomers have not yet discovered extraterrestrial intelligence does not mean that it does not exist.

15.5 CHECK YOUR Understanding

1. Explain the concept of a habitable zone around a star.
2. Liquid water is considered to be essential for the beginning of life as we know it (Figure 4). Outline the conditions for liquid water to exist on a planet.

Figure 4

3. The late astronomer Carl Sagan was a supporter of the idea that with billions of stars in the galaxy and the universe, surely there are other planets that support intelligent life. Explain why this reasoning is not considered to be hard scientific evidence.
4. Explain the significance of finding protoplanetary disks and extrasolar planets (Figure 5).

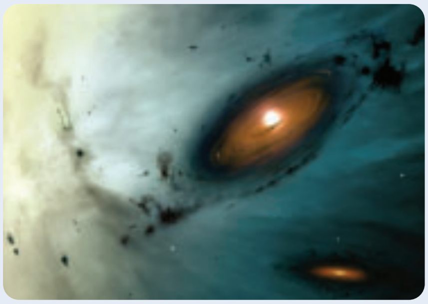

Figure 5

5. Using a diagram, explain the wobble, or radial velocity, method of detecting extrasolar planets.
6. Why does the wobble method only detect planets that are Jupiter-sized or larger?
7. Why are the wobble and wink methods of detecting extrasolar planets considered to be forms of indirect evidence?
8. For an extrasolar planet detected using the wobble method, what produces the alternating red shift and blue shift?
9. To detect an extrasolar planet using the wink method, what relationship or physical arrangement must exist between the target star, any planets it may have, and an observer on Earth?
10. The planet OGLE-2005-BLG-390Lb, whose mass is 5.5 times the mass of Earth, is the smallest extrasolar planet found so far. Why are Earth-sized planets difficult to find?
11. (a) The star HD 209458 in the constellation Pegasus has a planet circling it at a distance equal to one-eighth of Mercury's orbit. (Mercury's orbit is 0.39 AU.) Calculate this distance in kilometres.
    (b) The planet orbiting HD 209458 causes the star to dim every 3.5 days. How long is the planet's year?
    (c) Based on the planet's year and its distance from its sun, what can you conclude about the orbital speed of the planet?
12. Why is the Drake equation not capable of giving the exact number of intelligent, technological civilizations in the Milky Way galaxy? Use one of its variables as an example in your answer.
13. Why is the Drake equation still considered to be a useful tool?
14. What characteristics of the Allen Telescope Array make it such a powerful radio telescope (Figure 6)?

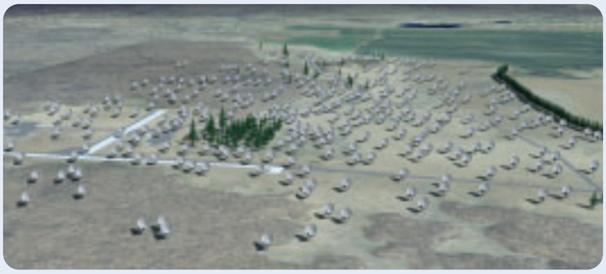

Figure 6

15. Explain the following statement: "The absence of evidence is not evidence of absence."

Tech CONNECT

THE MOST WITH THE LEAST: CANADA'S FIRST SPACE TELESCOPE

A new microsatellite called MOST is collecting high-precision data at a fraction of the cost of other important instruments.

MOST (**M**icrovariability and **O**scillations of **St**ars) is the first Canadian satellite in a new breed called microsatellites. Dwarfed in comparison with the HST (Figure 1(a)), the MOST satellite checks in at only 60 kg, with dimensions 65 × 65 × 30 cm, the size of a suitcase. In addition, MOST cost $10 million, while the HST cost $2 billion. By collecting light from stars and objects around other stars thousands of light-years away, MOST has made a significant impact on our understanding of our Sun and other stars (Figure 1(b)).

MOST is also special because it has no moving internal parts. It is very reliable and can operate over a wide range of temperatures. In addition, a highly innovative attitude control system keeps the telescope pointed at the target star 99 % of the time for two months. This is a level of performance that is twice as efficient as any previous system. The optical systems in MOST are capable of measuring extremely small changes in the brightness of a star.

This amazing, low-budget space telescope is outperforming its big and expensive cousin, the HST, in some areas. What it has discovered is impressive. Measurements of photometric transits across the face of the star HD 209458 have eliminated the possible presence of an Earth-sized planet in some of the orbits predicted by scientists. As MOST mission scientist Dr. Jaymie Matthews of the University of British Columbia stated in March 2006, there are no "hot Earths" in orbits near the "hot Jupiter" found previously. MOST is so sensitive that it would have seen smaller planets cross in front of the star—if they were there (Figure 2).

In June 2006, MOST directly measured the rotation of the sun-like star Epsilon Eridani. Different latitudes of Epsilon Eridani rotate at different rates, and sunspots on the star move past each other. On average, the star rotates twice as fast as our Sun. All of these data agree with the predictions that our Sun, when it was younger, spun twice as fast as it does today. In July 2006, MOST discovered a new class of variable star—the slowly pulsating B supergiant. The discoveries keep rolling in.

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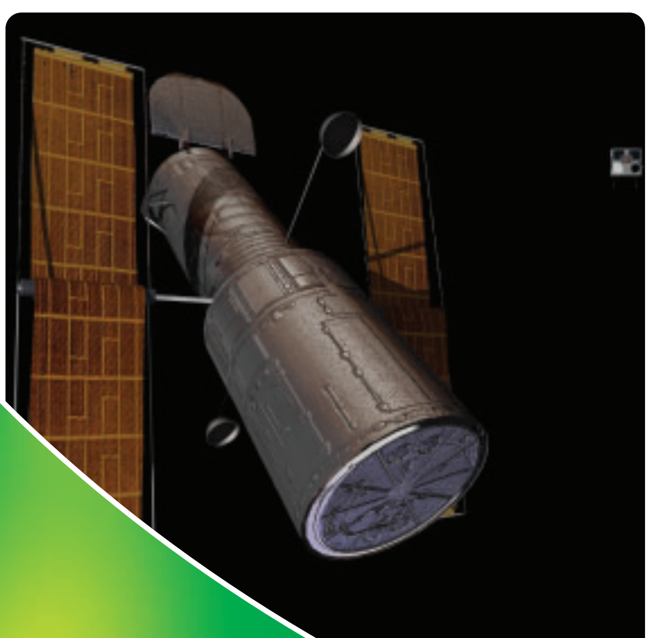
Figure 1 (a) On the left of this artist's impression is the HST, and on the right is the MOST satellite. Good things come in small packages! (b) The MOST satellite, showing the hatch open to allow light into its periscope mirror for distribution within the telescope

(a)



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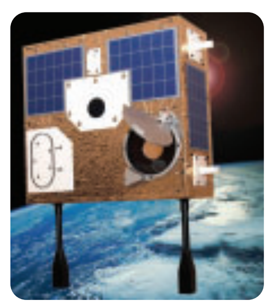


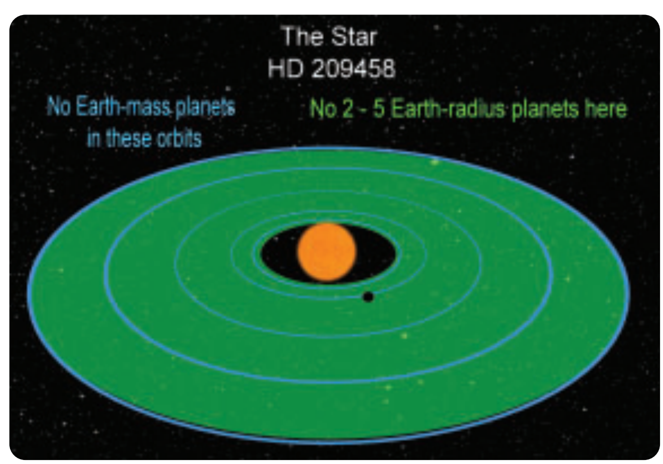


Figure 2 No Earth-like planets have been found close to HD 209548.

Launching a Simple Rocket

A toy water rocket is a safe and easy way to study how rockets work. Powered only by water and air, it works on the same principles as a chemical rocket. Your challenge is to make the water rocket go as high as possible.

Materials

- toy water rocket and instruction manual
- safety goggles
- angle measurer (from Investigation 13B)
- graph paper

Question

Ask a question that your investigation will answer.

Prediction

Identify the dependent variable and the independent variables. Write a prediction about how each independent variable will affect the dependent variable.

Experimental Design

Review your rocket and its instruction manual. One model is shown in Figure 1. Design a controlled experiment in which you will vary one independent variable at a time and determine its effect on the dependent variable. Your teacher must approve your experimental design before you begin.

Figure 1 After adding water to the rocket, you can use the pump to increase the air pressure inside the rocket. What factors will control how high the rocket will go? Which of these factors could become independent variables?

Wear safety goggles. Operate the rocket outdoors only in an open area such as a sports field. Do not aim the rocket at people, animals, or neighbouring buildings. Stand clear of the line of flight.

INQUIRY SKILLS

- ● Questioning
- ○ Hypothesizing
- ● Predicting
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Synthesizing
- ● Communicating

Procedure

1. In a group, list the safety precautions and the steps necessary to launch the rocket.
2. Discuss with your group how you will determine the height the rocket reaches. (Think back to the work you did on triangulation, measuring angles, and drawing scale drawings.) Record the steps you will take to determine the height the rocket reaches. Your teacher must approve these steps before you continue.
3. Prepare an appropriate format for recording your observations.
4. Once your procedure has been approved, put on your goggles and conduct your investigation outdoors. Record your observations, measurements, and calculations.
5. Create a graph of height versus the variable you tested.

Analysis

(a) How did the height of the rocket change as you altered each controlled variable?

(b) How did you create the force or thrust necessary to launch the water rocket?

(c) What factors affected the rocket's thrust?

(d) Answer the Question.

(e) Do your observations support your predictions? Explain.

Evaluation

(f) Review your procedure. Explain the steps that may have introduced errors into your investigation.

Synthesis

(g) Compare the operation of a water rocket and a chemical rocket.

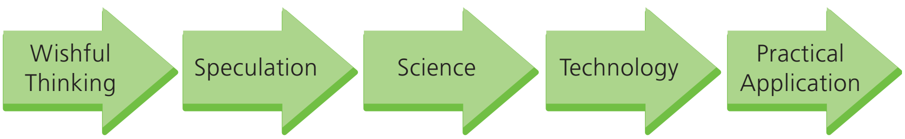
CHAPTER 15 Review

Exploring Space

Key Ideas

The technology required to travel beyond our solar system has not yet been developed, and the ideas are only in the speculation stage.

- The distances to other stars are vast, and we do not have the means to travel these distances.
- Distance, rate of travel, and health concerns are some of the problems associated with space travel.
- During a trip to Mars, exposure to cosmic radiation is a serious concern.



New technologies for travelling into Earth orbit are being researched or developed.

- Current spacecraft are beginning to meet our basic needs in space.
- New rockets are being developed to return us to the Moon and Mars.
- Research has begun to find alternative means of propulsion.
- The space elevator is one plan for getting into space.

Vocabulary

inertia, p. 483

antimatter, p. 484

free fall, p. 486

low Earth orbit, p. 487

escape velocity, p. 488

thrust, p. 488

geosynchronous, p. 489

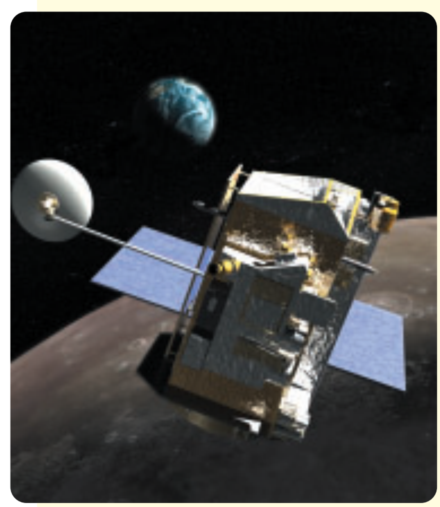
terraforming, p. 498

extrasolar planets, p. 500

radial velocity method, p. 500

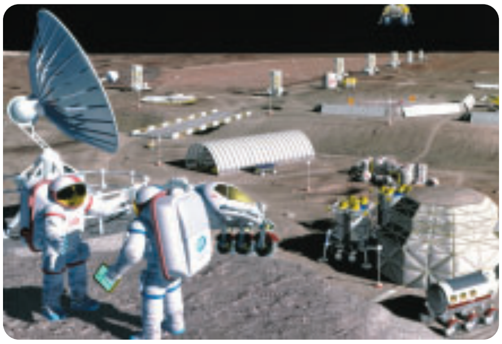
photometric transit method, p. 500

Drake equation, p. 501



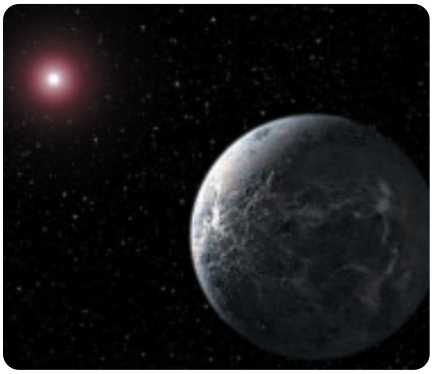
There are ethical issues associated with travelling in space and possibly colonizing other worlds.

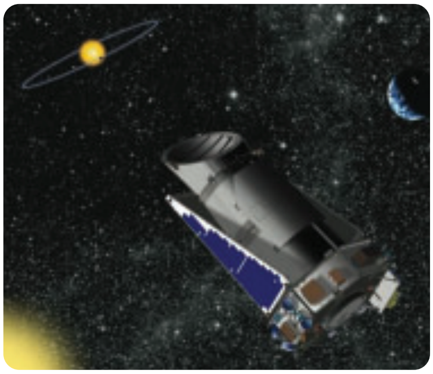
- To travel to and from other planets, we must make use of the resources there.
- To survive on Mars, we must be able to grow our own food, engineered to Mars' conditions.



NASA and other space agencies have planned for further exploration of the Moon and Mars in the coming decades.

- Current research is revealing newly formed protoplanetary disks and suns with planets around them.
- In 50 years of searching for signs of intelligent life, only the tiniest portion of space has been covered. The search has yet to discover any signs of intelligent life.
- The SETI project is expanding and will be able to listen to over 100 000 stars at once for signs of intelligent life.





Review Key Ideas and Vocabulary

1. Summarize the conditions that must be met to travel faster than the speed of light.
2. Why is travelling at the speed of our fastest rockets not an option for travelling to the stars?
3. Fusion engines and antimatter propulsion have one thing in common. What is it?
4. What is the difference between an antiproton and a proton and between an anti-electron and an electron?
5. Why would a base on the Moon be a desirable launch site for a trip to Mars?
6. What makes both the Moon and Mars (Figure 1) hostile environments?

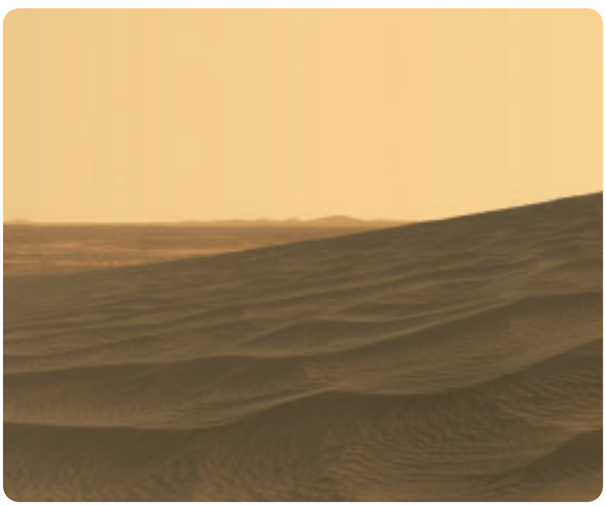


Figure 1

7. Explain how a smart spacesuit will be able to protect an astronaut.
8. Plastics are being proposed as a building material for future spacecraft. Cite three reasons why.
9. Why can the habitable zone around a star vary for different stars? Refer to Figure 1, page 500.
10. Describe the concept of terraforming, and explain why some people believe that we must terraform other worlds.

Use What You've Learned

11. Create a diagram using long and short arrows to show stronger or weaker forces to explain why people do not fall out of rides at amusement parks. As an example, use a ride that turns completely upside down (Figure 2).

Figure 2

12. Research the Lunar Reconnaissance Orbiter on the Internet. Summarize the four tests that this spacecraft will perform to find water on the Moon.

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13. Explain how water can be used as rocket fuel.
14. On the Internet, research life in deep ocean vents (Figure 3) and permafrost. Name one form of life found in deep ocean vents and one form of life found in permafrost.

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Figure 3

15. Create a series of diagrams to illustrate the photometric transit method of discovering extrasolar planets.

16. While a scientist was using the photometric transit method to record successful passes of a planet dimming the brightness of its star, the effect stopped. It has not reappeared for several months. Speculate about what could have possibly happened to the planet.

Think Critically

17. Research NASA's proposed new spacesuit for astronauts. Design your own version of the spacesuit to meet an astronaut's needs on either the Moon or Mars.

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18. Research the Urey-Miller experiment on the Internet. List the materials that scientists expect to find in an early planetary atmosphere. Explain what finding them in the atmosphere of a newly discovered extrasolar planet might mean.

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19. Research the terraforming of Mars, and explain how the planet's temperature could be increased. Offer an opinion on the practicality of doing this.

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20. Light travels at 300 000 km/s. In your theoretical spacecraft you are travelling at the speed of light. Is light travelling within the ship at 300 000 km/s or 600 000 km/s? Can light travel faster than itself? Does this have any implications for travel at speeds faster than the speed of light?
21. Pick one of the extrasolar planets discussed in this chapter or one of your own choosing from another source. Using the characteristics of the planet, design a life form that might survive in the planet's environment. Consider at least four aspects of the biology of the life form, including the way in which it moves around.

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22. "Protoplanetary disks and extrasolar planets are proof of life elsewhere in the solar system." Criticize or defend this statement.
23. Europa, one of Jupiter's moons, is thought to harbour liquid water beneath its icy crust (Figure 4). If life is found there, how could we modify the environment to promote the development of those life forms? If life is found there, should we alter Europa's environment?

Figure 4

24. Why is it difficult for astronomers to detect groups of planets similar to our solar system, even though they are believed to be quite common?

Reflect on Your Learning

25. Think about the questions in the Chapter Preview. How would you answer these questions now? What other questions do you have about travelling in space?
26. Our planet has often been called "spaceship Earth." What is your opinion about this name?
27. What is your opinion about the possibility of life elsewhere in the universe?

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UNIT D

Review

Space Exploration

Unit Summary

In this unit, you have learned about many astronomers and the tools they use to learn about Earth, the Moon, our solar system, the galaxy, and the universe. Astronomers have discovered over 200 planets beyond our solar system. However, the systems to which these other planets belong are not like ours. As astronomers learn about the formation of these extrasolar planets, they are forced to review our own planetary system.

You have also learned about the age of the universe, how we measure distances in space, and how our star and the universe were formed. You have examined observations and oral recordings from British Columbia's Aboriginal peoples, which provide other perspectives on astronomical events. You have learned that scientists have begun the steps back into human space exploration and that piloted expeditions to the Moon and Mars are being planned. Finally, you have learned that, in spite of their searching, scientists have yet to find life elsewhere in space. Does it exist? Only time will tell.

Create a timeline of the contributions made by early Aboriginal and Indigenous peoples and astronomers as our view of the universe changed from a geocentric model to a heliocentric model. Include the Big Bang theory and the theory of an expanding universe, as well as the support for each theory. Check the Key Ideas and Vocabulary at the end of each chapter to ensure that you have included all the major concepts.

Review Key Ideas and Vocabulary

1. Which description applies to the science of astronomy?
(a) studies stars
(b) predicts your personality traits based on the positions of planets when you were born
(c) studies asteroids
(d) studies objects and phenomena that occur beyond Earth and its atmosphere

2. The apparent path of the Sun through the sky is called the
(a) celestial sphere
(b) plane of the ecliptic
(c) celestial equator
(d) ecliptic

3. Why do people living in the northern hemisphere see circumpolar constellations throughout the year? Circumpolar constellations are
(a) fixed in their positions according to the celestial sphere
(b) near the pole star, Polaris
(c) so bright they can always be seen
(d) located above Earth's North Pole and never fall below the celestial equator

4. We always see the same side of the Moon because
(a) the Sun always shines on the same side of the Moon
(b) the Moon's period of rotation is the same as Earth's
(c) the Moon's period of revolution is the same as Earth's
(d) the Moon's period of revolution is the same as its period of rotation

5. Which of the following events occurs when the Moon's shadow falls on Earth?
   (a) a lunar eclipse
   (b) a solar eclipse
   (c) spring tides
   (d) neap tides
6. The name of the instrument that detected large clouds of dust and gases around newly forming stars is
   (a) SOHO
   (b) IRAS
   (c) NASA
   (d) HST
7. What are the solstices? Relate the position of the Sun to each solstice. When do the solstices occur?
8. What causes the Sun's position in the sky to vary throughout the year?
9. What general statement can be made about the order of the planets from the Sun and their relative densities?
10. Describe the evidence that scientists used to confirm the Big Splash theory.
11. In a table, summarize the unifying characteristics of the planets in our solar system and one unique feature of each planet.
12. How does the spectrum of a light bulb differ from the spectrum of a gas discharge tube?
13. Complete the following sentences in your notebook.
   (a) The __?__ is everything that exists, including all the matter and energy that have been or will be found.
   (b) The electromagnetic spectrum is a broad band of __?__ that can travel in a __?__.
   (c) Stars produce energy by the process of __?__.
   (d) Once a yellow star such as our Sun forms, it spends its life on the __?__ of the __?__ diagram.
   (e) An object with mass exerts a force of __?__ on all other objects.
   (f) A payload is to a(n) __?__ as an arrowhead is to a(n) __?__.
   (g) Plastic absorbs cosmic rays because plastic is rich in __?__.
14. In your notebook indicate whether each statement is true or false. If the statement is false, rewrite it to make it true.
   (a) Our Sun is the only star with planets orbiting it.
   (b) The light-year is a unit of time.
   (c) When using the technique of parallax, the longest baseline available to an Earth-bound astronomer is Earth's diameter at the equator.
   (d) The speed of light in a vacuum is 3×10^5 km/s.
   (e) Temperature variations discovered by the COBE and WMAP satellites show the uneven distribution of matter in the early universe and, thus, the beginnings of all the galaxies and clusters of galaxies.
   (f) A red shift to a star's spectrum means that the star is moving toward Earth.
   (g) Dark energy is thought to be the reason why the universe is continuing to collapse.
   (h) The fusion of four hydrogen protons produces one helium nucleus and little energy.
15. Explain why the spectrum of visible light reaching Earth from other galaxies has shifted into the red region of the spectrum.
16. Explain the difference between absolute and apparent magnitude using our Sun as an example.
17. Describe the composition of a nebula.
18. What is the most abundant element in the universe? How common is this element on Earth, and where is it found?
19. Describe the difference between the life cycle of a low-mass star and the life cycle of a high-mass star.
20. Why does a relatively cool star actually appear brighter than a hotter star?
21. What is the role of dark energy in the expansion of the universe?
22. What is the advantage of using very large arrays instead of one large radio telescope?

23. Describe the information that astronomers can obtain about distant objects using
    (a) a radio telescope
    (b) an X-ray telescope
    (c) a UV telescope
    (d) a gamma ray detector
24. Explain how probes are used by astronomers to learn about distant objects in space.
25. Summarize the problems with faster-than-light travel.
26. Explain the relationship between free fall and weightlessness.
27. Review the concept of geosynchronous orbit, and explain why the planned location for the space elevator was chosen.
28. What two discoveries have reinforced the possibility of life existing elsewhere in the universe?

Use What You've Learned

29. Do you think it is possible for other planets in our solar system to experience seasonal differences in their surface temperatures?
30. What is an example of an occultation from Chapter 12? Explain your answer.
31. To date, there are 165 known planetary moons in the solar system. If you check other reference books published in earlier years, you would find the number of moons shown in Table 1.
    (a) Why do you think that the number of known moons has changed so greatly in such a short period of time?
    (b) Do you think the number of moons will change as much in the next 25 years or so? Explain why or why not.
32. Calculate the time it would take to reach the following at the speed of light.
    (a) Sedna at aphelion
    (b) the centre of the Milky Way galaxy
33. Research the Lunar Reconnaissance Orbiter, and describe the experiments it will undertake to find water on the Moon. Based on your research, predict the best location on the Moon where water may be found.

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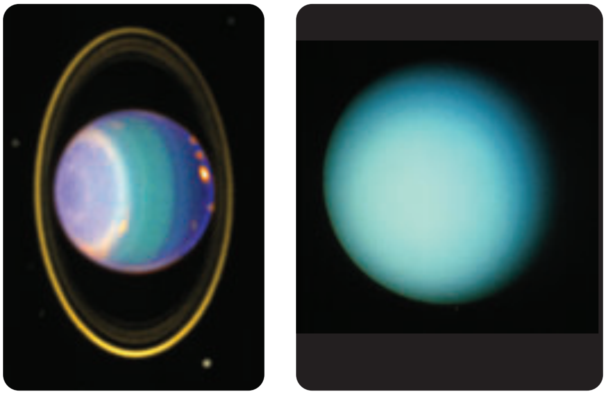
34. Figure 1 shows two images of Uranus. The image on the left is an infrared image taken by the Hubble Space Telescope. The image on the right is an image taken by *Voyager 2* in visible light. Uranus was once considered to be featureless. How does the infrared image change this notion?



(a) (b)

Figure 1

35. Explain why ancient peoples were concerned about astronomical events such as the solstices and equinoxes. Describe how other astronomical phenomena might have affected ancient peoples. Choose three examples.
36. Choose one West Coast legend, and retell it through one or more illustrations.

Table 1 Moons in the Solar System

Year of publication	1969	1984	1987	1991	2006
Number of known moons	28	44	53	60	165

Think Critically

37. Robotic rovers (Figure 2) currently operating on the irregular surface of Mars have to be "smart." They have to be able to make decisions about the safest route to follow as they carry out their missions. Describe, in detail, why these rovers cannot be adequately controlled by Earth-based researchers.

Figure 2

38 Outline the major characteristics of the wink and wobble methods for discovering extrasolar planets. Include one difficulty with each method.

39. Outline the procedure for an activity in which you use all the students in your class to model the expansion of the universe a few hundred million years after the Big Bang. Then modify your activity to show how the results from COBE and WMAP could be modelled.

40. Figure 3 shows a device in which a rolling ball moves faster and faster, finally getting swallowed in the centre. Explain why this can be used as a model of a black hole. In what ways is the model not realistic?

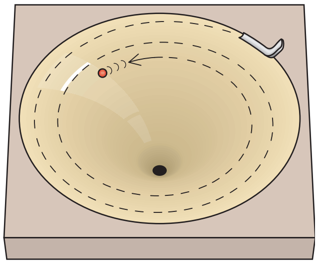


Figure 3

41. Why is it difficult to verify the predicted existence of a black dwarf? Describe the circumstances that might allow the discovery of a black dwarf.

42. Why do scientists consider the galaxies in our Local Group to be "local" when the farthest of them is 2.5 million light years away?

43. With reference to the International Space Station, explain the following statement: "Visual systems and robotics often operate together."

44. How do you think a space station of the future will generate artificial gravity?

45. One idea for "securing" the space elevator cable in space is to attach it to a captured asteroid. Is this idea feasible? Outline the benefits and difficulties with using an asteroid, and then give your own evaluation of the feasibility of this idea.

46. Research carbon nanotubes, and create a report outlining what they are made from and how they are built. Provide several uses for them in a non-space environment.

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47. Why would a Moon-based habitat be built with a layer of water, 1 m thick, surrounding it? What other purposes might this layer of water also serve?

Reflect On Your Learning

48. The planet known as OGLE-2005-BLG-390Lb is considered to be a "near Earth-like" planet. Do you think it is egocentric of us to suggest that life may only be found on near Earth-like planets? Explain.

49. The SETI project, which has been underway for about 50 years, has yet to reveal even one signal from space. Comment on whether the lack of success so far is a sufficient reason to conclude that no other intelligent forms of life exist.

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SWIFT
M3200

SKILLS HANDBOOK

WORKING AS A SCIENTIST

SCIENCE AND SOCIETY

READING FOR INFORMATION

COMMUNICATING IN SCIENCE

STUDY SKILLS

SAFE SCIENCE

Science investigations can be a lot of fun—you have the chance to work with new equipment and materials. Science investigations can also be dangerous, however, so you have to pay attention! As well, you have to know and follow special rules. Here are the most important rules to remember.

1 Follow your teacher's directions.	2 Act responsibly.	3 Be science-ready.
• Listen to your teacher's directions, and follow them carefully. • Ask your teacher for directions if you are not sure what to do. • Never change anything, or start an activity or investigation on your own, without your teacher's approval. • Get your teacher's approval before you start an investigation that you have designed yourself.	• Pay attention to your own safety and the safety of others. • Tell your teacher immediately if you see a safety hazard, such as broken glass or a spill. Also tell your teacher if you see another student doing something that you think is dangerous. • Tell your teacher about any allergies or medical problems you have, or about anything else your teacher should know. • Do not wear contact lenses while doing investigations. • Read all written instructions carefully before you start an activity or investigation. • Clean up and put away any equipment after you are finished.	• Come prepared with your student book, notebook, pencil, worksheets, and anything else you need for an activity or investigation. • Keep yourself and your work area tidy and clean. • Wash your hands carefully with soap and water at the end of each activity or investigation. • Never eat, drink, or chew gum in the science classroom. • Wear safety goggles or other safety equipment when instructed by your teacher. • Keep your clothing and hair out of the way. Roll up your sleeves, tuck in loose clothing, and tie back loose hair. Remove any loose jewellery.

Follow these guidelines to use chemicals and equipment safely in the science classroom.

Heat, Fire, and Electricity

- Never heat anything without your teacher's permission.
- Always wear safety goggles when you are working with fire.
- Keep yourself, and anything else that can burn, away from heat and flames.
- Never reach across a flame.
- Before you heat a test tube or another container, point it away from yourself and others. Liquid inside can splash or boil over when heated.
- Never heat a liquid in a closed container.
- Use tongs or heat-resistant gloves to pick up a hot object.
- Test an object that has been heated before you touch it. Slowly bring the back of your hand toward the object to make sure that it is not hot.
- Know where the fire extinguisher and fire blanket are kept in your classroom.
- Never touch an electrical appliance or outlet with wet hands.
- Keep water away from electrical equipment.

Chemicals

- If you spill a chemical (or anything else), tell your teacher immediately.
- Never taste, smell, touch, or mix chemicals without your teacher's permission.
- Never put your nose directly over a chemical to smell it. Gently wave your hand over the chemical until you can smell the fumes.
- Keep the lids on chemicals you are not using tightly closed.
- Wash your hands well with soap after handling chemicals.
- Never pour anything into a sink without your teacher's permission.
- If any area of your body comes in contact with a chemical, wash the area immediately and thoroughly with water. If your eyes are affected, do not touch them. Wash them immediately and continuously with cool water for at least 15 min. Inform your teacher.

HANDLE WITH CARE

Glass and Sharp Objects

- Handle glassware, knives, and other sharp instruments with extra care.
- If you break glassware or cut yourself, tell your teacher immediately.
- Never work with cracked or chipped glassware. Give it to your teacher.
- Use knives and other cutting instruments carefully. Never point a knife or sharp object at another person.
- When cutting, make sure that you cut away from yourself and others.

Living Things

- Treat all living things with care and respect.
- Never treat an animal in a way that would cause it pain or injury.
- Touch animals only when necessary. Follow your teacher's directions.
- Always wash your hands with soap after working with animals or touching their cages or containers.

Figure 1 Potential safety hazards are identified with caution symbols.

Caution Symbols

The activities and investigations in *B.C. Science Probe 9* are safe to perform, but accidents can happen. This is why potential safety hazards are identified with caution symbols (Figure 1) and red type. Make sure that you read the information carefully and understand what it means. Check with your teacher if you are unsure.

Safety Symbols

The Workplace Hazardous Materials Information System (WHMIS) provides workers and students with complete and accurate information about hazardous products (Figure 2). All chemical products that are supplied to schools, businesses, and industries must contain standardized labels and be accompanied by Material Safety Data Sheets (MSDS), which provide detailed information about the product. Clear and standardized labelling is an important component of WHMIS. The labels must be present on the product's original container or be added to other containers if the product is transferred.

The Canadian Hazardous Products Act requires manufacturers of consumer products to include a symbol that specifies both the nature and degree of any hazard. The Household Hazardous Products Symbols (HHPS) were designed to do this. The illustration in a symbol shows the hazard, and the border surrounding the illustration shows the degree of the hazard (Figure 3).

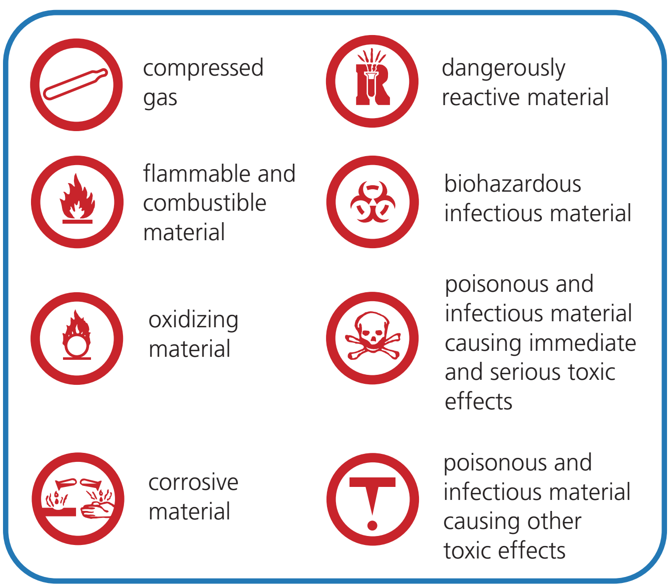


Figure 2 Workplace Hazardous Materials Information System (WHMIS) symbols

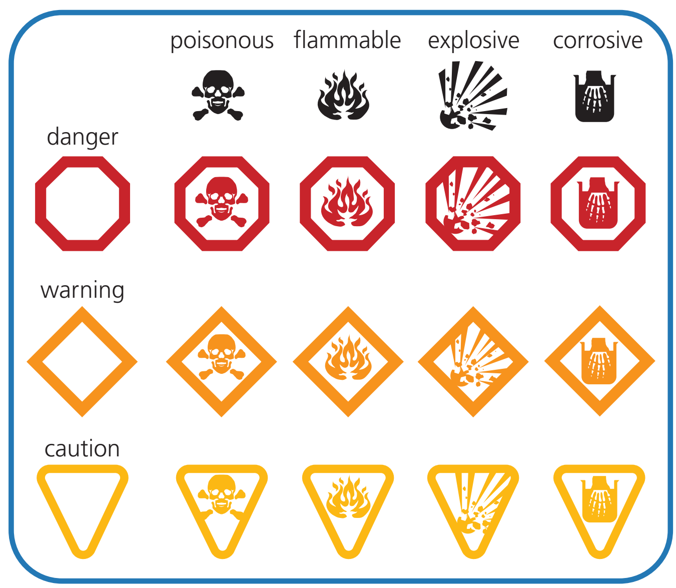


Figure 3 Household Hazardous Products Symbols (HHPS)

PRACTICE

In a group, create a safety poster for your classroom. For example, you could create a map of the route your class should follow when a fire alarm sounds, a map of where safety materials (such as fire extinguisher and a first-aid kit) are located in your classroom, information about the safe use of a specific tool, or a list of safety rules.

MODELS

When you hear the word "model," you probably think of a model airplane or a model car, or perhaps a young man or woman walking down a runway displaying the latest fashions (Figure 4). These are the usual uses of the word in everyday life. In science, the word "model" has a different meaning.

(a)

(b)

Figure 4 These images may come to mind when you hear the word "model."

Models are one of the main tools of science. Without models, scientific knowledge could not have progressed as it has. A **model** in science is a simplified representation of, or a substitute for, what you are actually studying. There are many different types of models in science, but we will consider two main categories: physical models and conceptual models.

A **physical model** is a physical construction that represents the real world. A physical model is constructed because the real thing is too big, too small, or too complicated to study easily, or simply not accessible (Figure 5). For example, a globe is a physical model that represents Earth. The only way to get a full view of Earth is from space. Since most of us will never have the chance to travel into space, a globe is used as a substitute. A cell is too small to see, so we use a large model of it so that we can visualize what the outside and inside look like. Models of the human body help us understand what the inside of our body looks like (Figure 6).

Figure 5 The model of the Sun–Earth–Moon system shows the movement of Earth around the Sun and the movement of the Moon around Earth.

Figure 6 A model allows us to see and understand ourselves.

A **conceptual model** is an idea or a concept that represents a natural phenomenon. Hypotheses and theories are conceptual models. These models help us visualize something that cannot be seen. For example, the model of the atom developed by Niels Bohr is a conceptual model. It is sometimes referred to as the planetary model because the electrons orbit the nucleus like the planets orbit the Sun. Conceptual models can often be drawn on paper, to help us form a mental image of something we cannot see directly (Figure 7). The current model of the atom is addressed in Unit B.

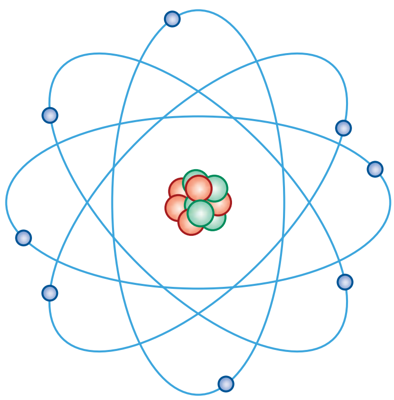


Figure 7 Niels Bohr used available evidence to visualize the internal structure of an atom and describe it in a way that we could understand.

Other types of models that are included in this category include mathematical models and computer models. Computer models can be used to study very complex, expensive, or dangerous situations—situations that cannot be studied easily in the real world. For example, engineers and technologists use computer models of crash tests to help them improve the design of cars. Meteorologists use computer models of weather systems to help them forecast the weather.

Ship captains and airplane pilots are trained using computer models of ships and airplanes (Figure 8).

Figure 8 Pilots can be trained to fly without ever sitting in a real airplane.

The purpose of a model is to simplify the real world in order to make it more understandable. A model starts out simply, but tends to become more complex as new knowledge is created and as scientific understanding advances. Sometimes a model is rejected based on new information that proves it wrong. For example, the Earth-centred model of the solar system, proposed by Ptolemy around 140 CE, lasted for about 1500 years until Copernicus published his sun-centred model in 1543. The history of the development of the sun-centred model is explored in Unit D.

Scientific models are continuously evaluated by a community of scientists. The scientists try to determine if the models are acceptable. In order to be acceptable, a scientific model must explain all observations to date, it must be consistent with other accepted ideas and models in science, and it must be able to predict in the same way that a hypothesis can predict.

SI UNITS

The scientific communities of many countries, including Canada, have agreed on a system of measurement called **SI** (Système international d'unités). In this system, all physical quantities can be expressed as a combination of seven fundamental SI units, called **base units** (for example, length, mass, and time). The seven SI base units are listed in Table 1.

Table 1 The Seven SI Base Units

Quantity name	Unit name	Unit symbol
length	metre	m
mass	kilogram	kg*
time	second	s
electric current	ampere	A
temperature	kelvin	K**
amount of substance	mole	mol
light intensity	candela	cd

* The kilogram is the only base unit that contains a prefix.

** Although the base unit for temperature (*T*) is a kelvin (K), the common unit temperature (*t*) is a degree Celsius (°C).

For example, the speed of an object is relative to the distance travelled during a specified time period. The unit for speed is metres (distance) per second (time). Units that are formed using two or more base units are called **derived units**. Some derived units have special names and symbols. For example, the unit of force that causes a mass of 1 kg to accelerate at a rate of 1 metre per second per second is known as a newton (N). In base units, the newton is $\mathrm{m{\cdot}kg/s^2}$. The dot between m and kg means "multiplied by," but m·kg is simply read as "metre kilogram." The slash means "divided by" and is read "per." The whole unit is read "metre kilogram per second squared." You can see why a special name and symbol are given to some derived units.

Some common quantities and their units are listed in Table 2. Note that the symbols representing the quantities are italicized while the unit symbols are not.

Table 2 Common Quantities and Units

Quantity name	Quantity symbol	Unit name	Unit symbol
distance	*d*	metre	m
area	*A*	square metre	m^2
volume	*V*	cubic metre	m^3
		litre	L
speed	*v*	metre per second	m/s
acceleration	*a*	meter per second per second	m/s^2
concentration	*c*	gram per litre	g/L
temperature	*t*	degree Celsius	°C
pressure	*p*	pascal	Pa
heat	*q*	joule	J
energy	*E*	joule	J
work	*W*	joule	J
power	*P*	watt	W
electric potential	*V*	volt	V
electrical resistance	*R*	ohm	Ω

An important feature of SI is the use of a common set of prefixes to express small or large sizes of any quantity conveniently. SI prefixes (Table 3) act as multipliers or factors to increase or reduce the size, in multiples of 10. The most common prefixes change the size in multiples of 1000 (10^3 or 10^{-3}), except for *centi*, as in centimetre.

Table 3 Common SI Prefixes

Prefix	Symbol	Factor by which unit is multiplied	Example
giga	G	1 000 000 000	1 000 000 000 m = 1 Gm
mega	M	1 000 000	1 000 000 m = 1 Mm
kilo	k	1 000	1 000 m = 1 km
hecto	h	100	100 m = 1 hm
deca	da	10	10 m = 1 dam
		1	
deci	d	0.1	0.1 m = 1 dm
centi	c	0.01	0.01 m = 1 cm
milli	m	0.001	0.001 m = 1 mm
micro	μ	0.000 001	0.000 001 m = 1 μm
nano	n	0.000 000 001	0.000 000 001 m = 1 nm

Converting Units

SI prefixes are also used to create conversion factors (ratios), which are used to convert to larger or smaller values of a unit. For example,

$$1\ \text{km} = 1000\ \text{m}$$

$$\text{Therefore, } \frac{1\ \text{km}}{1000\ \text{m}} = \frac{1000\ \text{m}}{1\ \text{km}} = 1$$

Multiplying by a conversion factor is like multiplying by 1. The conversion factor does not change the size of the quantity, only the unit in which it is expressed. The problem below illustrates how to convert from one unit to another.

SAMPLE PROBLEM 1

Convert Units

A block of cheese at a grocery store has a mass of 1256 g. Its price is given as $15.00 per kilogram. Determine the price of the block of cheese.

Solution

The first step is to convert the mass from grams to kilograms.

$$m = 1256\ \text{g}$$

There are two possible conversion factors between g and kg.

They are $\frac{1\ \text{kg}}{1000\ \text{g}}$ and $\frac{1000\ \text{g}}{1\ \text{kg}}$.

You should always choose the form of the conversion factor that cancels the original unit. In this case, the original unit is g, so the correct conversion factor is $\frac{1\ \text{kg}}{1000\ \text{g}}$.

$$1256\ \cancel{\text{g}} \times \frac{1\ \text{kg}}{1000\ \cancel{\text{g}}} = 1.256\ \text{kg}$$

Notice how the initial units, g, cancel (divide to give 1), leaving kg as the new unit.

Now that you have determined the mass in kg, the solution to the problem is simple. Multiply the price per kg by the mass in kg.

$$\$15.00/\text{kg} \times 1.256\ \text{kg} = \$18.84$$

The price of the block of cheese is $18.84.

Practice

Make the following conversions.

(a) Write 3.5 s in ms.

(b) Convert 3.5 cm to μm.

(c) Change 5.2 A to mA.

(d) Convert 7.5 μg to ng.

When creating a conversion factor for prefixes that represent fractions of a unit, you may find it easier to avoid fractions and use integers. For example,

$$1\ \text{mm} = \frac{1}{1000}\ \text{m, which means}$$

$$1000\ \text{mm} = 1\ \text{m}$$

Therefore, convenient conversion factors to convert between millimetres and metres are

$$\frac{1000\ \text{mm}}{1\ \text{m}} \text{ and } \frac{1\ \text{m}}{1000\ \text{mm}}$$

Conversion factors can be used for any unit equality, such as 1 h = 60 min and 1 min = 60 s. Sometimes, conversion factors are combined to convert several units in one step of a calculation. The problem below shows this multiple conversion method to convert a speed from metres per second to kilometres per hour.

SAMPLE PROBLEM 2

Convert Units: Multiple Step

John and his friends walked around the school at a speed of 1 m/s. Convert this speed to an equivalent speed in km/h.

Solution

$$v = 1\ \frac{\text{m}}{\text{s}}$$

In this problem, three conversions are necessary: metres to kilometres, seconds to minutes, and minutes to hours. Remember, always choose the form of the conversion factor that cancels the original unit.

$$1\ \frac{\cancel{\text{m}}}{\cancel{\text{s}}} \times \frac{1\ \text{km}}{1000\ \cancel{\text{m}}} \times \frac{60\ \cancel{\text{s}}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \text{h}} = 3.6\ \frac{\text{km}}{\text{h}}$$

1 m/s is equivalent to 3.6 km/h.

Practice

Use the appropriate conversion method to solve each of the following problems

1. A space shuttle travels in orbit around Earth at a speed of approximately 28 000 km/h. Convert this speed to m/s.
2. A DVD is capable of storing 4.7 GB of information. A CD can store 700 MB of information. How many CDs would be required to store the same amount of information as a DVD? (Hint: First determine how many MB equal one GB.)

SCIENTIFIC NOTATION

Scientists often work with very large or very small numbers. Such numbers are difficult to work with when they are written in common decimal notation. For example, the speed of light is about 300 000 000 m/s. There are many zeros to keep track of, if you have to multiply or divide this number by another number. Sometimes it is possible to change a very large or very small number, so that the number falls between 0.1 and 1000, by changing the SI prefix. For example, 237 000 000 mm can be converted to 237 km, and 0.000 895 kg can be expressed as 895 mg. A prefix change is not always possible, however, because an appropriate prefix may not exist or because the given prefix is essential if we want to use a particular unit of measurement. In such cases, it is best to deal with very large or very small numbers by using scientific notation. **Scientific notation** expresses a number by writing it in the form $a \times 10^n$, where the letter a, referred to as the coefficient, is a value between 1 and 10. The number 10 is the base, and n represents the exponent. The base and the exponent are read as "10 to the power of n." Powers of 10 and their decimal equivalents are shown in Table 4.

To write a large number in scientific notation, follow these steps:

1. To form the coefficient, place the decimal after the first digit and drop all the trailing zeros. If all the numbers after the decimal are zeros, keep one zero. For example, when writing the speed of light (300 000 000 m/s) in scientific notation, the coefficient becomes 3.0.
2. To find the exponent, count the number of places to the right of the decimal. In the speed of light example, there are eight places after the decimal, so the exponent is 8.
3. Combine the coefficient with the base and exponent. For example, the speed of light can be expressed in scientific notation as 3.0×10^8 m/s.

Very small numbers (less than 1) can also be expressed in scientific notation. For very small numbers, the base (10) must be given a negative exponent. For example, a millionth of a second, 0.000001 s, can be written in scientific notation as 1×10^{-6} s. Note that the number of the exponent is the number of places after the decimal that includes the first non-zero number.

Table 5 shows several examples of large and small numbers expressed in scientific notation.

Table 4 Powers of 10 and Decimal Equivalents

Power of 10	Decimal equivalent
10^9	1 000 000 000
10^8	100 000 000
10^7	10 000 000
10^6	1 000 000
10^5	100 000
10^4	10 000
10^3	1000
10^2	100
10^1	10
10^0	1
10^{-1}	0.1
10^{-2}	0.01
10^{-3}	0.001
10^{-4}	0.0001
10^{-5}	0.00001
10^{-6}	0.000001
10^{-7}	0.0000001
10^{-8}	0.00000001
10^{-9}	0.000000001

Table 5 Numbers Expressed in Scientific Notation

Large or small number	Common decimal notation	Scientific notation
124.5 million km	124 500 000 km	1.245×10^8 km
154 thousand nm	154 000 nm	1.54×10^5 nm
753 trillionths of a kg	0.000 000 000 753 kg	7.53×10^{-10} kg
315 billionths of a m	0.000 000 315	3.15×10^{-7} m

To multiply numbers in scientific notation, multiply the coefficients and add the exponents. Express the answer in scientific notation. Look at the following examples:

$$(3.5 \times 10^3 \text{ km})(7.4 \times 10^2 \text{ km}) = 25.9 \times 10^5 \text{ km}^2$$
$$= 2.59 \times 10^6 \text{ km}^2$$

$$(4.73 \times 10^5 \text{ m})(5.82 \times 10^7 \text{ m}) = 27.5 \times 10^{12} \text{ m}^2$$
$$= 2.75 \times 10^{13} \text{ m}^2$$

When dividing numbers in scientific notation, divide the coefficients and subtract the exponents.

$$(4.6 \times 10^4 \text{ m}) \div (2.3 \times 10^2 \text{ s}) = 2.0 \times 10^2 \text{ m/s}$$

$$(3.9 \times 10^4 \text{ N}) \div (5.3 \times 10^{-3} \text{ m}) = 0.74 \times 10^7 \text{ N/m}$$
$$= 7.4 \times 10^6 \text{ N/m}$$

Note that, when writing a number in scientific notation, the coefficient should be between 1 and 10. In the first example above, the product of 3.5 and 7.4 is 25.9. This can be expressed in scientific notation as 2.59×10^1. The answer can be combined as $2.59 \times 10^1 \times 10^5 \text{ km}^2$. Adding the exponents gives us $2.59 \times 10^6 \text{ km}^2$. The coefficient should be rounded to the same certainty (number of significant digits) as the measurement with the least certainty (fewest number of significant digits). In this example, both measurements have only two significant digits, so the coefficient 2.59 should be rounded to 2.6 to give a final answer of $2.6 \times 10^6 \text{ km}^2$.

UNCERTAINTY IN MEASUREMENT

There are two types of quantities that are used in science: exact values and measurements. Quantities that are exact values include defined quantities, such as those obtained from SI prefix definitions (e.g., 1 km = 1000 m) and from other definitions (e.g., 1 h = 60 min). Counted values, such as 5 beakers or 10 cells, are also exact values. All exact values are considered to be completely certain. In other words, 1 km is exactly 1000 m, not 999.9 m or 1000.2 m. Similarly, 5 beakers could not be 4.9 or 5.1 beakers; 5 beakers are exactly 5 beakers.

Every measurement, however, has some uncertainty or error. No measurement is exact. The uncertainty depends on the limitations of the particular measuring instrument used and the technological skill of the person making the measurement. The certainty of any measurement is communicated by the number of significant digits in the measurement. In a measured or calculated value, significant digits are the digits that are certain, plus one estimated (uncertain) digit. Significant digits include all the digits that are correctly reported from a measurement.

Significant Digits

Table 6 provides the guidelines for determining the number of significant digits, along with examples to illustrate each guideline.

Table 6 Guidelines for Determining Significant Digits

Guideline	Example	
	Number	Number of significant digits
Count from left to right, beginning with the first non-zero digit.	345 457.35	3 5
Zeros at the beginning of a number are never significant.	0.235 0.003	3 1
All non-zero digits in a number are significant.	1.123 76.2	4 3
Zeros between digits are significant.	107.05 0.02094	5 4
Zeros at the end of a number with a decimal point are significant.	10.0 3030.	3 4
Zeros at the end of a number without a decimal point are not significant.	3030 200 000	3 1
All digits in the coefficient of a number written in scientific notation are significant.	2.45×10^6	3

Rounding

Use these rules when rounding answers:

1. When the first digit discarded is less than 5, the last digit kept should not be changed.

   Example:

   3.141 326 rounded to four digits is 3.141.

2. When the first digit discarded is greater than 5, or when it is 5 followed by at least one digit other than zero, the last digit kept is increased by one unit.

   Examples:
   2.221 372 rounded to five digits is 2.2214.
   4.168 501 rounded to four digits is 4.169.

3. When the first digit discarded is 5 followed by only zeros, the last digit kept is increased by 1 if it is odd, but not changed if it is even.

   Examples: 2.35 rounded to two digits is 2.4
   2.45 rounded to two digits is 2.4
   6.735 rounded to two digits is 6.8

4. When adding or subtracting, look for the quantity with the fewest number of digits to the right of the decimal point. The answer can have no more digits to the right of the decimal point than this quantity has.

   Example: $12.52 + 349.0 + 8.24 = 369.76$

   Because 349.0 is the quantity with the fewest digits to the right of the decimal point, the answer must be rounded to 369.8.

   Example: $157.85 - 32.4 = 125.45$

   Because 32.4 has the fewest digits to the right of the decimal point, the answer must be rounded to 125.5.

5. When multiplying or dividing, the answer must contain no more significant digits than the quantity with the fewest number of significant digits.

   Example: $7.55 \times 0.34 = 2.567$

   This answer must be rounded to 2.6 because 0.34 has only two significant digits.

   Example: $2.4526 \div 8.4 = 0.291976$

   This answer must be rounded to 0.29 because 8.4 has only two significant digits.

6. When performing a series of calculations, do not round each calculated value before carrying out the next calculation. The final answer should be rounded to the same number of significant digits that are in the quantity with the fewest number of significant digits.

   Example: $(1.23 \times 4.321)(3.45 - 3.21)$

   Three calculations are required:
   - $3.45 - 3.21 = 0.24$ (Do not round.)
   - $(1.23 \times 4.321) = 5.31483$ (Do not round.)
   - $5.31483 \times 0.24 = 22.145125$

   Because the smallest number of significant digits among the quantities is three, the answer must be rounded to 22.1.

Measurement Errors

There are two types of error that can occur when measurements are taken: random and systematic. Random error results when an estimate is made to obtain the last significant digit for a measurement. The size of the random error is determined by the precision of the measuring instrument. For example, when measuring length, it is necessary to estimate between the marks on the measuring tape. If these marks are 1 cm apart, the random error is greater and the precision is less than if the marks were 1 mm apart. Systematic error is caused by a problem with the measuring system itself, such as the presence of an interfering substance, incorrect calibration, or room conditions. For example, if a balance is not zeroed at the beginning, all the measurements taken with the balance will have a systematic error.

The precision of measurements depends on the gradations of the measuring device. **Precision** is the place value of the last measurable digit. For example, a measurement of 12.74 cm is more precise than a measurement of of 127.4 cm because 12.74 was measured to hundredths of a centimetre whereas 127.4 was measured to tenths of a centimetre.

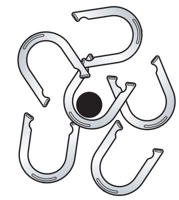
When adding or subtracting measurements of different precision, round the answer to the same precision as the least precise measurement. Consider the following example:

$$\begin{array}{r} 11.7\text{ cm} \\ 3.29\text{ cm} \\ 0.542\text{ cm} \\ \hline 15.532\text{ cm} \end{array}$$

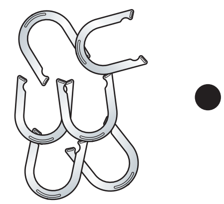
The first measurement, 11.7 cm, is measured to the nearest tenth of a centimetre and is the least precise. The answer must then be rounded to the nearest tenth of a centimetre, or 15.5 cm.

No matter how precise a measurement is, it still may not be accurate. **Accuracy** refers to how close a value is to its accepted value. Figure 9 presents an analogy that uses the results of horseshoe tosses to explain precision and accuracy.

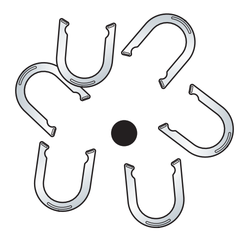
How certain you are about a measurement depends on two factors: the precision of the instrument and the size of the measured quantity. More precise instruments give more certain values. For example, a mass measurement of 13 g is less precise than a mass measurement of 12.76 g—you are more certain about the second measurement than the first. Certainty also depends on the size of the measurement. For example, consider the measurements 0.4 cm and 15.9 cm. Both have the same precision—that is, they are measured to the nearest tenth of a centimetre. If the measuring instrument is precise to ± 0.1 cm, however, the first measurement could be between 0.3 cm and 0.5 cm. The second measurement could be between 15.8 cm and 16.0 cm. An error of 0.1 cm is much more significant for the 0.4 cm measurement than it is for the 15.9 cm measurement, because the second measurement is much larger than the first. For both factors—the precision of the instrument used and the value of the measured quantity—the more digits there are in a measurement, the more certain you are about the measurement.



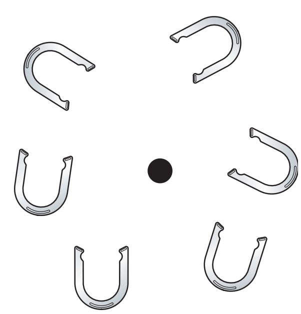
(a) precise and accurate



(b) precise but not accurate



(c) accurate but not precise



(d) neither accurate nor precise

Figure 9 The patterns of the horseshoes illustrate the comparison between accuracy and precision.

Estimating Measurement

All measurements are our best estimates of the actual values. The accuracy of a measuring device and the skill of the investigator determine how certain and precise a measurement will be. The usual rule is to estimate a measurement between the smallest divisions on the scale of the instrument. If the smallest divisions on the scale are fairly far apart (for example, greater than 1 mm), then you should estimate to one tenth (± 0.1) of a division (for example, 34.3 mL, 13.8 mL and 87.1 mL). If the divisions are closer together (for example, around 1 mm), then you should estimate to two tenths (± 0.2) of a division (for example, 12.6 °C, 11.2 °C, and 35.8 °C). If the divisions are very close together, then you should estimate to five tenths (± 0.5) or half of a division (for example, 13.0 g, 33.5 g, and 42.0 g).

USING A MICROSCOPE

Because cells are small, you must make them appear larger than they really are in order to see and study them. To view cells and other small objects closely, you need to use a compound light microscope (Figure 10). It uses two lenses and a light source to make an object appear larger. The object is magnified by a lens near your eye, called the ocular lens (sometimes called the eyepiece), and again by a second lens, called the objective lens, which is just above the object. The comparison of the actual size of the object with the size of its image is referred to as magnification. Table 7 lists the parts of a compound light microscope and their functions.

Figure 10 A compound light microscope

Table 7 Parts of a Compound Light Microscope

Structure	Function
stage	• supports the microscope slide • is a central opening that allows light to pass through the slide
clips	• are found on the stage and used to hold the slide in position
diaphragm	• regulates the amount of light that reaches the object being viewed
objective lenses	• magnify the object • are usually three complex lenses located on the nosepiece, immediately above the object; the low-power lens magnifies by 4×, the medium-power lens magnifies by 10×, and the high-power lens magnifies by 40×
revolving nosepiece	• rotates, allowing the objective lens to be changed • allows each lens to click into place
body tube	• contains the ocular lens • supports the objective lenses
ocular lens	• magnifies the object, usually by 10× • is the part you look through to view the object • is also known as the eyepiece
coarse-adjustment knob	• moves the body tube up or down to get the object into focus • is used with the low-power objective lens only
fine-adjustment knob	• moves the tube to get the object into sharp focus • is used with medium-power and high-power magnification • is used only after the object has been located and focused under lower-power magnification, using the coarse-adjustment nob

Basic Microscope Skills

The basic microscope skills are presented as sets of instructions. This will enable you to practise these skills before you are asked to use them in the investigations in *B.C. Science Probe 9*.

Materials

- newspaper that contains lower-case letter *f* or similar small object
- scissors
- microscope slide
- cover slip
- medicine dropper
- water
- compound microscope
- small piece of onion skin
- compass or Petri dish
- pencil
- transparent ruler

Preparing a Dry Mount

The microscope slide prepared using the following method is called a dry mount because no water is used.

1. Find a small, flat object, such as a lower-case letter *f* cut from a newspaper.
2. Place the object in the centre of a microscope slide.
3. Hold a cover slip between your thumb and forefinger. Place the edge of the cover slip to one side of the object (Figure 11). Gently lower the cover slip onto the slide so that it covers the object.

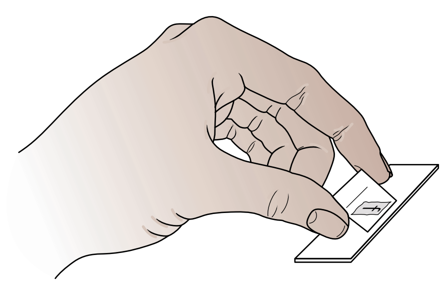


Figure 11

Preparing a Wet Mount

The microscope slide prepared using this method of preparing a microscope slide is called a wet mount because water is used.

1. Find a small, flat object such as a thin piece of onion.
2. Place the object in the centre of a microscope slide.
3. Place two drops of water on the object (Figure 12).

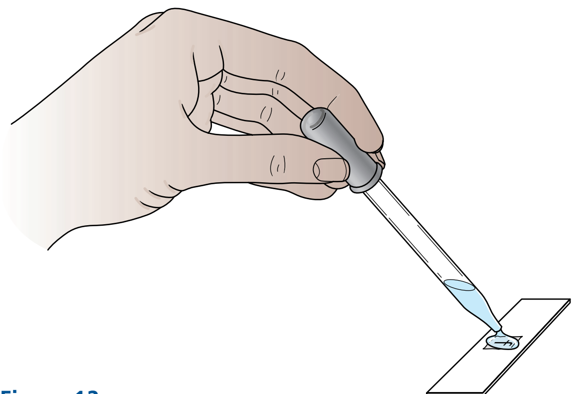


Figure 12

4. Holding the cover slip with your thumb and forefinger, touch the edge of the surface of the slide at a 45° angle (Figure 13). Gently lower the cover slip, allowing the air to escape.

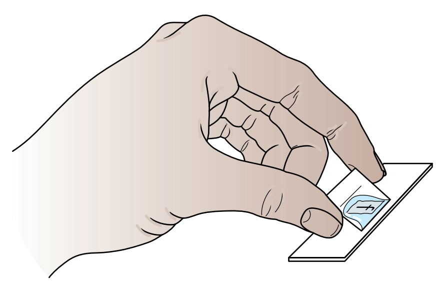


Figure 13

Positioning Objects Under a Microscope

1. Make sure that the low-power objective lens is in place on the microscope. Then put either the dry mount or wet mount slide in the centre of the microscope stage. Use the stage clips to hold the slide in position. Turn on the light source (Figure 14).

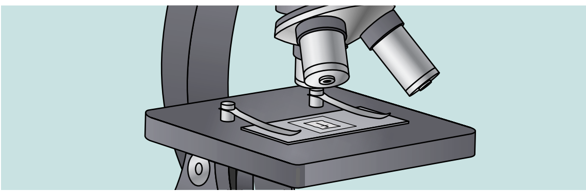


Figure 14

2. View the microscope stage from the side. Then, using the coarse-adjustment knob, bring the low-power objective lens as close as possible to the object. Do not allow the lens to touch the cover slip (Figure 15).

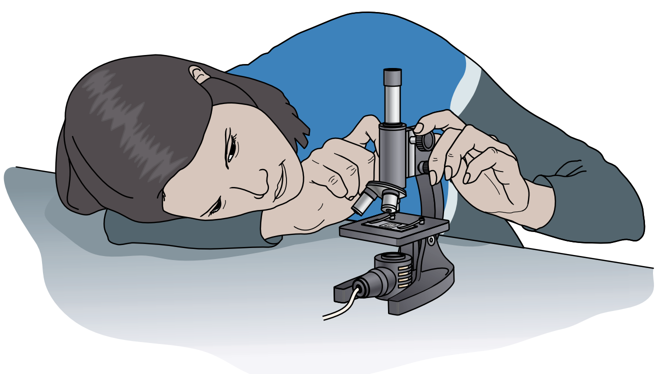


Figure 15

3. View the object through the eyepiece. Slowly move the coarse-adjustment knob so that the objective lens moves away from the slide, until you bring the image into focus. Note that the object is facing the "wrong" way and is upside down.
4. Using a compass or Petri dish, draw a circle in your notebook to represent the area you are looking at through the microscope. This area is called the field of view. Look through the microscope, and draw what you see. Make the object fill the same amount of area in your drawing as it does in the microscope.
5. While you are looking through the microscope, slowly move the slide away from your body. Note that the object appears to move toward you. Now move the slide to the left. Notice that the object appears to move to the right.
6. Rotate the nosepiece to the medium-power objective lens. Use the fine-adjustment knob to bring the object into focus. Notice that the object becomes larger (Figure 16).

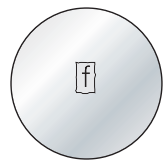


Figure 16

Never use the coarse-adjustment knob with the medium-power or high-power objective lenses.

7. Adjust the object so that it is directly in the centre of the field of view. Rotate the nosepiece to the high-power objective lens. Then, use the fine-adjustment knob to focus the image. Notice that you see less of the object than you did under medium-power magnification. Also notice that the object seems closer to you.

Storing the Microscope

After you complete an activity using a microscope, follow these steps:

1. Rotate the nosepiece to the low-power objective lens.
2. Remove the slide and the cover slip (if applicable).
3. Clean the slide and the cover slip, and return them to their appropriate location.
4. Return the microscope to the storage area.

Determining the Field of View

The field of view is the circle of light that is seen through a microscope. It is the area of the slide that you can observe.

1. Put the low-power objective lens in place. Place a transparent ruler on the stage. Position the millimetre marks of the ruler immediately below the objective lens.
2. Focus on the marks of the ruler, using the coarse-adjustment knob.
3. Move the ruler so that one of the millimetre markings is just at the edge of the field of view. Note the diameter of the field of view in millimetres, under the low-power objective lens (Figure 17).

Figure 17 Step 3

4. Put the medium-power objective lens in place. Repeat steps 2 and 3 to measure the field of view for the medium-power objective lens.
5. Most high-power objective lenses provide a field of view that is less than one millimetre in diameter, so it cannot be measured with a ruler. The following steps can be used to calculate the field of view of a high-power lens.
   - Calculate the ratio of the magnification of the high-power objective lens to the magnification of the low-power objective lens.

$$\text{ratio} = \frac{\text{magnification of high-power lens}}{\text{magnification of low-power lens}}$$

For example, if the low-power lens is 4× magnification and the high-power lens is 40× magnification, then

$$\text{ratio} = \frac{40\times}{4\times} = 10$$

   - Use the ratio to determine the diameter of the field of view under high-power magnification.

$$\text{field of view diameter (high power)} = \frac{\text{field of view diameter (low power)}}{\text{ratio}}$$

For example, if the diameter of the low-power field of view is 2.0 mm, then

$$\text{field of view diameter (high power)} = \frac{2.5\text{ mm}}{10} = 0.25\text{ mm}$$

The Stereo Microscope

A stereo microscope (Figure 18), or dissecting microscope, is used for observing small three-dimensional objects. You can use a stereo microscope when you cannot look at a sample on a slide. For example, you can use a stereo microscope to observe live specimens that are too large to fit under a cover slip.

Figure 18 A stereo microscope

SCIENTIFIC DRAWINGS

Scientific drawings are done to record observations as accurately as possible. They are also used to communicate, which means they must be clear, well labelled, and easy to understand. Below are some tips that will help you produce useful scientific drawings.

Before You Begin

- Obtain some blank paper. Lines might obscure your drawing or make your labels confusing.
- Find a sharp, hard pencil (such as H or 2H). Avoid using pen, thick markers, or coloured pencils. Ink can't be erased—even the most accomplished artists change their drawings—and coloured pencils are soft, making lines too thick.
- Plan to draw large. Ensure that your drawing will be large enough that people can see details. For example, a third of a page might be appropriate for a diagram of a single cell or a unicellular organism. If you are drawing the entire field of view of a microscope, draw a circle with a reasonable diameter (such as 10 cm) to represent the field of view.
- Leave space for labels, preferably on the right side of your drawing.
- Observe and study your specimen carefully, noting details and proportions.

Drawing

- A simple, two-dimensional drawing is effective.
- Draw only what you see. A diagram in your textbook may act as a guide, but it may show structures that you cannot see in your specimen.
- Do not sketch. Draw firm, clear lines, including only relevant details that you can see clearly.
- Do not use shading or colouring in a scientific drawing. A stipple (series of dots), as shown in Figure 19, may be used to indicate a darker area. Use double lines to indicate thick structures.

Figure 19

Label Your Drawing

- All drawings must be labelled fully in neat printing. Avoid printing labels directly on the drawing.
- Use a ruler to draw horizontal label lines from the structures being identified to the label (Figure 20).
- Label lines should never cross.
- If possible, list your labels in an even column down the right side.
- Title your drawing, using the name of the specimen and (if possible) the part of the specimen you have drawn. Underline the title.

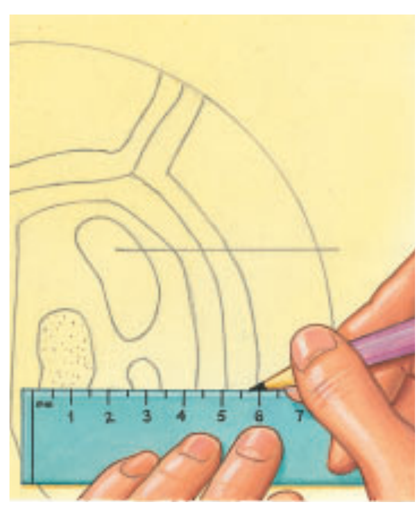


Figure 20

Scale Ratio

- To show the relation of the actual size to your drawing size, print the scale ratio of your drawing beside the title.

$$\text{scale ratio} = \frac{\text{size of drawing}}{\text{actual size of specimen}}$$

For example, if you have drawn a nail (Figure 21) that is 5 cm long and your drawing is 15 cm long, then the scale ratio, which in this case is a magnification, is

$$\frac{15\text{ cm}}{5\text{cm}} = 3\times$$

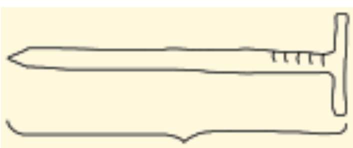


Figure 21

- The magnification is always written with an "×" after it. In a fully labelled drawing, the total magnification of the drawing should be placed at the bottom right side of the drawing. For example, suppose that the ocular lens magnified a specimen 10×, the low-power objective lens (4×) was used, and the scale ratio was 3×. The total magnification of the drawing would be

$$\begin{aligned}\text{total magnification} &= \text{ocular lens} \times \text{low-power objective lens} \times \text{scale ratio}\\ &= 10 \times 4 \times 3\\ &= 120\times\end{aligned}$$

The total magnification should be written on the bottom right-hand side of the drawing, as shown in Figure 22.

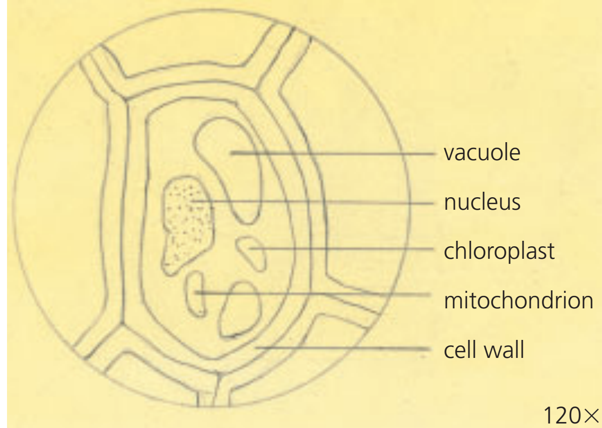


Figure 22

PRACTICE

Obtain a specimen from your classroom. It could be a piece of your hair, chalk dust, or something else you would be interested in looking at under a microscope. Prepare a dry mount slide, and focus your specimen under the medium-power objective lens. Complete a scientific drawing of your specimen. Use the checklist below to ensure that your drawing is accurate and complete. When your drawing is complete, exchange it with a classmate's drawing. Note the strengths and weaknesses of your classmate's drawing, keeping in mind all the features of a good scientific drawing. Evaluate your classmate's drawing using the checklist.

Checklist for Good Scientific Drawing

✓ Use blank paper and a sharp, hard pencil.
✓ Draw as large as necessary to show details clearly.
✓ Do not shade or colour.
✓ Draw label lines that are straight and parallel and run outside your drawing. Use a ruler for this!
✓ Include labels, a title, and the total magnification.

USING STAR MAPS

What Is a Star Map?

A star map shows the most easily seen stars in the sky, with many of the stars joined by lines into constellations. Each star map is designed for a range of latitudes, such as latitudes 45° north of the equator. Thus, a star map designed for southern Canada cannot be used in Australia.

You can use a star map to help you recognize the objects you can see in the sky, and to observe the motions of these objects as Earth goes through its cycles of rotation and revolution.

Maps for All Seasons

Different parts of the sky are visible during different times of the year. To show the stars and constellations that are visible, different star maps have been designed for different seasons or months (Figure 23 on the next page).

Some star maps have a "window" that can be rotated to expose different parts of the map. Each part of the star map represents the part of the sky that is visible at a certain time of the year.

Stargazing Trips

When you want to observe the night sky, consider these tips:

- Plan your stargazing trip in advance, taking into consideration the weather forecast, safety, transportation, location, what to wear, and what to bring.
- Choose a location that is far away, or at least screened away, from bright lights.
- Be prepared to record your observations.
- Before viewing, allow your eyes at least 10 min to adapt to the dark.
- Use a flashlight covered with red cellophane to view your star map.

Using a Star Map

To use a seasonal star map, follow these steps:

- Select the star map for the appropriate month or season.
- Hold the map, facing downward, above your head.
- Rotate the map so the top part (marked "Facing North") is facing north. This means that Orion is facing south.
- Compare what you see in the sky with what is on the map.
- Notice any planets or other objects, besides stars.

Keeping Records

Use a table to record your observations. Possible titles for the columns are shown in Table 8. Be careful when recording dates because, for example, December 15 becomes December 16 after midnight.

Table 8

Date	Object seen	Description (including a diagram)	Location (including angles)	Questions I want answered

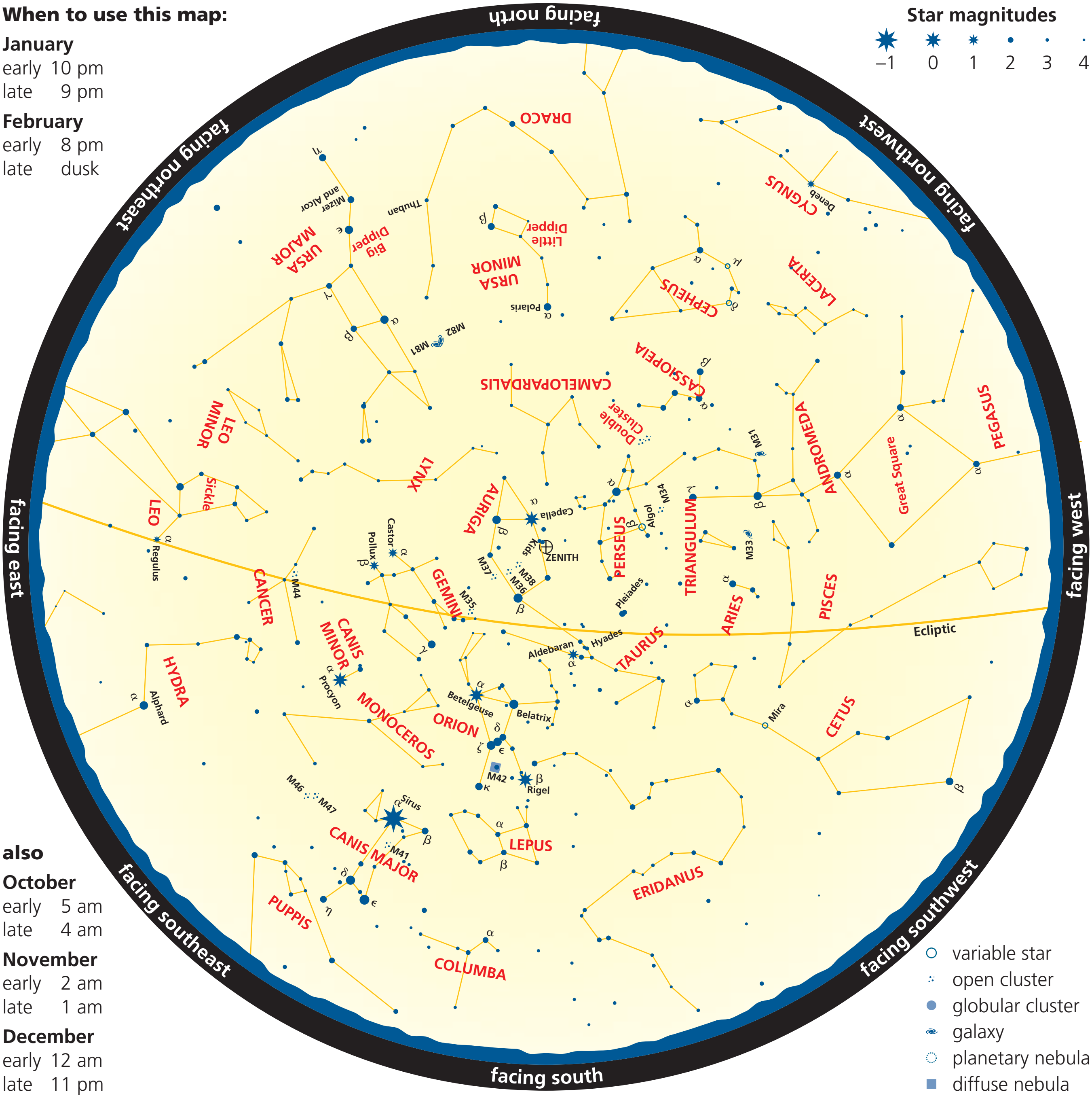
When to use this map:

January
early 10 pm
late 9 pm

February
early 8 pm
late dusk

Star magnitudes

–1 0 1 2 3 4



also

October
early 5 am
late 4 am

November
early 2 am
late 1 am

December
early 12 am
late 11 pm

variable star
open cluster
globular cluster
galaxy
planetary nebula
diffuse nebula

Figure 23 Star map

DRAWING AND CONSTRUCTING CIRCUITS

Sources of Electrical Energy

To provide the electrical energy in most of the circuits you create, you will be using a combination of dry cells or a special device called a power supply. A power supply can be set to supply the voltage required.

The source in the circuits you construct and test yourself will be a direct current, or DC, source of electrical energy. In a DC circuit, the current flows in only one direction. DC circuits are used in schools because the operating voltages are much safer to use, generally below 28 V.

Wall outlets provide a different kind of electrical energy known as an alternating current, or AC, source. In an AC circuit, the electric current reverses its direction 60 times a second. AC appliances are specially designed for this energy source and typically operate at 120 V or 240 V.

Drawing Circuit Diagrams

Before building a circuit, it is a good idea to draw a circuit diagram. This will remind you about how components should be connected. There are some conventions to follow when drawing a circuit diagram: connecting wires are generally shown as straight lines or 90° angles, and symbols (shown in Table 9 on the next page) are used to represent all the components.

Safety Considerations

It is important to observe and use appropriate safety procedures, especially when you see  or a WHMIS safety symbol.

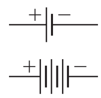
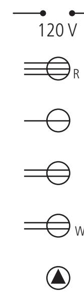
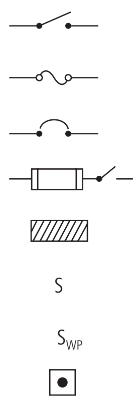
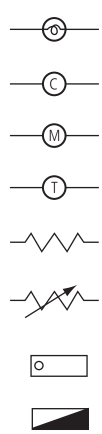
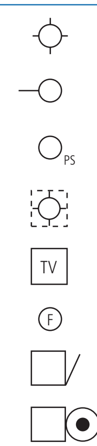
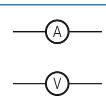
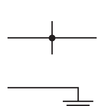
- Always ensure that your hands are dry, and that you are standing on a dry surface.
- Do not use faulty dry cells or batteries, and do not connect different makes of dry cells in the same battery. Avoid connecting partially discharged dry cells to fully charged cells. Take care not to accidentally short-circuit dry cells or batteries.
- Do not use frayed or damaged connectors.
- Handle breakable components with care.
- Only operate a circuit after it has been approved by your teacher.

Constructing a Circuit

When constructing or modifying a circuit, always follow the instructions. If you are unsure of the instructions, ask for clarification. Check that all the components are in good working order.

- Check the connections carefully when linking connecting dry cells in series or in parallel. Incorrect connections could cause shorted circuits or explosions. Ask your teacher for clarification if you are unsure.
- When attaching connecting wires to a meter, connect a red wire to the positive terminal and a black wire to the negative terminal of the meter. This will remind you to consider the polarity of the meter when connecting it in the circuit.
- Sometimes the ends of connecting wires do not have the correct attachments to connect to a device or meter. Use approved connectors, such as alligator clips, but be careful to position the connectors so that they cannot touch one another.
- Open the switch before altering a meter connection or adding new wiring or components.
- If a circuit does not operate correctly, open the switch and check the wiring and all the connections to the terminals. If you cannot find the problem, ask your teacher to inspect the circuit again.

Table 9 Circuit Diagram Symbols

	DC circuit		Household circuit (additional symbols)	
Sources/outlets		cell 3-cell battery		wall outlet range outlet single outlet double outlet (duplex) weatherproof outlet special-purpose outlet
Control devices		switch fuse circuit breaker switch and fuse distribution panel switch weatherproof switch push button		
Electrical loads		light bulb clock motor thermostat resistor variable resistor (rheostat) fluorescent fixture heating panel		ceiling light wall light lampholder with pull switch recessed fixture television outlet fan buzzer bell
Meters		ammeter voltmeter		
Connectors		conducting wire joined wires ground connection		

USING THE VOLTMETER, AMMETER, AND DIGITAL MULTIMETER

Since we cannot see electrons flowing in an electric circuit, we have to rely on instruments that can detect and measure electricity. There are at least two instruments that you are likely to use: a voltmeter (Figure 24(a)) and an ammeter (Figure 24(b)).

(a) (b)

Figure 24 (a) A voltmeter (b) An ammeter

These instruments may be digital (providing a digital readout) or analog (indicating voltage or current by the movement of a needle across a scale). You may also use a digital multimeter (Figure 25), which measures voltage, current, and resistance.

Figure 25
A digital multimeter

The Voltmeter

A voltmeter measures the voltage difference between two different points in a circuit. A voltmeter can be connected across the terminals of a cell to measure the voltage output of the cell, or across another component of a circuit to measure the voltage drop across this component. In other words, a voltmeter is always connected in parallel with the component you want to investigate.

Reading an Analog Voltmeter

The needle on a voltmeter usually moves from left to right, with the zero voltage on the left side of the scale and the maximum voltage on the right. If the voltmeter scale has only one set of numbers, it is relatively easy to measure the voltage. Be sure that you know the voltage value represented by the smallest division on the scale.

If the voltmeter has several sets of numbers, identify which set of numbers matches the voltage range selected by the switch on the voltmeter.

The two leads that connect a voltmeter to any part of an electric circuit must be attached so that the negative terminal of the voltmeter is connected to the more negative part of the circuit. If the leads are attached incorrectly, the needle will try to move to the left but will be unable to do so, and will not give a reading.

The Ammeter

An ammeter measures the amount of electric current that is flowing in a circuit. To measure the electric current, connect the ammeter directly into the circuit. In whatever part of the circuit you wish to measure the current, disconnect a wire and connect the ammeter, in series, to complete the circuit. Reading digital and analog ammeters is very similar to reading digital and analog voltmeters. The unit of current is the ampere (A) or milliampere (mA).

The Digital Multimeter

A digital multimeter can measure the voltage, current, or resistance in a circuit. Using the selector knob, select the electrical value and range that you wish to measure. Then connect the wire leads properly to the appropriate place in the circuit. Remember to connect the meter in parallel for measuring voltage or in series for measuring current. The multimeter will provide a digital readout of the measurement of the electrical value.

USING OTHER SCIENTIFIC EQUIPMENT

You can do many experiments using everyday materials and equipment. In your science classroom, however, there are some pieces of equipment that you may not be familiar with. Some of these are shown here.

Figure 26 Common laboratory equipment

DECISION MAKING: THE IMPORTANCE OF SCIENTIFIC LITERACY

You live in a time when growing scientific knowledge and technological achievements are playing a more important role in everyday life. You need to be scientifically literate to make wise personal decisions and to be a responsible citizen. Scientific literacy has been defined as "a combination of the attitudes, skills, and scientific and indigenous knowledge needed to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around us."

THE DECISION-MAKING PROCESS

Being scientifically literate will equip you with the knowledge, skills, and attitudes to make rational decisions. We often make poor decisions when we rely on only our feelings or emotions. If we use a logical, structured process for making personal or societal decisions, then we will probably make wise decisions. The decision-making process involves examining an issue, analyzing the evidence, weighing alternatives, anticipating the possible consequences, and then making a decision or taking a position on the issue.

Modern life is filled with environmental and social issues that have scientific and technological connections. An issue is a situation that has at least two possible solutions rather than a single right answer. Several points of view need to be considered in order to make a decision on an issue. Often what different people think is the best decision is based on what they think is important or on what they value. Therefore, it may be difficult to come to a decision that everyone agrees with. Ideally, the solution that is put into practice is the one that is most appropriate for society as a whole.

When a decision has an impact on many people or on the environment, it is important to explore the issue carefully. This means researching and investigating your ideas, and talking and listening to others. The different steps in the decision-making process are described on the next few pages.

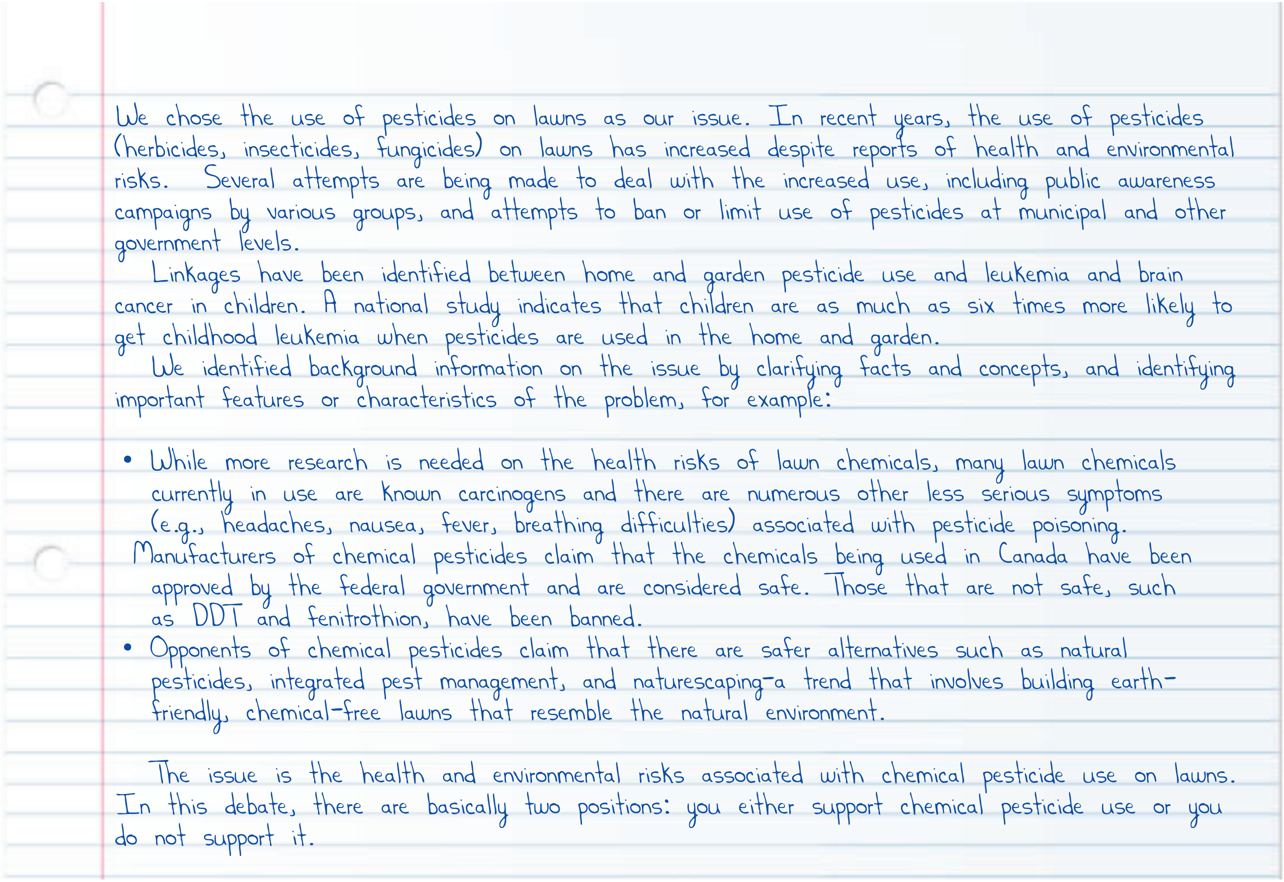
Defining the Issue

The first step in the decision-making process is defining the issue. To define, or understand, the issue, you need to determine why it is an issue. Describe the problems associated with the issue, and identify the individuals or groups, called stakeholders, involved in the issue. Ask yourself "Who?", "What?", "Where?", "When?", "Why?", and "How?" as a starting point for your research. Develop background information on the issue by clarifying the facts and concepts, and by identifying relevant features or characteristics of the issue (Figure 1 on the next page).

You need to consider the different ways of looking at the issue. The different ways of looking at an issue are called the perspectives (Table 1).

Table 1 Perspectives on an Issue

Perspective	Description
cultural	customs and practices of a particular group
ecological	interactions among organisms and their natural habitat
economic	production, distribution, and consumption of wealth
educational	effects on learning
emotional	feelings and emotions
environmental	effects on physical surroundings
esthetic	artistic, tasteful, beautiful
moral/ethical	what is good/bad, right/wrong
legal	rights and responsibilities of individuals and groups
spiritual	effects on personal beliefs
political	effects on the aims of a political group or party
scientific	logical or research based
social	effects on human relationships, the community, or society
technological	machines and industrial processes


We chose the use of pesticides on lawns as our issue. In recent years, the use of pesticides (herbicides, insecticides, fungicides) on lawns has increased despite reports of health and environmental risks. Several attempts are being made to deal with the increased use, including public awareness campaigns by various groups, and attempts to ban or limit use of pesticides at municipal and other government levels.

Linkages have been identified between home and garden pesticide use and leukemia and brain cancer in children. A national study indicates that children are as much as six times more likely to get childhood leukemia when pesticides are used in the home and garden.

We identified background information on the issue by clarifying facts and concepts, and identifying important features or characteristics of the problem, for example:

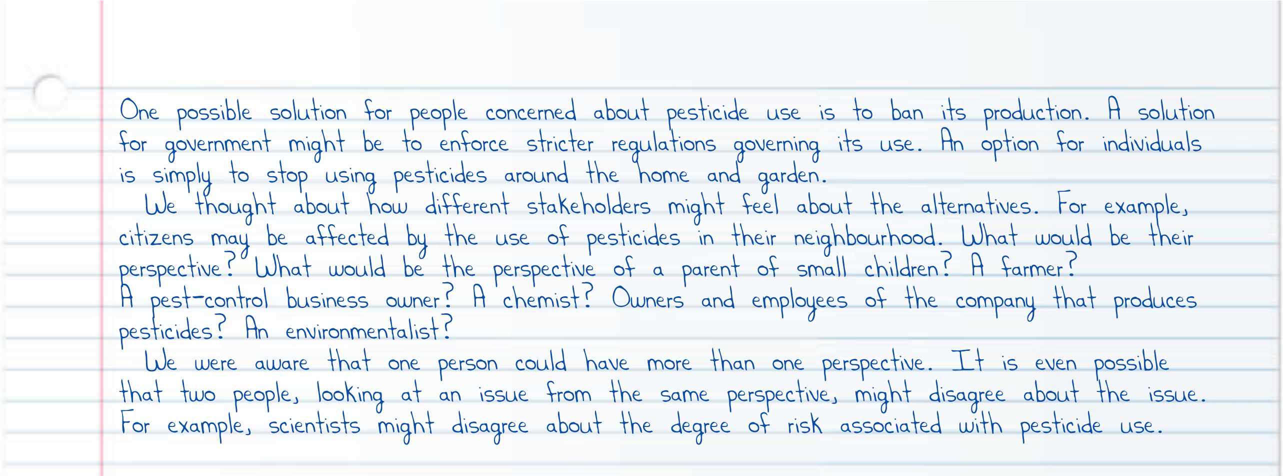
- While more research is needed on the health risks of lawn chemicals, many lawn chemicals currently in use are known carcinogens and there are numerous other less serious symptoms (e.g., headaches, nausea, fever, breathing difficulties) associated with pesticide poisoning.
  Manufacturers of chemical pesticides claim that the chemicals being used in Canada have been approved by the federal government and are considered safe. Those that are not safe, such as DDT and fenitrothion, have been banned.
- Opponents of chemical pesticides claim that there are safer alternatives such as natural pesticides, integrated pest management, and naturescaping—a trend that involves building earth-friendly, chemical-free lawns that resemble the natural environment.

The issue is the health and environmental risks associated with chemical pesticide use on lawns. In this debate, there are basically two positions: you either support chemical pesticide use or you do not support it.

Figure 1

Identifying Alternatives/Positions

Examine the issue and think of as many alternative solutions as you can (Table 1). At this step, it does not matter if the solutions seem unrealistic. To analyze the solutions, you should examine the issue from a variety of perspectives (Table 2). Stakeholders may bring different viewpoints to an issue and these may influence their position on the issue. Brainstorm or hypothesize how different stakeholders would feel about your solutions (Figure 2).


One possible solution for people concerned about pesticide use is to ban its production. A solution for government might be to enforce stricter regulations governing its use. An option for individuals is simply to stop using pesticides around the home and garden.

We thought about how different stakeholders might feel about the alternatives. For example, citizens may be affected by the use of pesticides in their neighbourhood. What would be their perspective? What would be the perspective of a parent of small children? A farmer? A pest-control business owner? A chemist? Owners and employees of the company that produces pesticides? An environmentalist?

We were aware that one person could have more than one perspective. It is even possible that two people, looking at an issue from the same perspective, might disagree about the issue. For example, scientists might disagree about the degree of risk associated with pesticide use.

Figure 2

Table 2 Potential Stakeholders in the Pesticide Debate

Stakeholder	Viewpoint (perspective)
cultural	This would depend on the customs and practices of the group.
parent	Children are more susceptible to pesticide poisoning than adults and should not be put at risk. (social perspective)
scientists	1. Active ingredients in many pesticides are known carcinogens. 2. Levels of the active ingredients in pesticides pose no risk to humans with short-term exposure. (scientific perspective)
doctor	Environmental factors that pose any risk to human health should be eliminated or severely restricted. (ecological and legal perspectives)
environmentalist	Pesticides from lawns are percolating into rivers, streams, and ground water and are affecting wildlife. (ecological perspective)
pest-control business owner	Used properly, pesticides pose no risk to humans. Only trained people should be allowed to use pesticides. The pest-control industry is a valuable contributor to the economy. (scientific, technological, legal, and economic perspectives)
owners of chemical company	Pesticides have been tested and approved by the federal government. (legal perspective) Jobs will be lost if these pesticides are banned. (economic and social perspectives)

Researching the Issue

Formulate a research question that helps to limit, narrow, or define the issue. Then develop a plan to identify and find reliable and relevant sources of information. Outline the stages of your information search: gathering, sorting, evaluating, selecting, and integrating relevant information. You may consider using a flow chart, concept map, or other graphic organizer to outline the stages of your information search. Gather information from many sources, including newspapers, magazines, scientific journals, the library, and the Internet (Figure 3).

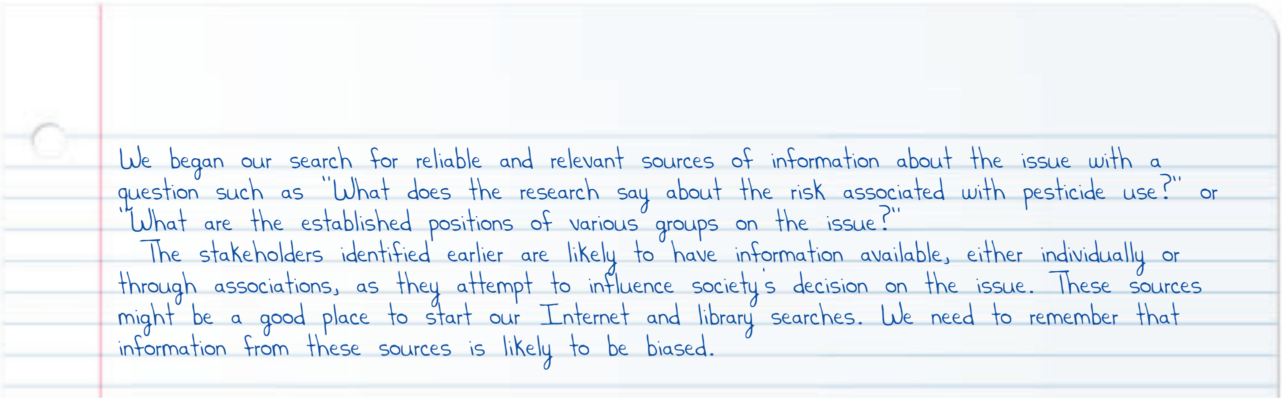

We began our search for reliable and relevant sources of information about the issue with a question such as "What does the research say about the risk associated with pesticide use?" or "What are the established positions of various groups on the issue?"
The stakeholders identified earlier are likely to have information available, either individually or through associations, as they attempt to influence society's decision on the issue. These sources might be a good place to start our Internet and library searches. We need to remember that information from these sources is likely to be biased.

Figure 3

Analyzing the Issue

In this step, you need to analyze the issue and clarify where you stand. First, you should establish criteria for evaluating your information to determine whether it is relevant and significant. You can then evaluate your sources, determine what assumptions may have been made, and determine if you have enough information to make your decision (Figure 4).

Pesticide use on lawns has arisen because of the desire of homeowners to increase the aesthetic appeal of their property by eliminating weeds, insects, and fungi.

After reviewing government, chemical industry, and university studies, and by reading newspaper articles and papers by environmental groups, we concluded that research seems to indicate that the active ingredients in many common pesticides are carcinogenic and therefore pose a significant risk to health.

There are reports that contradict our view, and domestic pesticides have been approved for use by federal government agencies. There are many jobs, some of them based in our town, that rely on continued use of pesticides.

After performing a risk-benefit analysis of the various alternative solutions, we decided that we should attempt to reduce or eliminate the use of pesticides on lawns.

Figure 4

There are five steps that must be completed to analyze an issue effectively.

1. Establish criteria for determining whether the information gathered is relevant and significant. Using a graphic organizer may help evaluate the information and clarify the perspectives.
2. Evaluate the sources of information so that you can separate fact from opinion. Are you able to confirm the facts given? Determine what perspectives and biases the authors have on the issue.
3. Identify and determine what assumptions have been made, and whether these assumptions are supported. If there is not enough supporting evidence, the assumptions should be challenged.
4. Identify any issues that may be associated with the issue being explored, but are not directly related. Related issues often attract attention away from the central issue.
5. Evaluate the alternative solutions using a risk-benefit analysis (Table 3). Remember that a **risk-benefit analysis** is only a tool to help you organize the risks and benefits of a solution. It cannot make the decision for you, but it can help you make the decision.

Table 3 Risk-Benefit Analysis of Continuing Use of Pesticides on Lawns

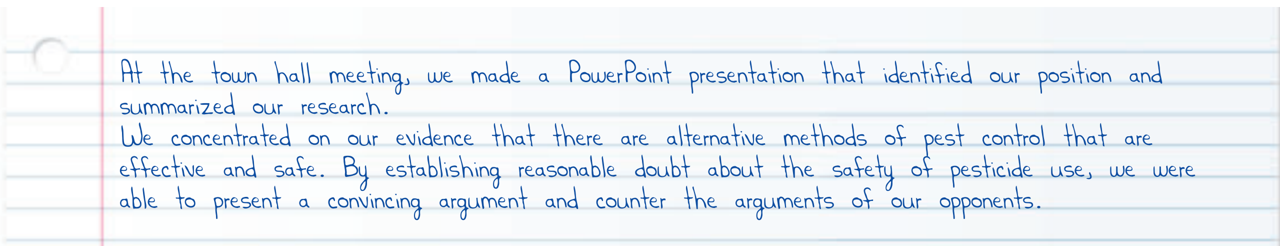
RISKS				BENEFITS			
Possible result	**Cost of result (scale 1 to 5)**	**Probability of result occurring (%)**	**Cost × probability**	**Possible result**	**Benefit of result (scale 1 to 5)**	**Probability of result occurring (%)**	**Benefit × probability**
Pesticide use on lawns has health risks for humans.	very serious 5	research is inconclusive (60 %)	300	Pesticides eliminate pests, which present health risks.	high 4	somewhat likely (60 %)	240
Pesticide use on lawns affects other species.	serious 4	likely (80 %)	320	The lawn-care business is a valuable part of our local economy.	high 4	certain (100 %)	400
Health care costs will increase.	very serious 5	likely (80 %)	400	A well-kept lawn increases property value.	neutral 3	likely (80 %)	240
Total risk value			1 020	**Total benefit value**			880

Defending the Decision

After analyzing your information, you can answer your research question and take an informed position on the issue. Justify your position on the issue using supporting information. You should be able to defend your position to people with different perspectives. Ask yourself the following questions:

- Do I have supporting evidence from a variety of sources?
- Can I state my position clearly?
- Can I show why this issue is relevant and important to society?
- Do I have solid arguments (with solid evidence) supporting my position?
- Have I considered arguments against my position, and identified their faults?
- Have I analyzed the strong and weak points of each perspective?

When you are able to defend your position effectively, you can communicate your decision in an appropriate format, such as a debate, speech, position paper, multimedia presentation (for example, computer slide show), brochure, poster, or video (Figure 5).



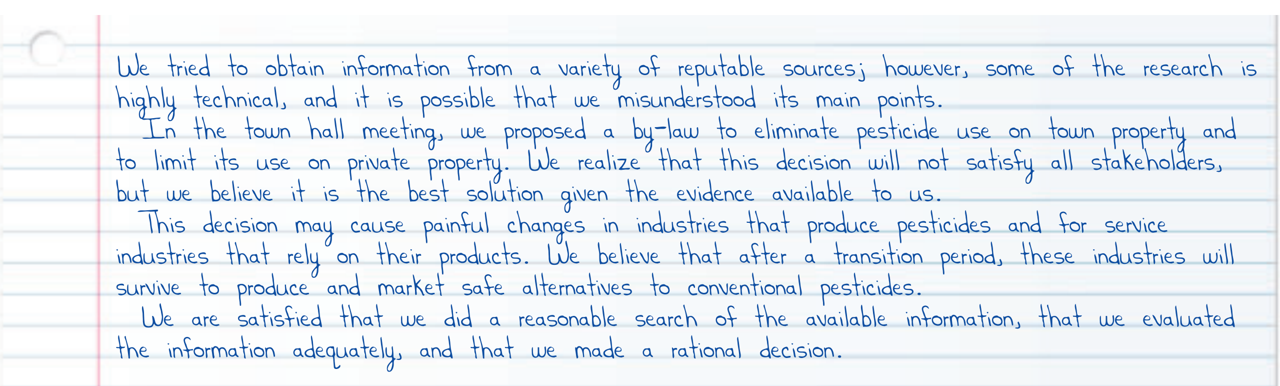
At the town hall meeting, we made a PowerPoint presentation that identified our position and summarized our research.
We concentrated on our evidence that there are alternative methods of pest control that are effective and safe. By establishing reasonable doubt about the safety of pesticide use, we were able to present a convincing argument and counter the arguments of our opponents.

Figure 5

Evaluating the Process

The final step of the decision-making process includes evaluating the decision itself and the process used to reach the decision. After you have made a decision, carefully examine the thinking that led to this decision (Figure 6). Some questions to guide your evaluation include:

- What was my initial perspective on the issue? How has my perspective changed since I first began to explore the issue?
- How did I gather information about the issue? What criteria did I use to evaluate the information?
- What information did I consider to be the most important when making my decision?
- How did I make my decision? What process did I use? What steps did I follow?
- In what ways does my decision resolve the issue?
- What are the likely short-term and long-term effects of my decision?
- How might my decision affect the various stakeholders?
- To what extent am I satisfied with my decision?
- If I had to make this decision again, what would I do differently?



We tried to obtain information from a variety of reputable sources; however, some of the research is highly technical, and it is possible that we misunderstood its main points.
In the town hall meeting, we proposed a by-law to eliminate pesticide use on town property and to limit its use on private property. We realize that this decision will not satisfy all stakeholders, but we believe it is the best solution given the evidence available to us.
This decision may cause painful changes in industries that produce pesticides and for service industries that rely on their products. We believe that after a transition period, these industries will survive to produce and market safe alternatives to conventional pesticides.
We are satisfied that we did a reasonable search of the available information, that we evaluated the information adequately, and that we made a rational decision.

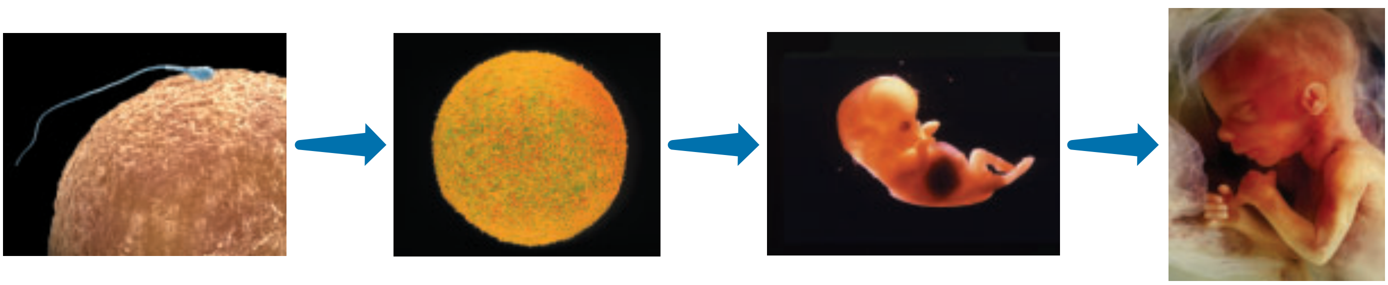
Figure 6

USING GRAPHIC ORGANIZERS

Diagrams that are used to organize and display ideas visually are called graphic organizers. A graphic organizer can help you see connections and patterns among different ideas. Different graphic organizers are used for different purposes:

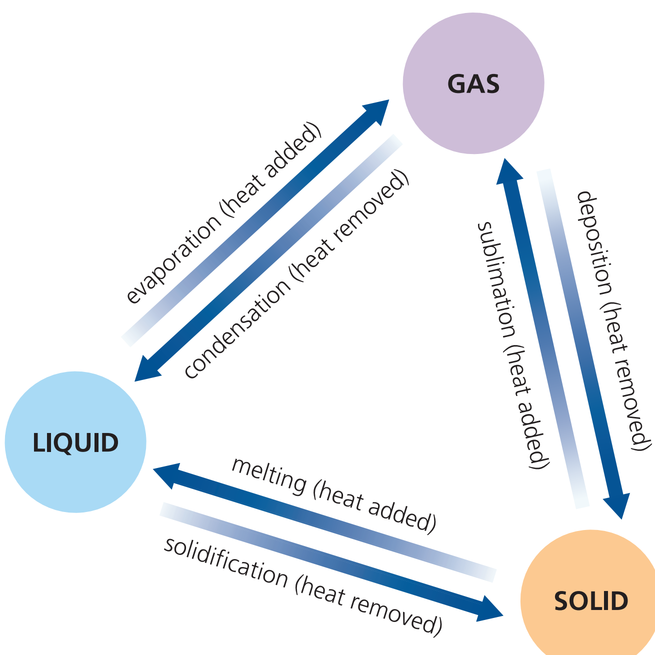
- to show processes
- to organize ideas and thinking
- to compare and contrast
- to show properties or characteristics

To Show Processes



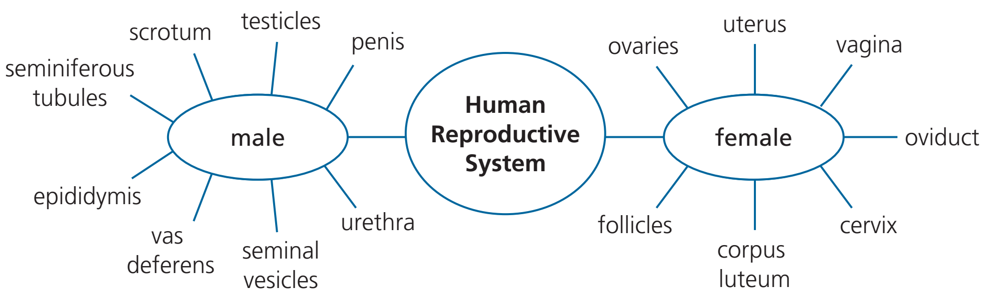
egg and sperm → zygote → embryo → fetus

You can use a **flow chart** to show a sequence of steps or a time line.

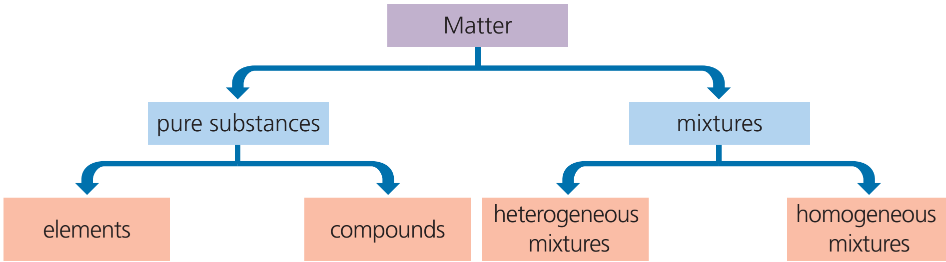


You can use a **cycle map** to show changes of state.

To Organize Ideas and Thinking



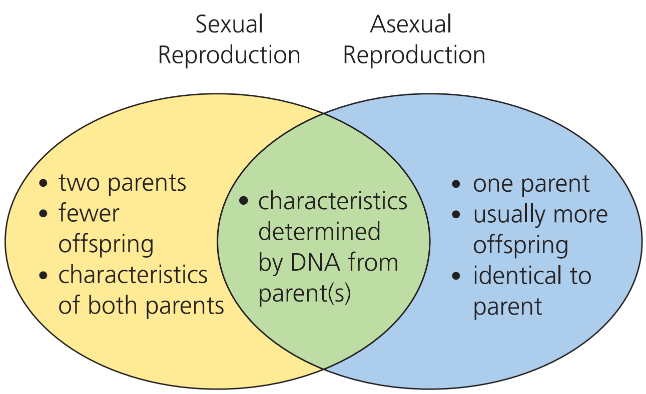
A **concept map** is a collection of words or pictures, or both, that are connected with lines or arrows. You can write on the lines or arrows to explain the connections. You can use a concept map to brainstorm what you already know, to map your thinking, or to summarize what you have learned.



You can use a **tree diagram** to show concepts that can be broken down into smaller categories.

To Compare and Contrast

Comparing Sexual and Asexual Reproduction

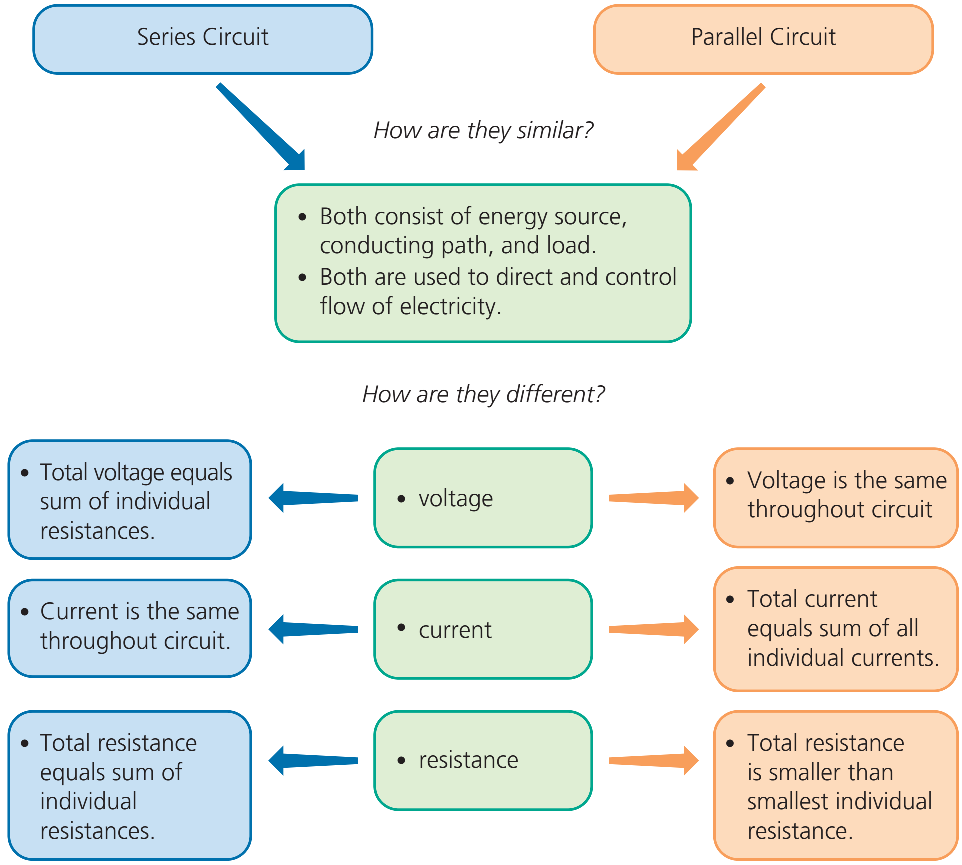


You can use a **Venn diagram** to show similarities and differences. Similarities go in the middle section.

Comparison of the Three States of Matter

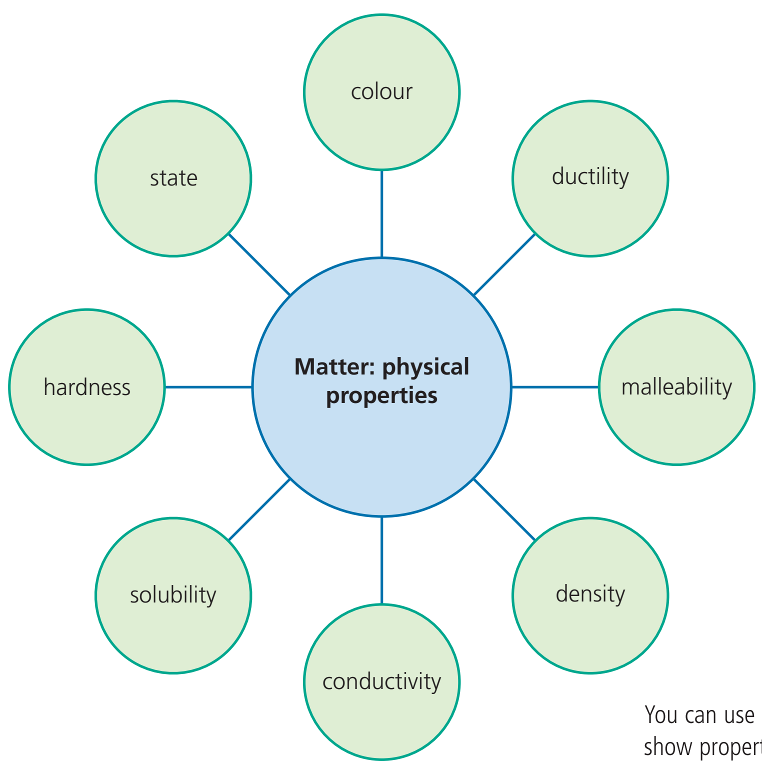
State	Fixed mass?	Fixed volume?	Fixed shape?
solid	✓	✓	✓
liquid	✓	✓	✓
gas	✓		

You can use a **comparison matrix** to record and compare observations or results.



You can use a **compare and contrast chart** to show both similarities and differences.

To Show Properties or Characteristics



You can use a **bubble map** to show properties.

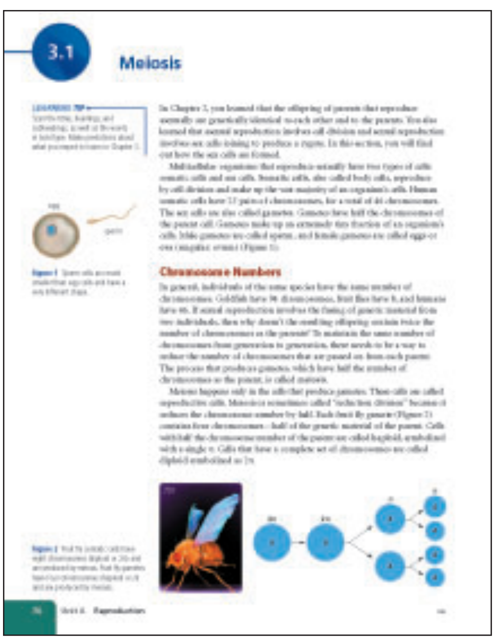
READING STRATEGIES

The skills and strategies that you use to help you read, depend on the type of material you are reading. Reading a science book is different from reading a novel. When you are reading a science book, you are reading for information. Here are some strategies to help you read for information.

Before Reading

Skim the section you are going to read. Look at the illustrations, headings, and subheadings.

- *Preview:* What is this section about? How is it organized?
- *Make connections:* What do I already know about the topic? How is it connected to other topics I have already learned?
- *Predict:* What information will I find in this section? Which parts will give me the most information?
- *Set a purpose:* What questions do I have about the topic?


3.1 Meiosis

Chromosome Numbers

During Reading

Pause and think as you read. Spend time on the photographs, illustrations, tables, and graphs, as well as on the words.

- *Check your understanding:* What are the main ideas in this section? How would I explain them in my own words? What questions do I still have? Do I need to reread? Do I need to read more slowly, or can I read more quickly?
- *Determine the meanings of key science terms:* Can I figure out the meanings of unfamiliar terms from context clues in the words or illustrations? Do I understand the definitions of terms in bold type? Is there something about the structure of a new term that will help me remember its meaning? Are there terms I should look up in the glossary?
- *Make inferences:* What conclusions can I make from what I am reading? Can I make any conclusions by “reading between the lines”?
- *Visualize:* What mental pictures can I make to help me understand and remember what I am reading? Would it help to make a sketch?

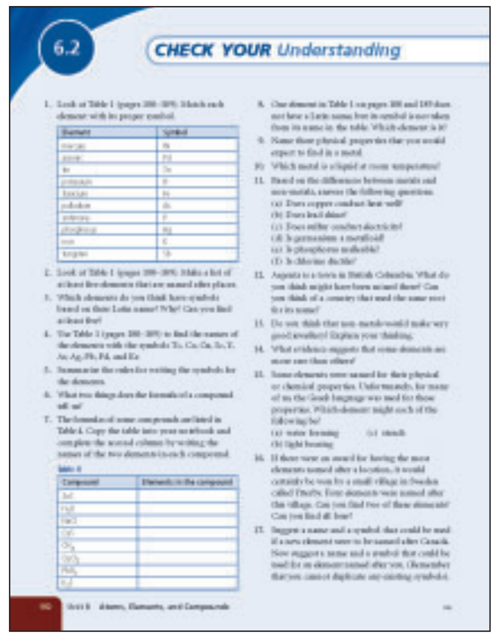

9.1 Types of Electric Charge

- *Make connections:* How is the information in this section like information I already know?
- *Interpret visuals and graphics:* What additional information can I get from the photographs, illustrations, tables, or graphs?


12.3 Our Solar System

Formation of the Solar System

- *React:* What are my opinions about this information? How does it, or might it, affect my life or my community? Do other students agree with my reactions?
- *Evaluate information:* What do I know now that I did not know before? Have any of my ideas changed as a result of what I have read? What questions do I still have?


6.2 CHECK YOUR Understanding

After Reading

Many of the strategies you use during reading can also be used after reading. In this textbook, for example, there are questions to answer after you read. These questions will help you check your understanding and make connections.

- *Locate needed information:* Where can I find the information I need to answer the questions? Under what heading might I find the information? What terms in bold type should I skim for? What details do I need to include in my answers?
- *Synthesize:* How can I organize the information? What graphic organizer could I use? What headings or categories could I use?

RESEARCHING

There is an incredible amount of scientific information that is available to you. Here are some tips to help you gather scientific information efficiently.

Identify the Information You Need

Identify your research topic. Identify the purpose of your research.

Identify what you (or your group) already know about your topic. Also identify what you do not know. Develop a list of key questions that you need to answer. Identify categories based on your key questions. Use these categories to identify key search words.

Find Sources of Information

Identify all the places where you could look for information about your topic. These places might include videotapes of science programs on television, people in your community, print sources (such as books, magazines, and newspapers), and electronic sources (such as CD-ROMs and Internet sites). The sources of information might be in your school, home, or community.

Evaluate the Sources of Information

Preview your sources of information, and decide whether they are useful. Here are four things to consider.

- *Authority:* Who wrote or developed the information or sponsors the Web site? What are the qualifications of this person or group?
- *Accuracy:* Are there any obvious errors or inconsistencies in the information? Does the information agree with other reliable sources?
- *Currency:* Is the information up to date? Has recent scientific information been included?
- *Suitability:* Does the information make sense to someone your age? Do you understand it? Is it organized in a way that you can understand?

Record and Organize the Information

Identify categories or headings for note taking. Use point form to record information, in your own words, under each category or heading. If you quote a source, use quotation marks.

Record the sources to show where you got your information. Include the title, author, publisher, page number, and date. For websites, record the URL (website address).

If necessary, add to your list of questions as you find new information.

Communicate the Information

Choose a format for communication that suits your topic, your audience, your purpose, and the information you found.

INTERNET RESEARCH

The Internet is a vast and constantly growing network of information. There are several ways to search the Internet for documents and web pages. Table 4 lists four main ways.

Table 4 Ways to Search the Internet

Search engine	Meta search engine	Subject gateway (or directory)	E-mail, discussion lists, and databases
searches using keywords that describe the topic you are looking for	enables you to search across many search engines at once	provides an organized list of web pages, divided into subject areas; some gateways are general and have information about many topics	puts you in touch with other people who are interested in your research topic
AltaVista Canada www.altavista.ca Lycos Canada www.lycos.ca Excite www.excite.com Google www.google.ca Go.com www.go.com Yahoo! www.yahoo.com Ask.com www.ask.com MSN Search www.msn.com all the web www.alltheweb.com	MetaCrawler www.metacrawler.com search.com www.search.com Webcrawler www.webcrawler.com KartOO www.kartoo.com Clusty www.clusty.com Dogpile www.dogpile.com SurfWax www.surfwax.com HotBot www.hotbot.com	About.com www.about.com Looksmart www.looksmart.com Yahoo! Search Directory http://dir.yahoo.com Librarian's Index http://lii.org Infomine http://infomine.ucr.edu WWW VirtualLibrary http://vlib.org SciCentral www.scicentral.com open directory project www.dmoz.org	Google Groups http://groups.google.com Yahoo! Groups http://groups.yahoo.com

Search Engines

Search engines are programs that create an index of web pages in the Internet. When you are using a search engine, you are not actually searching the Internet, you are searching through an index. When you type some words into a search engine, it searches through the index to find the web pages that contain the key words. It then lists the pages where these words are found.

Search Results

Once you have done a search, you will be provided with a list of web pages and the number of matches for your search. If your key words are general, you are likely to get a high number of matches and you may need to refine your search. Most search engines provide online help and search tips. Always look at these to find ideas for better searching.

Every web page has a URL (Universal Resource Locator). The URL can sometimes give you a clue about the usefulness of the web page. The URL may tell you the name of the organization, or it may indicate that you are looking at a personal page (often indicated by a ~ symbol in the URL). The URL includes a domain name, which also contains clues about the organization hosting the web page (Table 5). For example, the URL http://weatheroffice.ec.gc.ca/jet_stream/index_e.html is a page that shows a weather map of Canada; "ec.gc.ca" is the domain name for Environment Canada—a fairly reliable source.

Table 5 Some Organization Codes

Code	Organization
ca	Canada
com or co	commercial
edu or ac	educational
org	nonprofit
net	networking provider
mil	military
gov	government
int	international organization

Evaluating the Sources

Since it is so easy to put information on the Internet, anybody can post just about anything without any proof that the information is accurate. There are almost no controls on what people can write and publish on the Internet. Because of this, it is very important for you to evaluate the information that you find on the Internet.

Use the following questions to determine the quality of an Internet resource. The greater the number of questions that can be answered "yes," the more likely it is that the source is of high quality.

- Is it clear who is sponsoring the page? Does the site seem to be permanent or sponsored by a permanent organization?
- Is there information about the sponsoring organization? For example, is a phone number or address given to contact for more information?
- Is it clear who developed and wrote the information? Are the author's qualifications provided?
- Are the sources of factual information given so that they can be checked?
- If information is presented in graphs or tables, are the graphs or tables clearly labelled?
- Is the page presented as a public service? Does it present balanced points of view?
- If there is advertising on the page, is it clearly separated from the content?
- Are there dates to indicate when the page was written, placed online, or last revised? Are there any other indications that the material is updated periodically?
- Is there an indication that the page is complete and not still "under construction"?
- Is it clear whether the entire work or only a portion of the work is available on the Internet?

CREATING DATA TABLES

Data tables are an effective way to record both qualitative and quantitative observations. Making a data table should be one of your first steps when conducting an investigation. You may decide that a data table is enough to communicate your data, or you may decide to use your data to draw a graph. A graph will help you analyze your data.

Sometimes you may use a data table to record your observations in words, as shown in Figure 1.

Charging Materials by Friction

		Rubbing materials					
		paper	wool	cotton	silk	plastic	
Materials to be tested	vinyl						
	acetate						
	glass						
	wood						
	aluminium						

Figure 1

Sometimes you may use a data table to record the values of the independent variable (the cause) and the dependent variables (the effects), as shown in Figure 2. (Remember that there can be more than one dependent variable in an investigation.)

Follow these guidelines to make a data table:

- Use a ruler to make your table.
- Write a title that describes your data as precisely as possible.
- Include the units of measurement for each variable, when appropriate.
- List the values of the independent variable in the left-hand column of your table.
- List the values of the dependent variable(s) in the column(s) to the right of the column for the independent variable.

Average Monthly Temperatures in Cities A and B

Month	Temperature (°C) in City A	Temperature (°C) in City B
January	−7	−6
February	−6	−6
March	−1	−2
April	6	4
May	12	9
June	17	15

Figure 2

GRAPHING DATA

We organize the data collected from investigations so that we can identify a **trend** or pattern in the data, which will indicate a relationship between the data. Trends or patterns in data are usually easier to see if you graph the data. A graph is a visual representation of numerical or quantitative data. There are many types of graphs that you can use to organize your data. Three of the most useful kinds of graphs are bar graphs, circle graphs, and point-and-line graphs. Each kind of graph has its own special uses. You need to identify which type of graph is most appropriate for your data before you graph your data.

Bar Graphs

When at least one of the variables is qualitative, use a bar graph to organize your data (Table 1 and Figure 3). For example, a bar graph is a good way to present the data collected from a study of the number of births (quantitative) during each month of the year (qualitative). Each bar represents a different category, such as the month of the year. In this type of bar graph, the qualitative data is usually placed on the *x*-axis and the quantitative data is placed on the *y*-axis, so that differences among the numbers of births per month are more easily observed.

Table 1 Births per Month in 2006

Month	Number of births
January	2037
February	1863
March	1597
April	1698
May	1436
June	1752
July	1648
August	1871
September	2283
October	2562
November	2749
December	2624

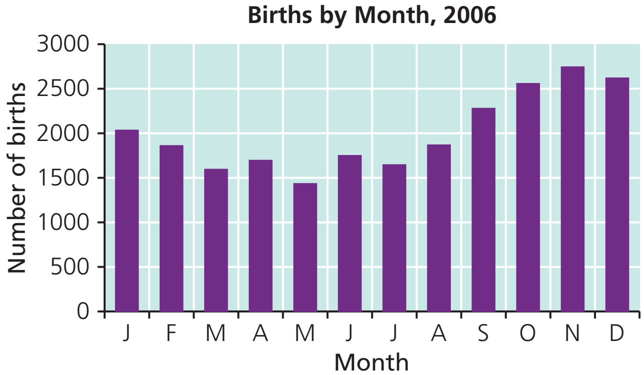


Figure 3 A bar graph clearly shows a trend in the data.

Circle Graphs

Circle graphs and bar graphs are used for similar types of data. If your quantitative variable can be changed to a percentage of the total quantity, then a circle graph is useful. A circle graph (sometimes called a pie graph) can show the whole of something divided into all its parts. For example, a circle graph can show a typical 28-day menstrual cycle in human females (Figure 4).

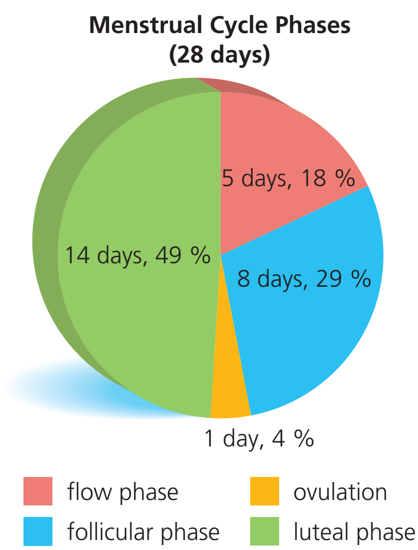


Figure 4 The circle graph shows the components of the whole.

Point-and-Line Graphs

When both variables in the data are quantitative, use a point-and-line graph. For example, we can use the following guidelines and the data in Table 2 to construct the point-and-line graph in Figure 5.

Table 2 Wire Diameter and Resistance

Wire Diameter (mm)	Resistance in 1000 m (ohms)
0.5	84.2
0.6	53.7
0.8	33.2
1	21.9
1.3	13.2
1.6	8.9
2.1	5.3
2.5	3.3

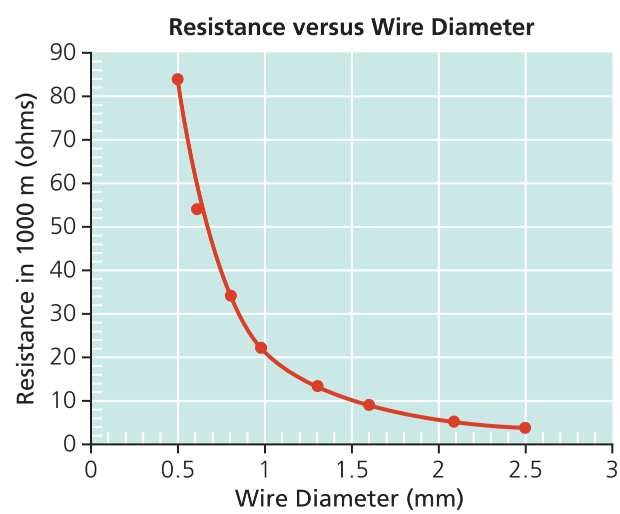


Figure 5 A line graph shows points formed by sets of quantitative data.

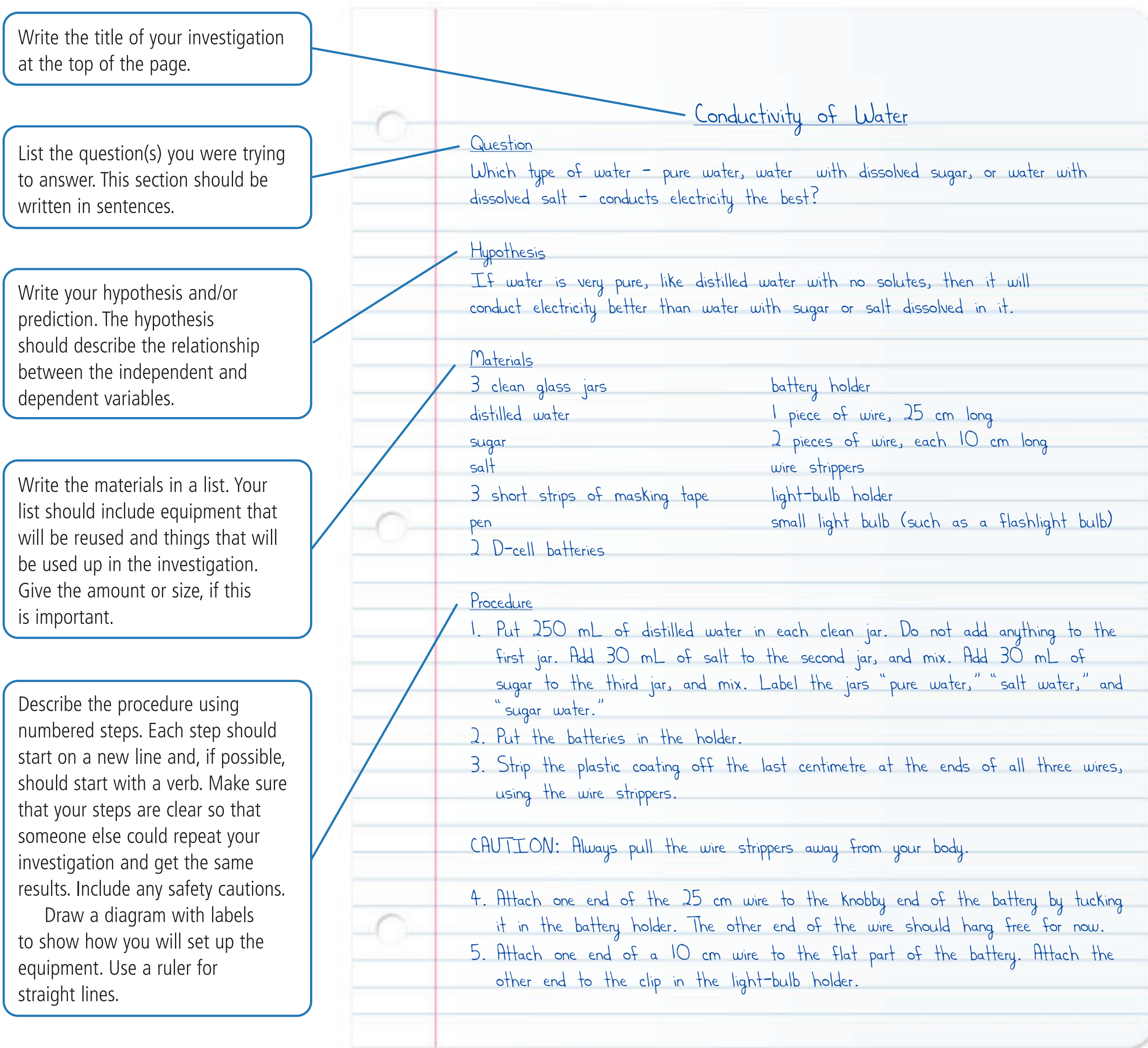
Making Point-and-Line Graphs

1. Use grid paper to construct your graph. Use the horizontal edge on the bottom of the grid as the *x*-axis and the vertical edge on the left as the *y*-axis. The larger the graph is, the easier it is to read and interpret.
2. Decide which variable goes on which axis. Label each axis, including the units of measurement. The independent variable is generally plotted along the *x*-axis, and the dependent variable is plotted along the *y*-axis. The exception is when you plot a variable against time. Regardless of which variable is the independent variable, always plot time on the *x*-axis. This convention ensures that the slope of the graph always represents a rate.
3. Title your graph. The title should be a short, accurate description of the data represented by the graph.
4. Determine the range of values for each variable. The range is the difference between the largest and smallest values. Graphs often include a little extra length on each axis, to make the axes less cramped. For example, the wire diameter in Table 2 ranges from 0.5 mm to 2.5 mm, but the *x*-axis in the graph in Figure 5 ranges from 0 to 3.0 mm.
5. Choose a scale for each axis. The scale will depend on how much space you have and the range of values for each axis. Each line on the grid usually increases steadily in value by equal increments, such as 1, 2, 5, 10, 50, or 100. In Figure 5, one line is used for every 0.5 mm in the *x*-axis, and for every 10 Ω on the *y*-axis.
6. Plot the points. Start with the first pair of values, which may or may not be at the origin of the graph. The origin of the graph is the point at which the *x*-axis and *y*-axis intersect. In the graph in Figure 5, the first set of points is 0.5 on the *x*-axis and 84.2 on the *y*-axis.
7. After all the points are plotted, draw a line through the points to show the relationship between the variables, if possible. Not all points may lie exactly on a line; small errors in each measurement may have occurred and moved the points away from the perfect line. Draw the **line of best fit**—a smooth line that passes through or between the points so that there are about the same number of points on each side of the line. The line of best fit, which may be a straight or curved line, attempts to minimize the effect of random measurement errors.
8. If you are plotting more than one set of data on the same graph, use different colours or symbols to indicate the different sets and include a legend.

You can use a point-and-line graph to make predictions. For example, you can use the graph in Figure 5 to predict that, if the diameter of the wire is 1.5 mm, then the resistance of the wire will be about 10 Ω. Predicting values that lie between known values is called **interpolation**. You can also predict outside the plotted values. From the graph in Figure 5 you can predict that, if the diameter of the wire is 3.0 mm, then the resistance of the wire will be about 2 Ω. Predicting values that lie outside known values is called **extrapolation**. You should be careful when extrapolating. The farther you are from the known values plotted on the graph, the less reliable your prediction will be.

WRITING A LAB REPORT

When you design and conduct your own investigation, it is important to report your findings. Other people may want to repeat your investigation, or they may want to use or apply your findings in another situation. Your write-up, or report, should reflect the process of scientific inquiry that you used in your investigation (Figure 7).



Conductivity of Water

Question

Which type of water – pure water, water with dissolved sugar, or water with dissolved salt – conducts electricity the best?

Hypothesis

If water is very pure, like distilled water with no solutes, then it will conduct electricity better than water with sugar or salt dissolved in it.

Materials

3 clean glass jars
distilled water
sugar
salt
3 short strips of masking tape
pen
2 D-cell batteries
battery holder
1 piece of wire, 25 cm long
2 pieces of wire, each 10 cm long
wire strippers
light-bulb holder
small light bulb (such as a flashlight bulb)

Procedure

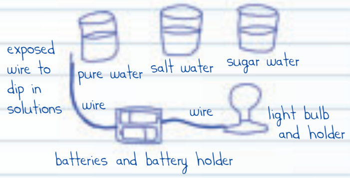
1. Put 250 mL of distilled water in each clean jar. Do not add anything to the first jar. Add 30 mL of salt to the second jar, and mix. Add 30 mL of sugar to the third jar, and mix. Label the jars "pure water," "salt water," and "sugar water."
2. Put the batteries in the holder.
3. Strip the plastic coating off the last centimetre at the ends of all three wires, using the wire strippers.

CAUTION: Always pull the wire strippers away from your body.

4. Attach one end of the 25 cm wire to the knobby end of the battery by tucking it in the battery holder. The other end of the wire should hang free for now.
5. Attach one end of a 10 cm wire to the flat part of the battery. Attach the other end to the clip in the light-bulb holder.

Figure 7

6. Place the light bulb in the holder.
7. Attach one end of the other 10 cm wire to the clip in the light-bulb holder. Let the other end hang free for now.
8. Dip the loose wire ends into the distilled water. Observe whether the light bulb goes on. Record "yes" or "no."
9. Repeat step 8 for the other two types of water.



Data and Observations

Type of water	Does the light bulb go on?
distilled water	no
water with salt	yes
water with sugar	no

> Present your observations in a form that is easily understood. The data should be recorded in one or more tables, with any units included. Qualitative observations can be recorded in words, drawings, or pictures. Observations in words can be in point form.

Analysis

(a) The salt water was the only type of water that turned on the light bulb. Something in the salt must help to conduct electricity. Since the distilled water did not turn on the light bulb, this must mean that it cannot conduct electricity.

(b) Something is missing from the distilled water. The sugar water did not conduct electricity either, so it must also be missing the ingredient that helps to conduct electricity.

> Interpret and analyze your results. If you have made graphs, include and explain them here. Answer any questions in the textbook.

Evaluation

(c) Pure (distilled) water does not conduct electricity. The hypothesis is not supported by the data, so it is incorrect. Salt water conducts electricity.

> Answer any Evaluation questions in the textbook. These questions will help you evaluate both the evidence you collected and the design of the investigation.

Synthesis

(d) Knowing that salt water conducts electricity might help scientists recover materials from seawater by running electricity through it. Also, I think the water in the human body has salt and other things dissolved in it. It would conduct electricity well, so people should be careful about electricity.

> Answer any Synthesis questions in the textbook. These questions will help you determine how the new information you gained from doing your investigation relates to real-life situations. How can this information be used? What other related investigations could be conducted?

WRITING FOR SPECIFIC AUDIENCES

In the working world, both individuals and companies often need detailed information on a particular topic to help them make informed decisions. In preparing to write your report, consider the purpose of your report. Are you presenting facts, presenting choices to your readers, or trying to change readers to your way of thinking? You should know your audience.

Research Reports

The purpose of a research report is to present factual information in an unbiased way. Your readers must be able to understand, without being talked down to. Be sure to include a complete list of your sources.

Issue Reports

Decisions are rarely based only on facts. When preparing an issue report, consider the issue from many points of view. Issues are controversial because there are various points of view. Try to consider and address as many points of view as possible.

Position Papers

When planning a position paper, you may

- start with a position on the issue, and then conduct research to support your position
- start by researching the issue, and then decide on your position based on your research

Once you have taken a position, support your arguments with evidence, reasoning, and logic.

Letters to the Editor

A letter to the editor of a newspaper or magazine is typically a shorter version of a position paper. Space is limited, so express your thoughts as briefly as possible. You do not have to support every point in your argument with scientific facts, but indicate that such support is available.

Magazine Articles

Magazine articles are usually written in response to a request from the editor. The editor will tell you how long the article should be, so there is no point in writing more than you are asked for. As you write the article, try to stick to factual information. You must be prepared to support your statements if you are challenged, maybe by letters to the editor.

Environmental Impact Reports

Environmental impact reports are a relatively new type of report. Until recently, the environment was not a consideration when developments or actions were planned. Today we must consider, study, and explain the possible results of any intended action.

Carrying out an environmental impact assessment begins with a listing of existing species, both plant and animal. If a similar development has taken place elsewhere, you may want to observe what is happening there. You may want to find out what experts think. All this information must then be brought together and presented in a report.

There is no single format for an environmental impact report. The following sections, however, should be included:

- an introduction stating what the report will contain
- a description of how data were collected
- an analysis of the data
- conclusions
- possible long-term results
- suggestions for further study to be conducted before a decision is made

ORAL PRESENTATIONS

You may be asked to make an oral presentation to debate an issue, role-play a situation, or present the results of an investigation. In an oral presentation, you are communicating with others using mainly your voice.

If you find this method of communication stressful, the following tips will help to reduce or eliminate your stress, improve your presentation, and effectively deliver your message to the audience:

- Plan your oral presentation well in advance. Waiting until the last minute increases stress dramatically.
- Find out how much time you are being given for your presentation.
- Write the key points of your presentation on cue cards or in a computer slide show.

- Practise your presentation to make sure that it fits into the allowed time.
- When you are giving the presentation, speak clearly and make eye contact with your audience.

Debating

A debate is essentially an organized argument. One group takes a position on an issue, while another group takes a different position. Each group tries to win the audience over to its way of thinking. The following suggestions may be helpful if you are taking part in a debate:

- Research the issue thoroughly. Make notes as you go.
- Pick four or five major points, with examples, to support your position. Write them out in point form.
- Present your argument logically and clearly, and within the allowed time period.
- Listen closely to the arguments presented by those who have taken the opposite position. Make notes on any points that you feel you can argue against in your rebuttal.
- At all times, show respect for the opposition. While you can question their evidence, never resort to name-calling or rudeness.

If you are expected to vote on the issue at the end of the debate, you need to evaluate the debate. The following questions may help you:

- Which group seemed more knowledgeable about the issue?
- Which group presented the best evidence to support its position?
- Which group had the strongest arguments?
- Which group was better organized and had the better presentation?
- Were the arguments of one group persuasive enough to change your opinion on the issue?

Role-Playing

Role-playing is simply a variation of debating, in which you are expected to take on the role of a "character." You then present an opinion, position, or decision from the point of view of this character. You are asked to deliver a speech to provide information on the issue and to convince the audience that your position or recommendation should be followed. Follow these guidelines as you prepare for and present your point of view:

- Research both your topic and your assigned or chosen character. Your arguments must appear to be those of your character.
- Include personal examples from your character's life to support the position you are taking and to make the experience realistic.
- In making your presentation, stay "in character." Use "I" and "my" to convince your audience that you are indeed the character you are portraying.
- Relax and have some fun with your presentation.
- After the role-play, spend some time thinking about and discussing your experience. How did you feel and think during the role-play? Discuss the positive and negative aspects of the experience.

It is always valuable to switch roles and have a second round of role-playing. This will help you appreciate other points of view.

Presenting Results

This is a very factual type of oral presentation. It must be clear and to the point.

Your presentation should include answers to the following questions:

- What was the reason for doing the investigation?
- What question were you trying to answer?
- What was your prediction or hypothesis?
- How did you carry out your investigation?
- What were your results?
- Were there any problems or other sources of error that might cause you to question your results?
- What conclusion did you reach?
- On the basis of your results, is there another investigation that could be done?

ELECTRONIC COMMUNICATION

Electronic communication is being used more often to communicate effectively with a wide audience. To create an effective electronic presentation, follow these guidelines:

- Be sure to have definite purpose that you can state in your own words.
- Know who your audience is.
- Begin by identifying your main goals, and include them in both your introduction and conclusion.
- Create a flow chart for your presentation (Figure 8). Remember to present only content that your audience will see as useful. Be sure to make the links between what you are presenting and how the audience will be able to use it.

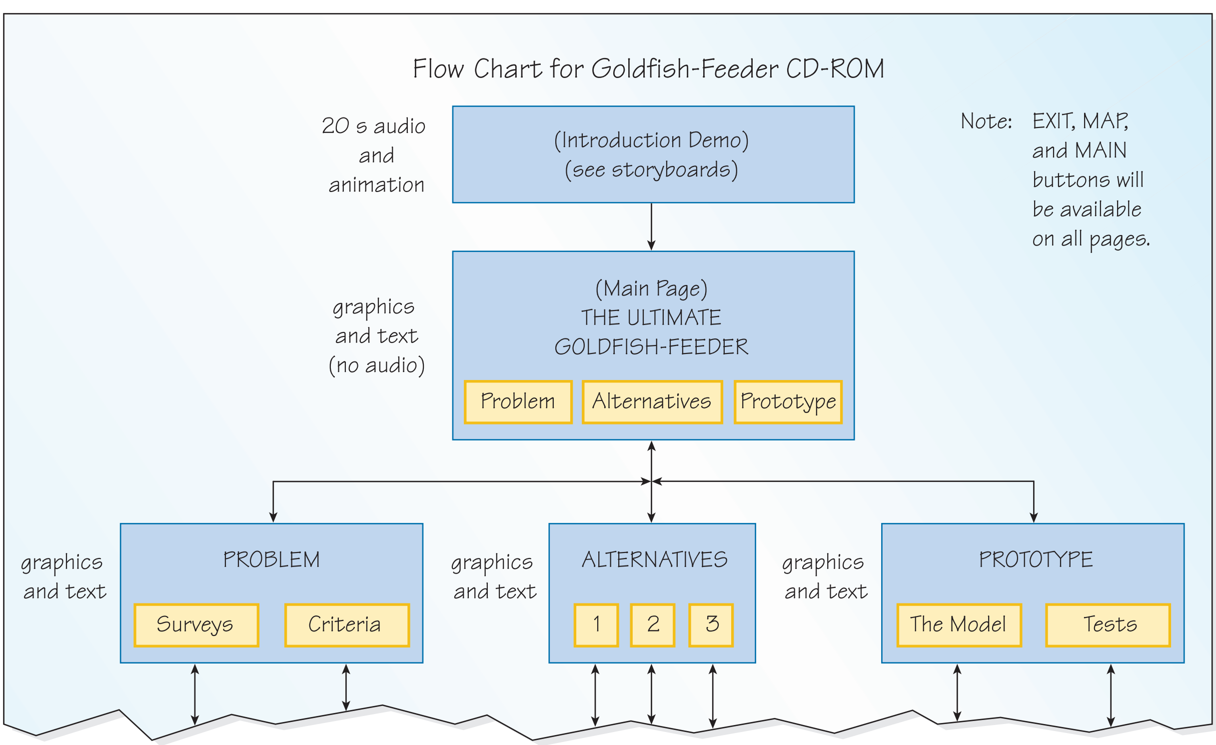


Figure 8

- Draw storyboards for your presentation (Figure 9). Be sure to consider all media. What is the audience going to see and hear at any given moment?
- Choose special effects that make your presentation more memorable, and clarify the information that you are presenting.

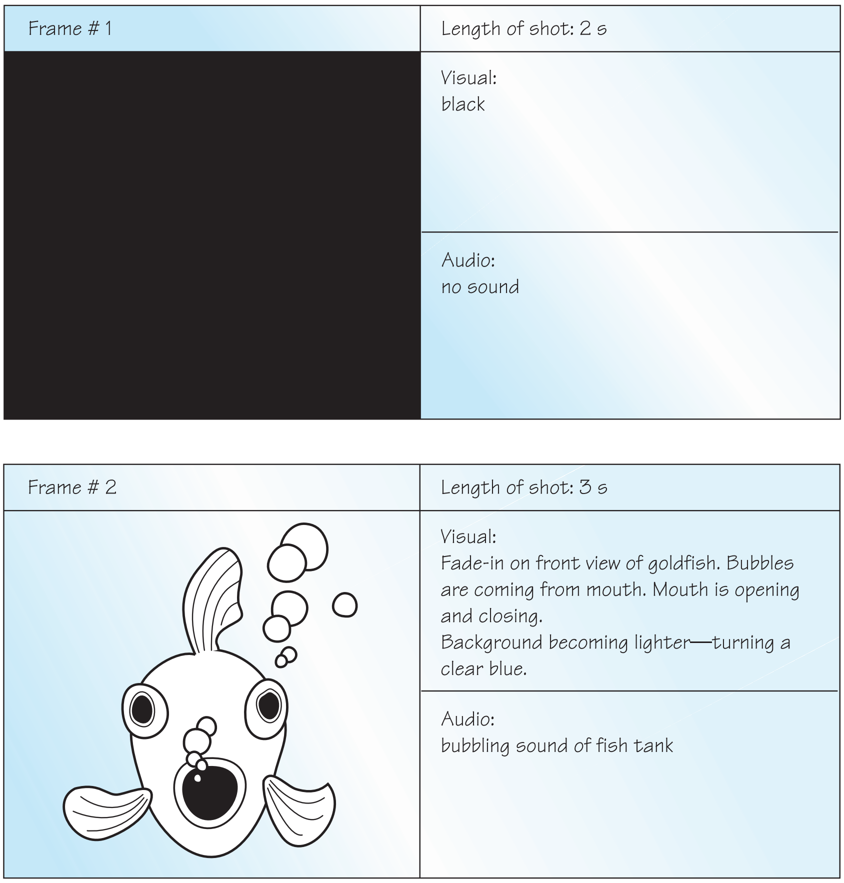


Figure 9

Creating a Presentation Using Overheads

Several software programs (such as Microsoft PowerPoint) allow you to create a series of slides that can be projected onto a screen. You can even add sound, music, or your recorded voice to the presentation. These guidelines may help you prepare a slide presentation:

- Use a storyboard to write your slides as point-form notes.
- Limit yourself to no more than 10 lines of text on each slide.
- Use a font that is large enough to be read by the audience.

Creating a Web Page

A web page is a way to communicate with anyone in the world who has access to the World Wide Web. Every page has its own unique address (URL) and may include graphics, sound, animation, and video clips, as well as links to other web pages. If you think that a web page presentation would be of benefit to others, ask your teacher for help creating one, or visit the Nelson web site.

www.science.nelson.com GO

WORKING TOGETHER

Teamwork is just as important in science as it is on the playing field or in the gym. Scientific investigations are almost always carried out by teams of people working together. Ideas are shared, experiments are designed, data are analyzed, and results are evaluated and shared with other investigators. Group work is necessary and is usually more productive than working alone.

Several times throughout the year, you may be asked to work with one or more of your classmates. Whatever the task that your group is assigned, you need to follow a few rules to ensure a productive and successful experience.

General Rules for Effective Teamwork

- Keep an open mind. Everyone's ideas deserve consideration.
- Divide the task among all the group members. Choose a role that is best suited to your particular strengths.
- Work together and take turns. Encourage, listen, clarify, help, and trust one another.

Investigations and Try This Activities

This kind of work is most effective when done by small groups. Here are some more suggestions for effective group performance during investigations and activities:

- Make sure that each group member understands and agrees to the role assigned to him or her.
- Take turns doing the work during similar and repeated activities.
- Safety must come first. Be aware of where other group members are and what they are doing.
- Take responsibility for your own learning. Make your own observations and compare them with the observations of other group members.

Explore an Issue

When there is research to be done, follow these guidelines:

- Divide the topic into several areas, and assign one area to each group member.
- Keep records of the sources used by each group member.
- Decide on a format for exchanging information (for example, photocopies of notes or, oral discussion).
- When the time comes to make a decision and take a position on an issue, allow for the contributions of each group member. Make decisions by compromise and consensus.
- Communicating your position should also be a group effort.

PRACTICE

Your group is stranded in the middle of nowhere, the result of a breakdown in the public transportation you were using in a wilderness area of the province. It will be five days before you are missed and searchers come looking for you.

You have gathered your combined resources from your luggage. As a group, review the following list of items and choose the five items that you feel are essential for survival over the five days. The final decision on the items should be reached by consensus.

Share your decision with the rest of the class.

flashlight and 4 batteries	4 hats	12 chocolate bars
box of matches	groundsheet	6 cans of beans
fruit (4 days' supply)	knife	pen, pencil, and paper
map of area	rope	calculator
water	books	chewing gum
Monopoly game	compass	first-aid kit
can opener	comic books	laptop computer

Evaluating Teamwork

After you've completed a task with your group, evaluate your team's effectiveness—strengths and weaknesses, opportunities, and challenges. Answer the following questions:

- What were the strengths of your teamwork?
- What were the weaknesses of your teamwork?
- What opportunities were provided by working with your group?
- What challenges did you see with respect to your teamwork?

SETTING GOALS AND MONITORING PROGRESS

Think back to the time you spent in school last year. What classes did you really do well in? Why do you think you were successful? What classes did you have some difficulty with? Why do you think you had difficulty? What could you do differently this year to improve your performance?

By answering these questions, you are reflecting on your past behaviour in an attempt to make positive changes. The things that you want to accomplish today, this week, and this year are all called **goals**. Learning to set goals and to make a plan to achieve them takes skill and practice.

Setting Goals

Assess Your Strengths and Weaknesses

The process of setting goals starts with honest reflection. Maybe you have noticed that you do better on projects than you do on tests and exams. You may perform better when you are not pressured by time. Inattention in class and poor study habits may be weaknesses that result in poor performance.

Set Realistic Goals That You Can Measure

Do not set yourself up to fail by setting goals that you cannot possibly achieve. "I will have the best mark in the class at the end of the semester" may not be realistic. Setting a goal "to increase my test marks by 10 % this semester" may be achievable, however. You will find it easier to reach your goals if you can tell whether you are getting closer to them. A goal "to increase my test marks by 10% this semester" is a goal that is easy to measure.

Share Your Goals

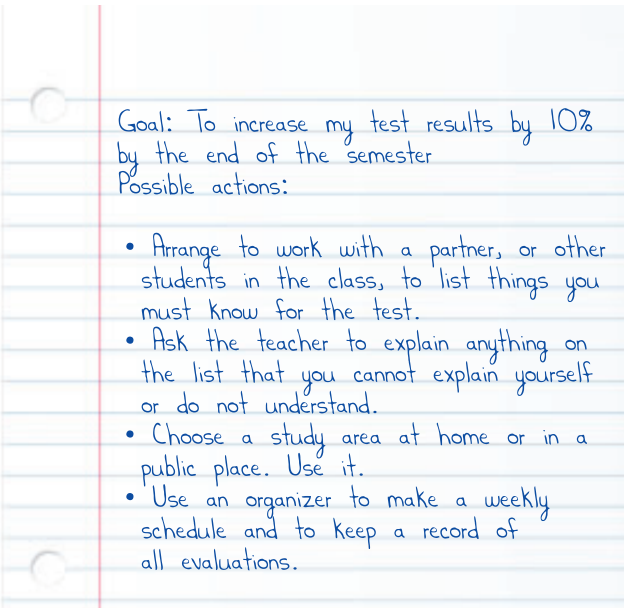
People who know you can often help you set and clarify goals. Someone who knows your strengths and weaknesses may be able to think of possibilities you haven't considered. Sharing your goals with a trusted friend or adult will often provide needed support to help you reach your goals.

Planning to Meet Your Goals

Once you have made a list of realistic goals, create a plan to achieve them. A successful plan usually consists of two parts: an action plan and target dates.

The Action Plan

First, make a list of the actions or behaviours that might help you reach your goals (Figure 1).


Goal: To increase my test results by 10% by the end of the semester

Possible actions:

- Arrange to work with a partner, or other students in the class, to list things you must know for the test.
- Ask the teacher to explain anything on the list that you cannot explain yourself or do not understand.
- Choose a study area at home or in a public place. Use it.
- Use an organizer to make a weekly schedule and to keep a record of all evaluations.

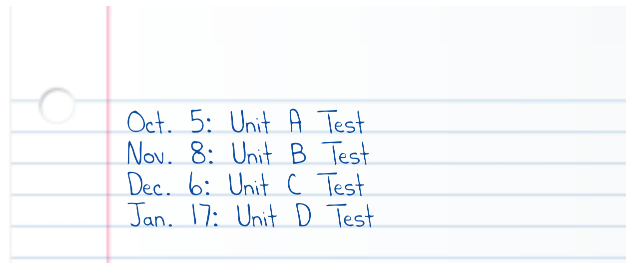
Figure 1

If you have made an honest assessment of your strengths and weaknesses, then you know what you have to do to improve. If you want to improve your test marks, you could try to work with others to prepare for tests. You could also use a weekly planner or organize your study area at home. Identify what is preventing you from achieving your goal. Plan ways to overcome these obstacles.

Setting Target Dates

If you want to improve test results by 10 % by the end of the semester, how much time do you have? How many tests are scheduled between now and then?

Work back from your target date at the end of the semester. Determine the dates of all the tests between now and the end of the semester. These dates will give you short-term targets that, if you hit them, will make it easier for you to hit your overall target. A working schedule appears in Figure 2.


Oct. 5: Unit A Test

Nov. 8: Unit B Test

Dec. 6: Unit C Test

Jan. 17: Unit D Test

Figure 2

Once you have completed your schedule in your planner, transfer it to a calendar in your study area. Refer to either your planner or your calendar every day.

Monitoring Progress

Do not wait until your final target date to determine whether you have achieved your goal. It is important to measure your progress along the way. You might decide, for example, to check your progress after the first test. Did your test result show a 10 % increase?

If the 10 % increase was not achieved, you may need to change your plan. For example, maybe the friends you're "studying" with are spending more time talking than identifying what needs to be learned. It is always possible to change your plan or even adjust your goal. The most important thing is to keep moving forward and to remain committed to improvement.

GOOD STUDY HABITS

Studying takes many forms. Developing good study skills can help you study and learn.

Your Study Space

- *Organize your work area:* The place where you study should be tidy and organized. Papers, books, magazines, and pictures all over your work area may distract you from the work you have to do.
- *Maintain a quiet work area:* Where possible, make sure that your work area is free from distractions—telephone, music, television, other family members. If there are too many distractions at home, you can usually find an appropriate space at the school or public library. Any quiet space, free from interruptions, can be a productive work area.
- *Make sure that you are comfortable in your work area:* If possible, personalize your work area. You will be the most productive when you work in an area where you feel at ease.
- *Be prepared—bring everything you need:* It is important to have all the necessary materials and equipment that you will need when you begin to study. If you find yourself continually getting up to find something you need, your productivity will decrease.

Study Habits

- *Take notes:* Take notes during class. Outside class, review the appropriate section of the textbook. Read or view additional material on the topic from other sources, such as newspapers, magazines, the Internet, and television.
- *Use graphic organizers:* You can use a variety of graphic organizers to help you summarize a concept or unit. (See "Using Graphic Organizers", on page 544.)
- *Schedule your study time:* Use a daily planner, and take it with you to class. Write any homework assignments, tests, or projects in it. Use it to create a daily "to do" list. This will help you complete work to hand in and avoid last-minute panic, the most ineffective way to study.
- *Take study breaks:* It is important to schedule breaks into your study time. For example, you could decide to take a study break after completing one or two items on your "to do" list.

Glossary

A

absolute magnitude refers to the actual amount of light a star gives off, recorded at a standard distance

alkali metal an element found in the first column of the Periodic Table, Group 1, with the exception of hydrogen: lithium, sodium, potassium, rubidium, cesium, and francium; each has an ion charge of 1+

alkaline earth metal an element found in the second column of the Periodic Table, Group 2: beryllium, magnesium, calcium, strontium, barium, and radium; each has an ion charge of 2+

allele [uh-LEEL] different form of the same gene

alternating current (AC) an electric current that periodically reverses its direction

amino acid small molecules that make up proteins; there are 20 different amino acids

ammeter an instrument that measures electric current in amperes or milliamperes

amniocentesis [AM-nee-oh-sen-TEE-sis] a procedure in which cells from the fetus are removed from the amniotic fluid to produce a karyotype of the fetus

amniotic fluid fluid that supports, protects, and maintains a warm environment for the fetus until birth

ampere (A) [AM-peer] the SI unit for measuring electric current

anaphase the third stage of mitosis

anther the part of the stamen that produces pollen

antimatter matter with its electrical charge reversed; for example, an antiproton has a negative charge

aphelion [ap-HEE-lee-uhn] the point at which Earth is farthest from the Sun; occurs around July 4

apparent magnitude the brightness of a star as it appears in the night sky

artificial insemination a procedure that involves introducing sperm into the reproductive tract of the female by a method other than sexual intercourse

asexual reproduction one parent produces offspring that are genetically identical to the parent

asteroid rocky and metallic object that revolves around the Sun but is too small to be called a planet; sometimes called minor planets, most are settled in the asteroid belt

astrolabe a historical instrument used by astronomers to determine the distance to stars; also used as a navigation tool

astronomer a scientist who studies astronomy; different astronomers study different aspects of astronomy

astronomical unit defined as the distance from Earth to the Sun, 150 million kilometres

astronomy the branch of science that involves observations and explanations of events and objects that occur beyond Earth and its atmosphere

atom the smallest piece of any element

atomic mass the average mass of all of the naturally-occurring isotopes of an element

atomic number the number of protons in the nucleus of an atom; used to identify the element

B

barred-spiral galaxy a galaxy that has a well-defined bar of stars running through its middle; if it is tightly wound, it is classified as SBa; if it is loosely wound, it is classified as SBc.

baseline an imaginary line from which the distance to an object is measured; the length of the baseline is known

battery a combination of two or more electric cells

benign tumour a mass of cells that grows but stays in one place and usually does not interfere with the normal functioning of the surrounding tissue or organ

bias the influence of emotional or personal values on the scientific process and the analysis of data

Big Bang theory the current theory that describes the beginning of the universe; at time zero, all the matter and energy in the universe were packed together into one immeasurably dense, hot mass, and exploded

Big Splash theory the current theory that explains the formation of the Moon; it states that, approximately 4.5 billion years ago, the Moon was formed as a result of an object approximately the size of Mars colliding with Earth, causing less dense portions to be blasted into space

binary fission a form of asexual reproduction used by single-celled organisms to produce two genetically identical daughter cells

black hole the end stage of a star, after a supernova; the core is so dense that not even light can escape

Bohr diagram a diagram used to help us to visualize the arrangement of electrons in an atom; drawn as a series of concentric rings (the shells) around a nucleus with electrons as dots on the rings

boiling point the temperature at which a liquid changes to a gas

budding a type of asexual reproduction in which the offspring begins as a small growth (called a bud) on the parent

C

cancer a disease in which cells divide very rapidly and uncontrollably; caused by a mutation in the genes that control cell division

carcinogen any substance that can cause cancer

celestial equator a circle on the celestial sphere; the extension of Earth's equator projected into the universe

celestial sphere an imaginary rotating sphere upon which lie the all the objects in the universe

cell cycle the sequence of events in the cell from one cell division to another; includes interphase and cell division

centrioles organelles made of special microtubules; they are active during cell division in most animal cells

cervix [SUHR-vicks] the muscular opening between the uterus and the vagina

charging by conduction transferring an electric charge from one object to another by touching the objects together (direct contact)

charging by friction transferring an electric charge from one object to another by a rubbing action

charging by induction transferring an electric charge from one object to another by bringing a charged object close to, without touching, another object (no direct contact)

chemical change a reaction in which a substance changes into one or more new substances with different properties

chemical family a group of elements that has similar properties and will form compounds with similar properties; can also be described as a column or numbered Group in the Periodic Table

chemical formula for any compound, a set of chemical symbols and numbers that identifies the elements it contains and the ratios in which the elements occur

chemical property describes the behaviour of a substance as it changes into a new substance

chromosphere a layer of somewhat thinner gases at 60 000 °C that make up the inner atmosphere of the Sun; lies outside of the photosphere

circuit diagram a diagram that uses a set of standard symbols to represent the components in an electric circuit

circumpolar refers to constellations around the pole; refers to constellations that never disappear below the horizon as Earth rotates

clone an offspring of asexual reproduction; genetically identical to the parent and to other offspring produced asexually by the parent

comet chunk of frozen matter that orbits the Sun in very long elliptical paths; some visit the Sun once; come from the Oort cloud and the Kuiper belt

compound a pure substance consisting of two or more elements in definite proportions that cannot be separated by physical means; consists of only one type of particle

conductivity the ability of a material to conduct electricity or heat

conductor a material in which the electrons are free to travel to a neighbouring atom; metals are good conductors

conjugation a type of sexual reproduction in which two unicellular organisms transfer or exchange some of their genetic material

constellation a group of stars that form a pattern

control setup that acts as a standard or reference with which results from an experiment can be compared

controlled experiment scientific inquiry that involves an experiment where the variables are controlled

controlled variable variable that is kept constant or unchanged during an experiment

convective zone the layer of the Sun above the radiative zone; has a temperature of 2×10^5 °C and a radius of 2×10^6 km

conventional current the flow of positive charges in a circuit, which is opposite in direction to the flow of electron: from the positive terminal to the negative terminal of the energy source

core the energy-producing centre of the Sun; has a temperature of 1.5×10^7 °C and a radius of 1.75×10^5 km

corona the Sun's outer atmosphere, consisting of thin gases at a temperature of 2×10^6 °C

corpus luteum the empty follicle after an egg has been released from the ovary

correlational study scientific inquiry that indicates a relationship between variables without purposefully changing or controlling any of the variables

corrosion the slow reaction of certain metals with oxygen to form metal oxides

cotyledon [KOT-uh-LEE-dun] seed leaf found inside a seed

coulomb (C) [KOO-loam] a measurement of the quantity of electrical charge; the amount of electricity transported by a current of one ampere flowing for one second; one coulomb of charge is equal to 6.28×10^{-18} electrons

current electricity the controlled flow of electric charges in a circuit

cytokinesis [SI-toe-kin-EE-sis] the process that divides the cytoplasm and the rest of the organelles in half during cell division; it usually begins before mitosis is finished

D

dark energy thought to be a stabilizing force in the universe; based on the idea that the universe contains energy in empty space. This energy, part of space itself, is increasing—not slowing down—the expansion of the universe.

dark matter theorized to be some form of elementary particle yet to be discovered; responsible for the gravity needed to hold the galaxies together; behaves like normal matter

daughter cell one of two genetically identical cells produced when a parent cell divides

density the mass per unit volume of a substance; a constant property of a substance no matter how much of it is present

dependent variable variable that changes in response to the change in the independent variable

differentiation the process of growing from unspecialized cells into many different specialized cells

diploid describes a cell that has a complete set of chromosomes; symbolized by $2n$

direct current (DC) an electric current that flows in one direction only through an electric circuit

discharge to remove all excess static electric charge so that the object is neutral

discovery observations of the natural world that lead to new knowledge

diversity the variety within and among different species

DNA (deoxyribonucleic acid) a long molecule that provides instructions for making, running, and repairing a cell; made of sugar, phosphate, and nitrogenous base molecules

dominant allele an allele that will express its trait (the trait will show up in a person's appearance) if it is present in the cell

Down syndrome a common disorder that results from a zygote with 47 chromosomes; Down syndrome individuals have three copies of chromosome 21

Drake equation an equation used to estimate the number of planets in our galaxy that can harbour intelligent, technological civilizations; $N = N^* \times f_p \times n_e \times f_l \times f_i \times f_c \times f_L$.

ductile capable of being pulled or "drawn" into wires

E

egg a female gamete; a structure produced by some terrestrial animals to protect the developing embryo

electric current a flow of electric charges though an electric circuit; measured in amperes; the symbol is I

electric force the force exerted on an object with an electric charge; can be a force of attraction or a force of repulsion

electromagnetic (EM) spectrum the classification of the different forms of energy and radiation produced; the energy emitted from matter

electron a negatively charged particle that orbits the nucleus of an atom

electron flow the direction that electrons move in an electric circuit: from the negative terminal to the positive terminal of the energy source

electron transfer the process of transferring electrons between metals and non-metals to create an ionic bond; can occur in a collision between metal and non-metal atoms

electrostatics the study of static electric charge

element a pure substance that cannot be changed into anything simpler; contains only one kind of particle

elliptical galaxy galaxy classification; a galaxy that is elliptical or oval in shape; the roundest of the elliptical galaxies are classified as E0, the most elliptical as E7; elliptical galaxies have little interstellar matter, are thought to be quite old, and rarely form new stars

embryo a developing organism produced from a zygote

embryonic development an orderly series of changes that an embryo undergoes, which eventually results in a fully formed baby

emission spectrum the pattern of light that an element gives off when its atoms absorb electrical or heat energy and re-emit that energy as light; each element will give off a very specific combination of wavelengths, or colours, of light

empirical knowledge knowledge gained through observation and experimentation

endometrium [end-owe-MEE-tree-um] the lining of the uterus

energy the ability of an object to do work; it exists in many forms including electrical energy, light energy, and nuclear energy; measured in joules; the symbol is *E*

epicotyl the part of the plant embryo that becomes the stem and leaves

epididymis [eh-pee-DID-ee-miss] structure that sits above the testis; stores mature sperm

equinoxes the two dates when the Sun, on the ecliptic, crosses the celestial equator; occurring around March 21 and September 22, and known as the spring and fall equinoxes, respectively. On these days, the number of hours the Sun is above the horizon and below the horizon is equal.

escape velocity the speed needed for a vehicle to overcome the force of Earth's gravity and travel into deep space

estrogen [ESS-truh-jen] a female sex hormone produced by the ovaries

ethics the study of what is right and wrong and how this affects the way we behave as individuals or in groups

expanding universe refers to the concept that galaxies are moving away from us and that the farther away they are, the faster they are moving

external fertilization the union of the egg and sperm outside the body

extrasolar planet a planet that is beyond the solar system; a planet orbiting another star

F

fallopian tube see **oviduct**

fertilization the joining or fusing of male and female gametes

filament a stalk that supports the anther on the stamen of a flower

flammability the ability of some substances to react rapidly with oxygen, resulting in the release of energy

flow phase the first stage of the menstrual cycle in which the endometrium is shed

follicle a structure in the ovary that contains a single immature egg and cells that nourish and protect the developing egg

follicular phase the second phase of the menstrual cycle in which a new follicle starts to develop

fragmentation a type of asexual reproduction in which a small part of an animal breaks off and grows into a new organism

free fall the term used to describe a situation where the pull of gravity and the forward speed of an object or person are perfectly balanced, so that the object or person is continuously falling toward Earth at the same time as it is trying to speed away from Earth

G

gamete a haploid sex cell; a male gamete is called a sperm or sperm cell, a female gamete is called an egg or egg cell

gas giants the name given to the four planets beyond Mars: Jupiter, Saturn, Uranus, and Neptune; also known as the outer planets; their atmospheres consist mainly of hydrogen and helium gases

gene [jeen] a short section of DNA on a chromosome that contains the instructions to make a specific protein

genetically modified organism (GMO) an organism that contains genes that have been intentionally altered; includes many food crops

genome [JEE-nome] all of an organism's genes (thus its entire DNA)

geocentric Earth-centred; refers to the Earth-centred model of the universe, which places a motionless Earth at the centre with all the planets and stars at fixed positions within eight concentric spheres that spin in circles called orbits

geosynchronous refers to an orbit in which an object, for example, a satellite, stays in the same position over Earth

germinate start to grow

globular [GLOB-you-lur] **cluster** spherically shaped star cluster with tight groups of thousands to millions of very old stars

ground a connection of an object to Earth through a conductor

H

halogen an element found in the second-last column of the Periodic Table, Group 17: fluorine, chlorine, bromine, iodine, and astatine; each has an ion charge of 1−

haploid describes a cell with half the chromosome number of the parent; symbolized by *n*

heliocentric Sun-centred; refers to the Sun-centred model of our solar system, in which all planets revolve around the Sun

hermaphrodite [her-MAF-ruh-dite] an organism that produces both male and female sex cells

heterogeneous mixture a mixture that is not uniform in its composition; the components can be visibly distinguished

homogeneous mixture a mixture that has components that are evenly and microscopically mixed together; a solution is a homogeneous mixture of liquids and/or gases

homologous chromosomes a pair of corresponding chromosomes

hypocotyl the part of the plant embryo that pushes up through the soil and protects the epicotyl

hypothesis a tentative answer or an untested explanation

I

independent variable variable that is regulated by the investigator

Indigenous Knowledge (IK) understandings, values, and beliefs about the natural world that are unique to a particular group or culture who have lived for a very long time in a particular area. This specialized knowledge is passed from generation to generation in the form of stories told, experience shared, or songs sung by Elders or other people

induced charge separation a slight shift in the position of electrons

inertia the tendency for an object in motion to stay in motion, or an object at rest to stay at rest

inference tentative conclusion based on logic or reasoning

inner planets see **terrestrial planets**

insulator a material in which the electrons are bound tightly to the nucleus and are not free to move to a neighbouring atom; plastic is a good insulator

internal fertilization the union of the sperm and egg inside the female

interphase phase of the cell cycle in which cells grow and work

invention newly developed device or process created to help people meet their needs or satisfy their desires

ion a charged atom; results when electrons are added to or removed from an atom

ion charge the charge of an ion; can be positive or negative

ionic bond the bond between metal and non-metal ions; based on electrical attraction between positive and negative ions

ionic compound a compound that forms when metal atoms react with non-metal atoms

irregular galaxy galaxy classification; a galaxy that has no definite outline or shape, neither elliptical nor spiral; is believed to be the result of the collision of two or more galaxies

J

joule (J) the SI unit for measuring energy and work

K

karyotype [KAR-ee-oh-type] an image which shows individual chromosomes from a cell arranged into homologous pairs

Kepler's laws of planetary motion three laws that state: (1) the planets travel in elliptical orbits around an off-centre Sun, with the Sun at one focal point; (2) the speed of a planet's orbit depends on its distance from the Sun; (3) the farther a planet (or dwarf planet) is from the Sun, the longer its orbit.

kilowatt•hour (kW•h) the SI unit for measuring energy usage; the use of one kilowatt of power for one hour

kinetic energy energy that an object has because of its motion; measured in joules; its symbol is *KE*

kinetic molecular theory the theory that explains the behaviour of substances and changes in matter that we can see; states that matter is made up of moving particles and that the more energy the particles have the faster they move

Klinefelter syndrome a disorder in which a male's cells have two X chromosomes and a Y chromosome

L

labour the birth process; involves the dilation of the cervix, the breaking of the water, and uterine contractions that push the baby through the birth canal

law general statement based on extensive observational data about what has happened

Law of Conservation of Energy the law which states that when energy changes from one form to another, no energy is lost

Law of Definite Proportions the law which states that a specific compound always contains the same elements in definite proportions

Law of Electric Charges the law which states that opposite electric charges attract, and like electric charges repel

light year the distance that light travels in one year: 9.5×10^{12} km

low Earth orbit an altitude, in space, between 200 km and 1000 km above Earth

lunar cycle refers to the Moon's phases, which can be divided into eight distinct stages

lunar eclipse results when Earth is positioned between the Sun and the Moon such that Earth casts its shadow on the surface of the Moon; the Moon must be at a node

luteal phase final stage of the menstrual cycle in which the empty follicle develops into the corpus luteum

M

main sequence the diagonal band in the Hertzsprung–Russell (H-R) diagram where most stars fit; a star's position on the main sequence band depends upon its mass

malignant tumour mass of cells that invades the surrounding tissues and interferes with the normal functioning of the tissues and organs

malleable capable of being beaten or pressed into thin sheets

mammary glands glands that produce milk to nourish a baby

mass the measure of the amount of matter an object has; the SI unit of mass is the kilogram (kg)

mass number the total number of protons and neutrons in the nucleus of an atom

matter anything that has mass and volume

meiosis [my-OH-sis] the process that produces gametes, which have half the chromosome number as the parent

meiosis I the first phase of meiosis

meiosis II the second phase of meiosis; produces haploid gametes

melting point the temperature at which a substance changes from solid to liquid

menopause the permanent end of the menstrual cycle; occurs between the ages of 40 and 50

menstrual cycle the female reproductive cycle; in each cycle, an egg matures and is released; lasts approximately 28 days

menstruation [MEN-stroo-AY-shun] the shedding of the endometrium

metal a substance that is usually shiny, malleable, ductile, a good conductor of heat and electricity, usually solid at room temperature, denser than a non-metal, and that reacts with acids or water

metalloid an element that does not fit well into metals or non-metals but exhibits some qualities of both; is also called semi-metal

metaphase the second stage of mitosis

metastasis the spread of cancer cells away from their original location

meteor smaller chunk of solid matter that burns up in Earth's atmosphere due to friction, creating a bright streak of light; often called a shooting star

meteorite larger meteor that actually reaches Earth's surface

meteoroid lump of rock or metal that encounters Earth as it travels through space

minor bodies refers to the non-planetary matter in the solar system; includes asteroids, meteoroids (meteors and meteorites), and comets

miscarriage the situation where a fetus is involuntarily expelled from the uterus before it is developed enough to survive on its own

mitosis [my-TOE-sis] the process that divides the nuclear material during cell division

mixture any substance that contains two or more pure substances; for example salt dissolved in water or iron mixed with sulfur

molecule two or more atoms joined together by chemical bonds; the smallest particle of a pure substance that still has the properties of the pure substance; for example a water molecule

monovalent an element that has only one ion charge

multivalent an element that has more than one possible ion charge; occur only after atomic number 20

mutation a change in the DNA, or the genetic code of a cell

N

nebula refers to a collection of dust and gases, consisting mainly of hydrogen and helium gases and, to a lesser extent, grains of solid matter such as iron, rock, and ice

negative correlation indicates an inverse relationship among sets of data; an increase in one variable corresponds to a decrease in the other variable

negative ion an atom that has more electrons than protons; the ion has a negative charge

neutron a particle found in the nucleus of an atom; it has no charge

neutron star star stage after the collapse of a massive star, after supernova; stars whose initial mass is between 10 and 50 solar masses will become neutron stars

nitrogenous base there are four different bases: adenine (A), thymine (T), cytosine (C), and guanine (G); pairs of these molecules form each rung of the DNA ladder

noble gas an element found in the last column of the Periodic Table, Group 18: helium, neon, argon, krypton, xenon, and radon; each has an ion charge of 0

node the points at which the Moon's orbital plane intersects Earth's orbital plane; eclipses occur only at lunar nodes

nondisjunction an error in meiosis in which the homologous chromosomes do not separate; produces gametes with the wrong number of chromosomes

non-metal a substance that is usually dull, brittle, often a gas at room temperature, a poor conductor of heat and electricity, and has lower boiling and melting points than metals

nuclear fusion the process whereby hydrogen nuclei fuse to form helium nuclei with a small loss of mass and a huge release of energy

nuclear membrane surrounds the nucleus and allows certain materials to pass into and out of the nucleus

nucleolus an organelle in the nucleus of a cell that produces and assembles ribosomes

nucleotide molecule made up of a sugar molecule, a phosphate molecule, and a nitrogenous base

nucleus the central part of an atom that contains most of the mass; contains two types of particles: positively-charged protons and uncharged neutrons

O

observation evidence gained by the five senses—touch, smell, taste, vision, hearing

observational study scientific inquiry made through observations of a subject or phenomenon in a structured manner, in a way that does not interfere with or influence the subject or phenomenon

observatory permanent building that houses telescopes

ohm Ω the SI unit for measuring resistance

Ohm's law the law that defines the relationship between voltage, current, and resistance; voltage varies directly with current

open cluster a cluster of stars, usually containing only a few hundred stars (typically young stars); found only in the galactic disk and nearly always in the spiral arms; they are less dense than globular clusters

optical telescope instrument that gathers and focuses visible light to make distant objects appear nearer

outer planets see **gas giants**

ovary a structure in the flower that contains the eggs; in animals the organ in which egg cells mature and are released

oviduct a tube that transports the egg to the uterus

ovulation the release of a mature egg from the ovary

ovum (plural is *ova*) see **egg**

P

parallax the apparent motion of a star against the background of more distant stars; used to measure the distances to and between stars

parallel circuit a circuit in which each electrical load is connected to the energy source by its own separate path; the electric current is split among the loads

parent cell a cell before it divides

penis the organ that contains the urethra; enters female during sexual intercourse to allow the transfer of sperm

perihelion the point at which Earth is closest to the Sun; occurs around January 3

petal coloured leaf-like structure found on most flowers; attracts organisms such as pollinators

photometric transit method a method for detecting extrasolar planets that measures the changes in a star's brightness (photometric) as a planet crosses in front it

photoperiod the number of hours of daylight between sunrise and sunset

photosphere the thin, outermost layer of the Sun; has a temperature of 5500 °C

physical change a change in form or state, but not in substance; for example, paper cut into pieces is still paper

physical property a property of matter that can be observed through the senses, measured, or calculated

pistil the female reproductive structure of a flower

plane of the ecliptic [ee-KLIP-tick] the apparent path the Sun takes through the sky, as marked by the 12 constellations of the zodiac

planet a large object that orbits the Sun

pollen tiny grains produced by the anther; contain the male gametes

pollination the process by which pollen is moved from the male structures of a flower to the female structures of the same or another flower

polyatomic ions group of atoms that occur together in a compound and are treated as a single element; have a charge like an ion due to an imbalance of electrons and protons

positive correlation indicates a direct relationship among sets of data; an increase in one variable corresponds to an increase in the other variable

positive ion an atom that has fewer electrons than protons; the atom has a positive charge

potential energy energy stored by an object as a result of its position relative to the ground (gravitational potential energy), its shape (elastic potential energy), or its condition (chemical potential energy) rather than its motion; measured in joules

power the rate of doing work or transforming energy; measured in watts; the symbol is *P*

precession the changing direction of Earth's axis

progesterone [pro-JESS-ter-own] a female sex hormone produced by the ovaries

prophase the first stage of mitosis

proton a positively charged particle found in the nucleus of an atom

protoplanet small clumps of matter, forced together by gravity, that condense to form a planet

puberty [PYOO-bur-tee] the period in human development in which the person becomes sexually mature and able to reproduce

pulsar a type of neutron star that beams out light and very high-energy radio waves; the pulsar rotates while emitting energy. If the neutron star is small, less than two solar masses, it will slowly release its energy and will fade into oblivion.

pure substance matter that contains only one type of particle; for example, water is a pure substance that contains only water particles

Q

qualitative observation an observation based on the description of the qualities of objects or events without using measurements

quantitative observation an observation based on measurements or counting

quasars acronym for **quas**i-stell**ar** radio sources; starlike objects that emit powerful radio waves; they are found in the centre of distant galaxies and are thought to have formed when two galaxies collided

R

radial velocity method an indirect method for finding extrasolar planets that relies on the planet's gravitational tug on its sun

radiative [RAY-dee-ay-tiv] **zone** the layer surrounding the core of the Sun; approximately 3.5×10^5 km thick

radicle the part of the plant embryo that develops into the roots

recessive allele an allele that will express its trait (the trait will show up in a person's appearance) only if both of the homologous chromosomes contain the recessive allele

recombinant DNA technology combining genes from different individuals or different species into a single molecule of DNA

red giant the state of a star when fusion has exhausted almost all its hydrogen supply and made it into helium; red giants are 0.4 to 10 times the mass of the Sun; reddish in colour

red shift the shift of the spectral lines toward the red end of the visible spectrum when light from stars or galaxies is examined through a spectroscope

resistance a measurement of the opposition to the flow of electric current through a circuit; measured in ohms; the symbol is *R*

resistor an electrical device designed to resist the flow of electric current in a circuit; a load in a circuit that converts electrical energy to another form of energy, such as light energy or heat energy

retrograde [RET-ruh-grayd] **motion** the apparent slowing, reversal, and then looping of a planet in its path across the sky

revolution the motion of an object in a circular or elliptical path (usually around another object)

rotation the spinning of an object around an imaginary line called an axis

S

scientific method the general types of mental and physical activities that scientists use to create, refine, extend, and apply knowledge

scrotum a protective sac that encloses the testes

seed the fertilized egg in the ovary of a flower

selective breeding two plants or two animals of one species that have desirable traits are bred with each other to produce offspring with the same traits as the parents

semen [SEE-muhn] the sperm and the seminal fluid combined

seminiferous tubules a mass of coiled tubes in the testis that produce haploid sperm cells

sepal [SEE-puhl] tiny leaf-like structure that protects the flower while it is in the bud; found at the base of the flower

series circuit circuit in which the components are connected end to end so that the electric current has only one path to follow

sex-linked characteristic a trait that is controlled by a gene on the X chromosome

sexual reproduction two separate organisms (parents) contribute genetic information to produce offspring that are genetically different from both parents

shell a specific "allowed" orbit in which electrons circle the nucleus

sister chromatids a chromosome and its copy; chromosomes make copies of themselves during interphase

solar eclipse results during a new moon, when the Moon, at one of its nodes, is directly between Earth and the Sun

solar flare brief expulsion of large quantities of gas and charged particles produced by the rapidly changing magnetic fields around sunspots; a flare occurs above an active sunspot and emits high-energy X-rays and ultraviolet radiation

solar mass a unit of measure, equal to the mass of the Sun

solar prominence huge, arching line of gas, approximately 100 billion tonnes of glowing hydrogen; released from the photosphere

solar wind an ionized gas emitted from the Sun continuously; peaks in intensity with solar flare and prominence activity

solstices occur when the Sun reaches its highest and lowest positions in the sky, when Earth is tilted closer to or farther away from the Sun (due to the 23.5° axis tilt). The summer solstice usually occurs on June 21, marking the first day of summer and the longest day of the year. The winter solstice usually occurs on December 21 and marks the beginning of winter and the shortest day of the year.

solubility the degree to which a substance will dissolve in a given amount of another substance, usually water

somatic cell cell that reproduces by cell division; also called body cell

space probe an unpiloted spacecraft that leaves Earth's orbit

sperm (plural is *sperm*) a male gamete

spindle moves the chromatids during the later phases of cell division; made of spindle fibres

spiral galaxy a galaxy which is spiral in shape; a tightly wound spiral is classified as an Sa galaxy, and loose spirals are classified Sc; spirals have interstellar matter and are full of young, new stars

spore cell with thick cell walls similar to seeds, but is produced by cell division and grows into organisms genetically identical to the parent organism

stamen [STAY-muhn] the male reproductive structure in a flower

standard candle object either of known brightness or predictable behaviour that astronomers can use to determine distance

state the physical property that describes the form in which matter can usually be found: solid, liquid, or gas

static charge an electric charge that builds up because of an imbalance between the number of electrons (negative charges) and protons (positive charges)

stem cell unspecialized cell that has the ability to reproduce itself and differentiate into a specialized cell

stigma the sticky part of the pistil that receives the pollen grain

style a tube-like structure in a flower that connects the stigma to the ovary; pollen travels down the style to the ovary

subatomic particle one of the parts that make up the atom; includes electrons, protons, and neutrons

sunspot dark spot on the Sun's surface, varying in size and regularity; caused by disturbances in the Sun's magnetic field

surrogate mother a woman who carries embryos produced by in vitro fertilization for an infertile couple

T

telophase the final stage of mitosis

terraforming the process of changing another planetary body to a body with an environment capable of supporting human life

terrestrial planets the name given to the four planets closest to the Sun: Mercury, Venus, Earth, and Mars; also known as the inner planets. They resemble Earth in that they are small and have densities similar to most rocks, about 5 g/cm^3

testes (singular is *testis*) produce and nourish sperm as they develop, and also produce testosterone

testosterone [tess-TOSS-tuhr-own] the male sex hormone produced by the testes

theory an explanation of observations or of a law

thrust the force that moves an object, for example, a spacecraft, forward

tide the alternate rising and falling of the surface of large bodies of water; caused by the interaction between Earth, the Moon, and the Sun

Traditional Ecological Knowledge and Wisdom (TEKW) see **Indigenous Knowledge**

trait one version of a characteristic

Turner syndrome a disorder in which a female's cells have only one X chromosome

U

ultrasound a technology that uses high-frequency sound waves to create a 3-D image

urethra in males, a tube that transports both sperm and urine outside the body

uterus [YOO-tuh-ruhs] the organ in which the embryo develops; also called the womb

V

vagina [vuh-JI-nuh] the structure that receives the male penis and sperm during sexual intercourse and is the birth canal through which a baby is born

Van de Graaff generator a type of static electicity generator that separates large amounts of charge; used to research and demonstrate static electricity

variable any condition that could change in an investigation

vas deferens a tube that carries sperm from the epididymis to the urethra

vegetative reproduction asexual reproduction in plants; includes producing runners, bulbs, tubers, and cuttings

volt (V) the SI unit for measuring voltage (electric potential difference)

voltage the electric potential difference between two points in an electric circuit; measurement of the energy that would be required to move a unit of electric charge from one point to the other; measured in volts; the symbol is V

voltmeter an instrument that measures voltage (electric potential difference) in volts

volume the measure of the amount of space an object occupies

W

watt (W) the SI unit for measuring power

white dwarf star stage after a red giant; the star with slightly less than its original mass compressed to a diameter about that of Earth. Its density is enormous, and its surface temperature is 100 000 °C

womb [woom] see **uterus**

work a measure of the amount of energy transformed from one form of energy (such as electrical energy) into another form of energy (such as light energy); measured in joules; the symbol is W

Z

zygote the first cell of a new organism; a fertilized egg cell